Coalition for a Sustainable Delta

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Dear Drs. Goodwin and Reed,

I am writing on behalf of the Coalition for Sustainable Delta (Coalition) with respect to the Delta Science Program Independent Science Review of the Fall Low Salinity Habitat (FLaSH) Study Synthesis. The Coalition is a California nonprofit corporation comprised of agricultural, municipal, and industrial water users, as well as individuals in the San Joaquin Valley. The Coalition and its members depend on water from the Sacramento-San Joaquin Delta (Delta) for their continued livelihood. Individual Coalition members frequently use the Delta for environmental, aesthetic and recreational purposes; thus, the economic and non-economic interests of the Coalition and its members are dependent on a healthy and sustainable Delta ecosystem. The Coalition takes great interest in efforts to manage Bay-Delta ecosystems and the desired and protected species that depend on those systems.

We understand that the Delta Science Program has convened an Independent Review Panel chaired by Dr. Reed to review implementation of one component (that is, the Fall X2 Action) of a reasonable and prudent alternative prepared by the U.S. Fish and Wildlife Service in conjunction with a biological opinion in December, 2008, regarding the effects of continued operation of the Central Valley Project and State Water Project on the threatened delta smelt.[1] We further understand that the Panel, which provided a detailed critique of the draft adaptive management plan for the Fall X2 Action in July, 2011, intends to convene July 31 and August 1, 2012, to review the draft FLaSH report and draft 2012 adaptive management plan produced by federal and state agency personnel who have been charged to implement the Fall X2 Action. According to the panel charge, the Bureau of Reclamation anticipates that implementation of the adaptive management plan, including the work of the Independent Review Panel, "will provide important new information that can be used to

[1] This component is triggered in wet and above normal years, and requires the monthly average location of X2 to be no further upstream from the Golden Gate Bridge in September and October than 74 kilometers (km) in wet years and 81 km in above normal years. In November, it does not set a specific X2 target, but requires that reservoir inflow be allowed to pass through upstream reservoirs to provide additional outflow in the Delta up to the 74 km or 81 km marker, depending on the water year.

improve the effectiveness of the action, the efficiency of the action, to change the nature of the action if findings support such change or to consider other alternatives." We urge the panel to remain cognizant of this essential aspect of its charge as it moves ahead with a critical assessment of the draft FLaSH report, the draft 2012 adaptive management plan, and the underlying Fall X2 Action.

In the balance of this letter, we seek to draw the attention of the Panel to four points: (1) the Fall X2 Action is flawed as a management action intended to contribute to the survival and recovery of delta smelt, and the Panel is uniquely well-positioned to reaffirm past statements regarding the Action's inherent shortcomings; (2) this review process is biased, because the convenors have screened the materials you received and excluded information critical of the Fall X2 Action; (3) a careful review of the draft FLaSH report reveals both the shortcomings of the federal agencies' efforts to test a range of hypotheses and their unwillingness to acknowledge the critical flaws inherent in the Fall X2 Action; and (4) the 2012 draft adaptive management plan suffers from many of the same infirmities that this Panel identified when it reviewed a prior iteration of the plan last summer. For the Panel's consideration, we have also enclosed a number of documents directly pertinent to its charge.

The Fall X2 Action is fundamentally flawed

The Fall X2 Action was developed as the Fish and Wildlife Service was completing its 2008 biological opinion. According to the Service, the objective of the Fall X2 Action is "to improve fall habitat for delta smelt through increasing Delta outflow during fall." Both the Bureau of Reclamation and the California Department of Water Resources questioned the premise for the action, which was developed in reliance on two studies – one published and one unpublished (Feyrer et al. 2007 and Feyrer et al. 2008, respectively) – as of the time the biological opinion was completed. When that document was completed, neither the Bureau nor the Department concluded that the Action would be effective. Instead, the Bureau only provisionally accepted the reasonable and prudent alternative due to concerns regarding the Fall X2 Action, and the State of California opted to sue the Fish and Wildlife Service and thereby challenge the legitimacy of the Action.

Shortly after the biological opinion and its attendant reasonable and prudent alternative were completed by the Fish and Wildlife Service, Congress appropriated funds for a National Research Council review of the reasonable and prudent alternative, including the Fall X2 Action. As a member of the National Research Council committee that completed the review, Dr. Reed can speak firsthand of the committee's assessment of the Fall X2 Action. Therefore, rather than interpret that assessment, we simply reproduce several relevant paragraphs here:

> The relationship between the position of X2 and habitat area for delta smelt, as defined by smelt presence, turbidity, temperature, and salinity (Nobriga et al, 2008; Feyrer et al., in review), is critical in designing this action. A habitat-

area index was derived from the probability of occurrence estimates for delta smelt (fall mid-water trawl survey, FMT) when individuals are recruiting to the adult population. Presence/absence data were used because populations are so small that quantitative estimates of populations probably are unreliable. The authors show a broad relationship between the FMT index and salinity and turbidity, supporting the choice of these variables as habitat indicators. The statistical relationship is complex. When the area of highly suitable habitat as defined by the indicators is low, either high or low FMT indices can occur. In other words, delta smelt can be successful even when habitat is restricted. More important, however, is that the lowest abundances all occurred when the habitat-area index was less than 6,000 ha. This could mean that reduced habitat area is a necessary condition for the worst population collapses, but it is not the only cause of the collapse. Thus, the relationship between the habitat and FMT indexes is not strong or simple. Above a threshold on the x-axis it allows a response on the y-axis (allows very low FMWT indices).

The controversy about the action arises from the poor and sometimes confounding relationship between indirect measures of delta smelt populations (indices) and X2. The weak statistical relationship between the location of X2 and the size of smelt populations makes the justification for this action difficult to understand. In addition, although the position of X2 is correlated with the distribution of salinity and turbidity regimes (Feyrer et al., 2007), the relationship of that distribution and smelt abundance indices is unclear. The X2 action is conceptually sound in that to the degree that habitat for smelt limits their abundance, the provision of more or better habitat would be helpful. However, the examination of uncertainty in the derivation of the details of this action lacks rigor. The action is based on a series of linked statistical analyses (e.g., the relationship of presence/absence data to environmental variables, the relationship of environmental variables to habitat, the relationship of habitat to X2, the relationship of X2 to smelt abundance), with each step being uncertain. The relationships are correlative with substantial variance being left unexplained at each step. The action also may have high water requirements and may adversely affect salmon and steelhead under some conditions (memorandum from FWS and NMFS, January 15, 2010). As a result, how specific X2 targets were chosen and their likely beneficial effects need further clarification.

The X2 action for delta smelt includes a requirement for an adaptive management process that includes evaluation of other possible means of achieving the RPA's goal and it requires the establishment and peer review of performance measures and performance evaluation. It also requires "additional studies addressing elements of the habitat conceptual model" to be formulated as soon as possible and to be implemented promptly. Finally, it

> requires the FWS to "conduct a comprehensive review of the outcomes of the Action and the effectiveness of the adaptive management program ten years from the signing of the biological opinion, or sooner if circumstances warrant." This review is to include an independent peer review; the overall aim is to decide whether the action should be continued, modified, or terminated. It is critical that these requirements be implemented in light of the uncertainty about the biological effectiveness of the action and its high water requirements.

Committee on Sustainable Water and Environmental Management in the California Bay-Delta, *A Scientific Assessment of Alternatives for Reducing Water Management Effects on Threatened and Endangered Fishes in California's Bay Delta* (2010).

The Fall X2 Action was also subject to independent review in federal court. The court benefitted from the assistance of two court-appointed experts – Dr. Andre Punt and Dr. Thomas Quinn both of the University of Washington – as it conducted its review of the Action and supporting information in the biological opinion. The court held that the Fall X2 Action was arbitrary in violation of law and set it aside, in part due to its lack of foundation in reliable science, including its dependence on an ostensible "habitat index" that was derived from Feyrer et al. (2008 – subsequently published as Feyrer et al. 2011).

Dr. Ken Burnham addressed the derivation of Feyrer et al.'s (2011) "habitat index," finding that it was internally flawed with built-in bias, because abundance data from the FMWT was a contributor to the variables on both X- and Y-axes of the index. The degree of correlation induced by using FMWT abundance data on both axes was apparently sufficient to account for most or the entirety of the 25 percent correlation between X2 and delta smelt abundance (Declaration of Dr. Kenneth Burnham, p. 8 (Sept. 14, 2011)). The federal court agreed that this fundamental error diminishes the reliability and utility of the "habitat index."

In addition, the court pointed out that, in justifying the Fall X2 Action, the Service improperly used simulation models, comparing historical fall X2 positions from DAYFLOW to modeled fall X2 positions from CALSIM II, but failing to calibrate their respective outputs (Memorandum Decision re Cross Motions for Summary Judgment, pp. 100-104 (Dec. 14, 2010)). The assertion that project operations have a significant effect on the position of the X2 in the estuary in the fall, which is the premise for the need for the Fall X2 Action, thus was found to be unsupported and was remanded to the Fish and Wildlife Service for better explanation and validation.

The court also found a "total lack of explanation" for the notion that X2 must be located at 74 km during the autumns of "wet" water years to avoid jeopardy and adverse modification of critical habitat, and the absence of a rational connection between the facts found and the conclusion that such positioning of X2 in the fall was necessary to enhance the prospects for delta smelt survival and recovery (Memorandum Decision re Cross Motions for

Summary Judgment, pp. 125-126, 221). The court subsequently noted that there was no scientific support for any specific location for X2 in the autumn that would serve to contribute to the conservation of delta smelt.

Two reviews – one by a National Research Council committee and another by a federal district court aided by two preeminent scientists – should have led to a re-assessment of the appropriateness of the Fall X2 Action by the federal government. Instead, the federal government has chosen to ignore them and plow ahead with the Fall X2 Action and the development of an adaptive management scheme ostensibly to support it. This Panel has an opportunity to remind the federal government of the impropriety of its current trajectory.

The review process appears to be biased

Independent review can be a powerful tool to improve agency decision-making. But there are certain prerequisites for independent scientific review that should be considered obligatory in order to assure that the product of the review process is rigorous and widely perceived as both objective and legitimate. For example, it is imperative that an agency seeking review of its decisions avoid manipulation of the scope of the task statement or the materials available to reviewers to influence the outcome of the review. Such action undermines a fundamental purpose of the independent review process.

In this review of the Bureau of Reclamation's adaptive management plan and autumn research "studies," agency personnel tasked with convening the Panel have contributed to undermining the independence of the process by providing reviewers with an incomplete and biased set of supporting materials, and by expressing an unwillingness to include materials submitted by concerned outside parties. The supporting materials provided to the Panel were listed in the scope and charge to the Panel posted on the Delta Science Program website. They exclude much pertinent material, including:

- MacNally R., Thomson J.R., Kimmerer W.J., Feyrer F., Newman K.B., Sih A., Bennett W.A., Brown L., Fleischman E., Culberson S.D., and G. Castillo. 2010. Analysis of pelagic species decline in the upper San Francisco Estuary using multivariate autoregressive modeling (MAR). Ecological Applications 20:1417-1430.

- Maunder, M.N., and R. Deriso. 2011. A state-space multistage life cycle model to evaluate population impacts on the presences of density dependence: illustrated with application to delta smelt (*Hyposmesus transpacificus*). Can. J. Fish Aquatic Sci. 68:1285-1306.

- Merz, J. E., S. Hamilton, P. S. Bergman, and B. Cavallo. 2011. Spatial perspective for delta smelt: a summary of contemporary survey data. California Fish and Game 97:164-189.

- Miller, W.J., Manly, B. F. J., Murphy, D.D., Fullerton, D., and R.R. Ramey. 2012. An investigation of factors affecting the decline of delta smelt (*Hypomesus transpacificus*) in the Sacramento- San Joaquin Estuary. Reviews in Fisheries Science 20:1-19.

- Thomson J.R., Kimmerer W.J., Brown L.R., Newman K.B., MacNally R., Bennett W.A., Feyrer F., and E. Fleishman. 2010. Bayesian change point analysis of abundance trends for pelagic fishes in the upper San Francisco Estuary. Ecological Applications 20:1431-1448.

In addition, a substantial amount of highly pertinent material on the subject was generated in the course of litigation regarding the Fall X2 Action. This includes court decisions, legal briefs, and declarations by expert biologists and hydrologists. In particular, two court decisions – one setting aside the biological opinion and reasonable and prudent alternative, including the Fall X2 Action, on the grounds they were unlawful, and a second making findings of fact and conclusions of law in support of an order enjoining the Fall X2 Action in 2011 – are directly relevant to the Panel's tasking. None of this material supports the Fall X2 Action, and none was included among the supplemental materials provided to the Panel.

Furthermore, the State and Federal Water Contractors Agency prepared two sets of technical comments and asked that they be provided to the Panel. Rather than pass the comments along, the Delta Science Program apparently has taken the position that it has sole discretion to withhold such comments from the Panel. This is, needless to say, inconsistent with the notion of independent science review, as it allows those agencies advocating a particular perspective to control the flow of information to the Independent Review Panel.

The FLaSH report reveals a number of shortcomings of the Fall X2 Action

The Synthesis of Studies in the Fall Low Salinity Zone of the San Francisco Estuary, September-December 2011 (Synthesis) reports on results from a number of studies undertaken to facilitate adaptive management of water project operations in the autumn of certain years with higher than average precipitation in California. It includes a number of statements that merit critical assessment by this Panel. For example, it states that "[i]n general, the FLaSH investigation has been largely inconclusive as of the writing of this report" (Synthesis, p. 65). Inexplicably, the authors of the Synthesis report that "[m]any of the predictions [made by the federal government] either could not be evaluated with the data available or the needed data are not being collected" (Synthesis, p. 2). It appears that the federal government inserted a multitude of hypotheses in the adaptive management plan without giving any consideration to the availability of existing data or potential to collect additional data needed to test those hypotheses. This is reflected in the Synthesis in a collection of statements that can only lead reviewers to conclude that data collection

efforts during last autumn did not serve to inform a hypothesis-driven adaptive management effort.

- The prediction regarding habitat complexity could not be evaluated.
- The prediction regarding wind speed could not be evaluated because [sic] lack of data.
- The prediction for delta smelt entrainment at the Suisun region power plants could not be directly assessed because no fish counts were available.
- The prediction regarding fish health and condition cannot be assessed at this time.
- The predictions regarding recruitment to the next year and delta smelt life history variability also could not be assessed at this time.
- The assessments of predictions concerning biotic habitat components either could not be addressed or the data were inconclusive for all or part of a prediction.

There is little point to developing hypotheses or making predictions when data are unavailable to test those hypotheses or evaluate those predictions.

The Synthesis makes no effort to reconcile the contention that distribution of delta smelt is determined by salinity with the acknowledgement that delta smelt are present year-round in the Cache Slough and Sacramento River Deep Water Ship Channel (Synthesis, p. 11). Even as the authors report that the entire delta smelt population is a single, panmictic demographic unit, they fail to account for the presence of substantial numbers of delta smelt in Cache Slough and the Sacramento River Deep Water Ship Channel. In light of the subpopulation present in Cache Slough and the Sacramento River Deep Water Ship Channel, one plausible hypothesis is that if delta smelt are found outside the narrow salinity range that the federal government claims constitutes delta smelt habitat then the federal government has improperly defined delta smelt habitat. Instead of testing this hypothesis using available data, the Synthesis proposes an alternate hypothesis that delta smelt are present outside their optimal habitat due to unknown factors that could include differences in food availability or predation rates (Synthesis, p. 34). This alternative hypothesis is less parsimonious and likely cannot be tested due to a dearth of pertinent data. Importantly, the federal government has put the cart before the horse by assuming that X2 is a valid surrogate for delta smelt habitat, and then crafting a management action based on that assumption, instead of first validating the legitimacy of a purported surrogate relationship between the low-salinity zone and delta smelt habitat.

The response to input from this Panel and others regarding the adaptive management plan is inadequate

On April 29, 2011, the Bureau circulated a document entitled *First Draft Plan: Adaptive Management of Fall Outflow for Delta Smelt Protection and Water Supply Reliability* to the public water agencies. The Bureau scheduled a facilitated workshop on May 11-12, 2011, "for the exchange of ideas on the adaptive management of Fall outflow." The Bureau brought in Nick Aumen of the National Park Service as the facilitator. On May 11, 2011, staff from the Bureau and the Fish and Wildlife Service received a day-long review and critique of both the draft adaptive management plan and the underlying Fall X2 Action. At the end of that day, the Bureau announced it was cancelling the second day of the review. The public water agencies submitted written comments on the first draft plan dated May 20, 2011.

On June 6, 2011, the Bureau provided a second draft plan, entitled *Draft Plan: Adaptive Management of Fall Outflow for Delta Smelt Protection and Water Supply Reliability*, to this Independent Review Panel. Subsequently, it made the second draft plan available to the public water agencies. With the second draft plan, the Bureau provided supplemental materials to the Panel, but initially it did not include the written comments of the public water agencies or the briefs and expert declarations filed in the litigation regarding the request by the State of California and others for an injunction to halt imposition of the Fall X2 Action in 2011. Counsel for the public water agencies asked the Bureau to provide those materials to the Panel, but it is unclear whether they did so. They are not listed among the materials provided to the Panel on the Delta Science Program website. (See http://deltacouncil.ca.gov/independent-review-draft-plan-adaptive-management-fall-outflow-delta-smelt-protection-and-water-supp.)

The Bureau ignored the comments provided previously by the public water agencies in the production of the second draft plan[2] – indeed the review by the Panel expressed nearly identical concerns to the public water agencies that the document did not actually describe adaptive management and reiterated the absence of proposed data collection in an explicit experimental frame, the lack of monitoring focused on the effects of the action, and reliance on standing data-collection schemes and "studies" not relevant to the management action. The Panel includes 17 specific recommendations in its report along with a series of statements signaling its concern about the content of the second draft plan. For example, the report states that "the plan fails to articulate explicit and measurable objectives – an essential element of any adaptive management plan," and "[t]he lack of clear use of detailed conceptual models to link actions to objectives is probably the greatest weakness of the

[2] The Coalition appreciates your admonition to the Bureau that it incorporate stakeholder input. *Independent Review Panel Report on the Draft Plan for Adaptive Management of Fall Outflow for Delta Smelt Protection and Water Supply Reliability*, p. 10 (July 1, 2011). But we are concerned that the message did not get through.

plan." *Independent Review Panel Report on the Draft Plan for Adaptive Management of Fall Outflow for Delta Smelt Protection and Water Supply Reliability*, p. 11 (July 1, 2011).

Following the issuance of the Panel report, the Bureau issued its final plan, *Adaptive Management of Fall Outflow for Delta Smelt Protection and Water Supply Reliability*, on August 9, 2011. That draft substantively ignored many of this Panel's more abiding concerns regarding the lack of a structured approach to adaptive management, and dependence on off-the-shelf monitoring schema and an unfocussed research agenda. The fall low-salinity zone "studies" were initiated in short order outside of any reference to and without design to meet explicit adaptive management goals related to the Fall X2 Action – and, without any clear reference to critical comments from the Panel. A fourth adaptive management plan is now before the Panel. The document appears again to be unresponsive to previous comments and criticisms. It attempts to justify the Fall X2 Action without acknowledgement of the multiple findings that obviate its intended effects. It neither describes an adaptive management effort to enhance the effectiveness and efficacy of the Fall X2 Action, nor monitoring or research designed to test salient hypotheses linking the Fall X2 Action to population responses by delta smelt.

We appreciate your work on the Panel and commitment to provide rigorous and independent input to the federal government, the State of California, and its citizens. We also thank you for considering our comments as you deliberate.

Sincerely,

William D. Phillimore
Board Member

Encl.

California Fish and Game 97(4):164-189; 2011

Spatial perspective for delta smelt: a summary of contemporary survey data

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We utilized recently available data from the 20-mm Tow-Net and Spring Kodiak Trawl, together with other Interagency Ecological Program and regional monitoring programs, to provide a comprehensive description of the range and temporal and geographic distribution of delta smelt (*Hypomesus transpacificus*) by life stage within the San Francisco Estuary, California. Within 21 sampled regions we identified 289,401 survey events at 624 monitoring stations. Delta smelt were observed at 430 stations (69%) in an area from northern San Francisco Bay in the west, to the confluence of the Sacramento and Feather rivers in the north, and to the disjunction of Old and San Joaquin rivers in the south, an area of approximately 51,800 ha. Delta smelt were observed more frequently and at higher densities (at all life stages) near the center of their range, from Suisun Marsh down through Grizzly Bay and east Suisun Bay through the Confluence to the Lower Sacramento region, and into the Cache Slough region. Delta smelt larvae were observed in the San Francisco Estuary from March through July, sub-juveniles in April through August, juveniles in May through December, sub-adults in September through December, and pre-spawning and spawning adults in January through May. This comprehensive review provides managers and scientists an improved depiction of the spatial and temporal extent of the delta smelt throughout its range and lends itself to future analysis of delta smelt population assessment and restoration planning.

Key words: Delta smelt, distribution, *Hypomesus transpacificus,* spatial analysis, life stage, observed presence, Sacramento River delta, San Francisco estuary, San Joaquin River delta

The delta smelt (*Hypomesus transpacificus*) is a small, euryhaline fish endemic to the San Francisco Estuary of California (Estuary). Once the most abundant fish captured in trawl surveys conducted in the Sacramento-San Joaquin Delta (Stevens and Miller 1983, Moyle and Herbold 1989, Stevens et al. 1990) the species suffered a reduction in numbers sufficient to justify threatened listing in 1993 under both the federal and California Endangered Species Acts (ESA). Similar to other Estuary fish species, delta smelt experienced a further decline beginning in 2000 (Sommer et al. 2007) and was listed as endangered under the California ESA in 2009. As a result, the delta smelt has received considerable attention as one of four pelagic fish species experiencing declines in abundance (see Armor et al. 2005, Baxter et al. 2008, Feyrer et al. 2010, Mac Nally et al. 2010, Thompson et al 2010).

Despite the critical condition of the delta smelt population, a geographical summary of its distribution by life stage has not been clearly defined. Conservation planning under federal and state statutes requires spatial resolution (Tracy et al. 2004, Carroll et al. 2006). Distributional summaries of delta smelt were provided in the formal notice conferring its federal protection (USFWS 1993), subsequent designation of critical habitat (USFWS 1994), and completion of conservation planning documents (see USFWS 1996, 2003; California Resources Agency 2005, 2007). However, these sources lack a spatial depiction of where and when delta smelt have been observed. In a California Department of Fish and Game (CDFG) status review (Sweetnam and Stevens 1993), the historical range for the species was described using life history descriptions from existing literature. The United States Fish and Wildlife Service (USFWS 1996) has also provided delta smelt distribution maps using data from the Fall Midwater Trawl, and the CDFG has created interactive maps using individual surveys for some of its monitoring programs (see http://www.dfg.ca.gov/delta). However, to our knowledge, no effort has been made to map the range of delta smelt using all available sampling data or to summarize distribution of delta smelt by life stage.

The distribution of at-risk species is important information for conservation planning. Nearly all ecological data necessary to develop effective resource management agendas have attributes that can be portrayed spatially. Distributional data in the forms of species range maps, breeding surveys, and biodiversity atlases have become tools used commonly in analyses of species-environment relationships (Brundage and Meadows 1982, Flather et al. 1997, Ferrier 2002, Ceballos and Ehrlich 2006, Hulbert and Jetz 2007, Cabeza et al. 2010) and for conservation and management plans for endangered or threatened species, environmental risk assessment, and for calculating responses of at-risk species under future management scenarios (Dormann et al. 2007). Conservation and monitoring programs designed to assess the effectiveness of those actions frequently are site-specific, and are more likely to be successful when spatial elements of planning are well understood (Tracy et al. 2004, Carroll et al. 2006).

Delta smelt are vulnerable to many environmental stressors (USFWS 1993, Moyle 2002, Baxter et al. 2008, Healey et al. 2008), and the significance of a particular stressor may change in relation to its manifestation or proximity to the species (Tong 2001, Armor et al. 2005). Furthermore, delta smelt are migratory (Bennett et al. 2002, Dege and Brown 2004, Hobbs et al. 2007, Sommer et al. 2011), and habitat requirements differ by life stage. An understanding of where delta smelt are distributed throughout their range at each life stage may provide insight about habitat attributes important for each life stage and, therefore, help inform strategies as managers undertake habitat restoration actions.

The purpose of this paper is to present a geographic summary of publicly available data on the distribution of delta smelt by life stage. With initiation of the 20-mm Tow-Net in 1995 and the inception of the Spring Kodiak Trawl in 2002, the CDFG and other agencies that comprise the Interagency Ecological Program (IEP) provide data on the distribution of delta smelt at various life stages. Using data from these surveys and a variety of publicly available sources, we refined knowledge of the spatial extent and distribution of delta smelt in the Estuary. Specifically, we reviewed all available data on observed presence and density of delta smelt from a spatial perspective in an effort to document (1) the observed geographic extent of delta smelt, and (2) the spatial and temporal distributions for identified life stages.

Methods

Study area.—The Estuary is the largest of its kind along the U.S. Pacific Coast (approximately 1,235 km^2, Rosenfield and Baxter 2007; Figure 1). Formed by the confluence of the Sacramento and San Joaquin watersheds with San Francisco Bay, the Estuary drains an area of approximately 163,000 km^2 (40% of California's surface area; van Geen and Luoma 1999, Sommer et al. 2007) that stretches from the upstream limits of the Sacramento River in the north to the mountain tributary streams of the San Joaquin River in the south (Moyle 2002, Sommer et al. 2007). The Estuary is brackish and tidally influenced through its connection to San Francisco Bay, and is an example of an inverted river delta (whereby the narrow end of the delta emerges on the seafront and the wide end is located further inland), one of only a few existing worldwide. The water bodies east of the Sacramento River confluence with the San Joaquin River are commonly referred to as the Sacramento-San Joaquin Delta (Delta). The Delta is the upstream portion of the Estuary where riverine freshwater tidally washes back and forth within leveed channels, roughly between the cities of Sacramento, Stockton, Tracy, and Antioch. The Delta extends about 37 km east to west and 77 km north to south and includes parts of Sacramento, San Joaquin, Contra Costa, Solano, and Yolo counties (Moyle 2002, Lund et al. 2007).

To facilitate the spatial depiction of delta smelt, we grouped monitoring locations into Estuary regions (Table 1; Figure 1) based on preliminary work by Kimmerer (2009) and physical landmarks (e.g., bays, sloughs) (Figure 1). To distinguish areas with large-scale habitat differences (e.g., watershed drainages, confluences), we subdivided (1) the upper Sacramento River into two regions, differentiating the Ship Channel, Yolo Bypass, and Cache Slough from the rest of the upper Sacramento River; (2) San Pablo Bay into western and eastern regions; and, (3) the South Delta into the South Delta and upper San Joaquin River. We also added a Sacramento Valley region (covering upstream from the confluence of the Sacramento and American rivers), two Napa River regions (split between the lower and upper), and a San Francisco Bay region.

IEP monitoring programs.—The CDFG and USFWS, as members of the IEP, have surveyed fish at a number of stations throughout the Estuary for several decades (Table 2, Figure 1). These monitoring programs include the 20-mm Tow-Net (20-mm), Summer Tow-Net (STN), Fall Midwater Trawl (FMWT), Bay Study Midwater Trawl (BMWT), Spring Kodiak Trawl (Kodiak), and Beach Seine (herein collectively referred to as the IEP monitoring programs). Each IEP monitoring program is conducted during a different season and sampling frequency (monthly or bi-weekly), and at a varying number of stations (30-113; Table 2). By employing different gears during different time periods, each monitoring

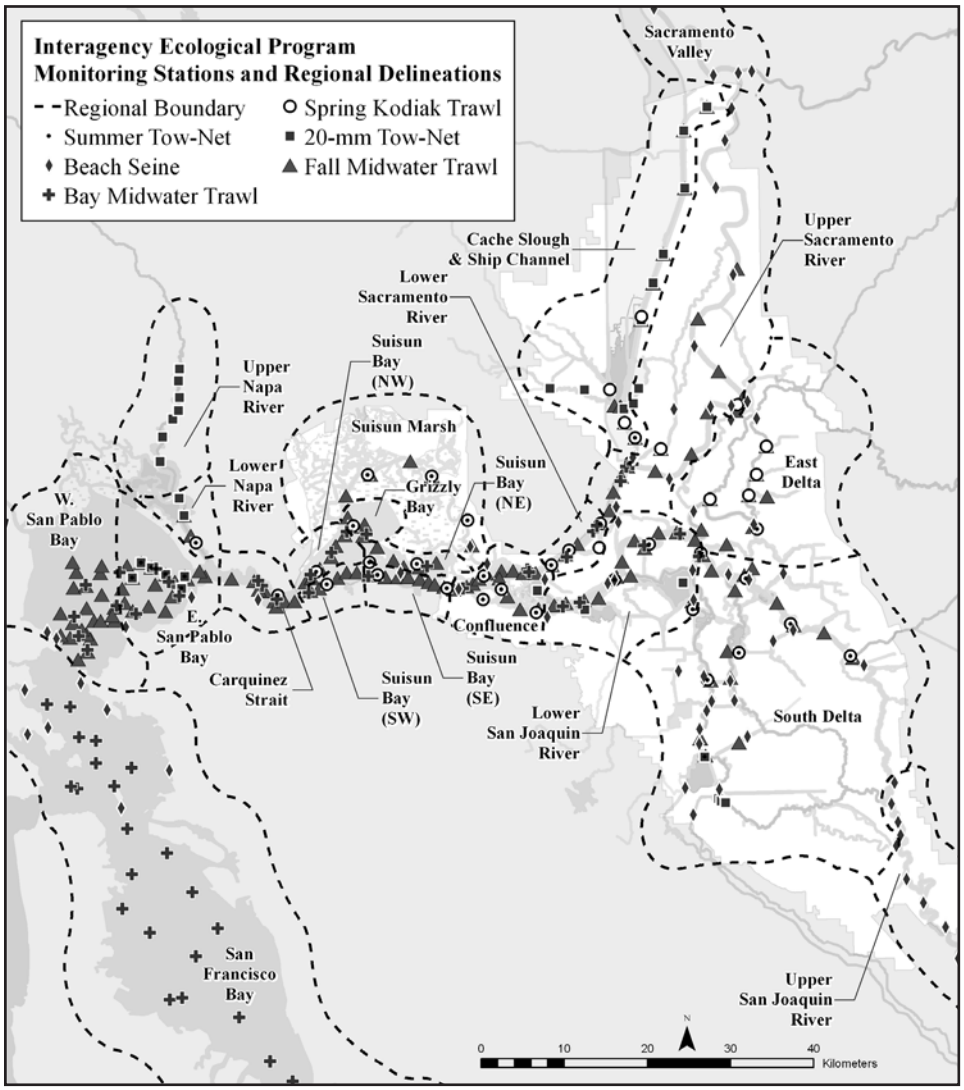

Figure 1.—Monitoring stations of Interagency Ecological Program surveys conducted in the San Francisco Estuary by the California Department of Fish and Game (Summer Tow-Net, Fall Mid-Water Trawl, Bay Mid-Water Trawl, Spring Kodiak Trawl, and 20-mm Tow Net) and the United States Fish and Wildlife Service (Beach Seine). Dashed lines indicate regional boundaries. The white area represents the legal Delta as set forth in the Delta Protection Act of 1959.

Table 1.—San Francisco Estuary sampling regions and associated stations by sample method. IEP monitoring programs are described in Table 2 and regional monitoring programs are described in Table 3. NS = not sampled and NI = no regional sampling identified.

	IEP Monitoring Programs						
Region	20-mm Tow-Net	Summer Tow-Net	Fall Midwater Trawl	Spring Kodiak Trawl	Bay Midwater Trawl	Beach Seine	Regional Monitoring
San Francisco Bay	NS	NS	NS	NS	20	7	NI
West San Pablo Bay	NS	NS	12	NS	5	3	NI
East San Pablo Bay	7	7	19	NS	5	2	NI
Lower Napa River	3	1	2	2	NS	NS	NI
Upper Napa River	7	NS	NS	4	NS	NS	NI
Carquinez Straight	1	1	7	1	2	NS	1
Suisun Bay Southwest	1	1	5	1	1	NS	1
Suisun Bay Northwest	1	1	5	1	2	NS	1
Suisun Bay Southeast	2	3	8	2	1	NS	2
Suisun Bay Northeast	2	1	5	2	1	NS	2
Grizzly Bay	1	1	4	1	2	NS	1
Suisun Marsh	3	3	5	5	NS	1	73
Confluence	5	4	10	4	2	1	8
Lower Sacramento River	4	3	4	4	3	NS	4
Upper Sacramento River	1	2	16	4	3	12	3
Cache Slough and Ship Channel	13	NS	3	5	NS	10	43
Lower San Joaquin River	6	4	12	6	5	4	6
East Delta	1	1	8	5	NS	5	29
South Delta	9	6	11	6	NS	18	12
Upper San Joaquin River	NS	NS	NS	NS	NS	16	NI
Sacramento Valley	NS	NS	NS	NS	NS	18	1
Total	67	39	136	53	52	97	187
Percent of Regions Represented	81%	71%	81%	76%	62%	57%	71%

Table 2.—Interagency Ecological Program monitoring programs that sample delta smelt: years and months surveyed, number of survey stations, and size of delta smelt captured for each monitoring program.

Monitoring Program (Agency)	Years	Sampling Period (Frequency)	No. of Stations	Captured Delta Smelt Lengths (mm)
Fall Midwater Trawl (CDFG)	1967-present	Sep-Dec[a] (Monthly)	53-113	> 30
Summer Tow-Net (CDFG)	1959-present[b]	Jun-Aug (Bi-Weekly)	~30	15 - 65
20-mm Tow-Net (CDFG)	1995-present	Mar-July (Bi-weekly)	41-49	5 - 60
Spring Kodiak Trawl (CDFG)	2002-present	Jan-May (~Bi-weekly)	30-40	> 50
Bay Midwater Trawl (CDFG)	1980-present[c]	All Year (Monthly)	52	> 30
Beach Seine (USFWS)	1977-present	All Year[d] (~Bi-weekly)	~40	> 30

[a]Survey continued through March during 1991-2001.

[b]Delta smelt were not measured or consistently enumerated until 1973.

[c]Delta stations added in 1991 and 1994.

[d]Since 1994. Before 1994 only January-March were consistently sampled each year.

program is selective for different sizes of delta smelt, and therefore different life stages (Table 2). The methods for the IEP monitoring programs have been described previously (Moyle et al. 1992, USFWS 2003, Bennett 2005), as have the merits of several resulting abundance indices (Bennett 2005).

Regional monitoring programs.—In addition to the IEP monitoring programs, numerous other monitoring programs are carried out by various governmental and non-governmental entities, and for a variety of purposes (Table 3). These programs utilize an assortment of gears including seining, electrofishing, and tow-nets. Some of these programs have been carried out for a decade or more. Collectively, they are referred to as regional monitoring programs throughout the remainder of this paper.

Table 3.—Regional monitoring programs sampling delta smelt: survey location, survey gear, project, study period, and data source.

Location	Survey Gear Used	Project	Study Period	Source
Cosumnes River	seine, electrofishing	Floodplain Monitoring	1998-2005	Moyle et al. 2007
Cosumnes River	light trap	Floodplain Monitoring	1999-2001	Crain et al. 2004
Cosumnes River	seine	Stream Evaluation	1990s-2000s	R. Titus[a]
Lower American River	rotary screw trap	Stream Flow and Habitat Evaluation Program	1990s-2000s	R. Titus[a] Snider and Titus 2000 Snider et al. 1998
Yolo Bypass	rotary screw trap, fyke net/trap, beach seine, purse seine	Yolo Bypass Study	1998-2005	CDWR[b]
Yolo Bypass	rotary screw trap, and egg and larval nets	Yolo Bypass Floodplain	1999-2002	Sommer et al. 2004
Sacramento Deep Water Shipping Channel	tow nets and trawl	20 mm, STN, FMWT	2009	Samii-Adib 2010
Suisun Marsh	beach seine, larval sled, midwater trawl, otter trawl	Suisun Marsh Fisheries Monitoring	1979-2005	UCD[c]
Lower Mokelumne River	seining, backpack electrofishing surveys, boat electrofishing surveys	East Fish Community Survey	1997-2004	Merz and Saldate 2005
Lower Mokelumne River	rotary screw trap	Mokelumne River Salmon and Steelhead Monitoring	1990-2009	EBMUD[d]
Lower Calaveras River	beach seine	Calaveras River Barrier Removal program	2010	T. Kennedy[e]
West Delta	beach seine	West Delta Survey	2005-2006	T. Kennedy[e]
North Delta	plankton net	North Bay Aqueduct Survey	1994-2004	CDFG
Upper San Francisco Estuary	plankton net	Smelt Larval Survey	2009 -2010	CDFG
South Delta	louvers	Central Valley Project	1955-present	CDFG
South Delta	louvers	State Water Project	1972-present	CDFG
Chipps Island	boat trawling	Chipps Island Midwater Trawl	1976-2008	USFWS
South-east Suisun Bay, Confluence of Sacramento & San Joaquin Rivers	sieve net	Mirant Power Plants	2006	IEP
South Delta	sieve net	Contra Costa Water District Intake Facility	1995-present	CDFG

[a]CDFG, personal communication
[b]California Department of Water Resources
[c]University of California, Davis
[d]East Bay Municipal District
[e]Fishery Foundation of California, personal communication

Observed geographic extent.—To identify the geographic extent of delta smelt, we utilized records taken from IEP and regional monitoring programs. We present all years of available data for each monitoring program (Tables 2 and 3). If delta smelt were detected at least once at any given monitoring location, they were designated as present at that site; otherwise they were designated as not observed. Because the detection probability for each type of survey gear is not available and each monitoring program is conducted at different sampling frequencies and levels of effort, we did not consider delta smelt to be absent from locations where the species was not observed (Pearce and Boyce 2006). Since our objective was to identify the range of delta smelt presence, and not to examine where delta smelt are absent, we did not further assess the likelihood of falsely identifying delta smelt as being absent at a given location.

We developed a boundary for the observed geographic extent of delta smelt by using a 1-km buffer around sites where delta smelt were observed, including all open water between points within the boundary (Graham and Hijmans 2006 for discussion of buffer size). We then calculated the surface area of all waters within the boundary.

We also examined the geographic distribution of sampling stations and sampling effort among the IEP and regional monitoring programs. We enumerated how many stations were sampled by each of the IEP monitoring programs and all the regional monitoring programs combined within each of the 21 identified regions, and calculated the percentage of regions sampled by each monitoring program.

Distribution by life stage.—Extending from the life history discussions of Moyle (2002) and Bennett (2005), we differentiated five separate delta smelt life stages: larvae,

Table 4.—Delineation of delta smelt life stages by the Interagency Ecological Program, fish size or reproductive stage, time periods, and years of available samples. 20-mm = 20-mm Tow-Net, STN = Summer Tow-Net,

Life Stage	Monitoring Program	Life Stage Distinction	Time Period	Years of Data Used
Larvae	20-mm	<15 mm	Apr-Jun	1995-2009
Sub-juveniles	20-mm, STN	≥15,<30 mm	20-mm: Apr-Jul STN: Jun-Aug	1995-2009
Juveniles	20-mm, STN, FMWT	30-55 mm	20-mm: May-Jul STN: Jun-Aug FMWT: Sep-Dec	1995-2009
Sub-adults	FMWT	>55 mm	Sep-Dec	1995-2009
Mature Adults	Beach Seine, BMWT	>55 mm	Beach Seine: Dec-May BMWT: Jan-May	Beach Seine: 1995-2009 BMWT: 1995-2006
Mature Adults: Pre-spawning	Kodiak	Reproductive stages[a]: females 1-3; males 1-4	Jan-Apr	2002-2009
Mature Adults: Spawning	Kodiak	Reproductive stages[a]: females 4; males 5	Jan-May	2002-2009

[a]Gonadal stages of male and female delta smelt found in Spring Kodiak Trawl database were classified by California Department of Fish and Game following Mager (1986). Descriptions of these reproductive stages are available at: http://www.dfg.ca.gov/delta/data/skt/eggstages.asp

sub-juveniles, juveniles, sub-adults, and mature adults (Table 4). We chose a 15-mm total length as the cut-off between larvae and sub-juveniles because when delta smelt reach 16-18 mm their fins are more developed and their swim bladder is filled with gas, making them more mobile within the water column (Moyle 2002). We used 30 mm as the cut-off between sub-juveniles and juveniles because this size is associated with a change in feeding regime (Moyle 2002). We chose 55 mm as the cut-off between juveniles and sub-adult and mature adults because growth slows between 55 and 70 mm (with most of the available energy diverted to gonadal development [Radtke 1966, Erkkila et al. 1950]). Because maturation rate of captured delta smelt was reported for the Spring Kodiak Trawl, we used reproductive stage to further subdivide mature adults into pre-spawners and spawners. Reproductive stages 1 to 3 for females, and 1 to 4 for males, were classified as pre-spawning. Reproductive stages 4 in females, and 5 in males, were classified as spawning (J. Adib-Samii, CDFG, personal communication; additional information is available at: http://www.dfg.ca.gov/delta/data/skt/eggstages.asp).

We used data from the IEP monitoring programs to elicit information on the temporal and spatial distribution of life stages. For each life stage, we delineated a period of several months when delta smelt of that life stage often were observed. We excluded months when delta smelt were caught in very low numbers (<3% of the total for that life stage) because those data would have biased frequency of observation and observed density results downward. Where possible, we used data from multiple monitoring programs that sampled the same life stage at different months during the year (Table 4).

Although data are available for juveniles and adults back to 1967 (FMWT), we present only results from 1995 onward to compare life stage distributions during similar time periods; 20-mm Tow-Net surveys were first conducted in 1995, and provided data for larvae, sub-juveniles, and juveniles. Data from two monitoring programs were not available for the full period from 1995 to 2009: the Kodiak (2002-2009), and the BMWT (1995-2006), which after 2006 was adjusted to avoid high levels of delta smelt take (R. Baxter, CDFG, personal communication). We excluded supplemental samplings because such surveys were conducted for special purposes and were not always consistent with the protocol for the program (R. Baxter, CDFG, personal communication). To avoid introducing anomalies caused by the addition of new stations, we included only sampling stations that were sampled consistently (i.e., stations that were sampled ≥ 90% of the years).

We calculated the average annual frequency of delta smelt observation at consistently surveyed stations for each life stage in each region for all years as

$$P_{lrpy} = (S_{lrpy} / N_{rpy})(100) \qquad (1)$$

where: P_{lrpy} is the percent of sampling events (i.e., a sample at a station) when delta smelt of life stage l were caught in region r during time period p and year y, S_{lrpy} is the number of sampling events in region r when delta smelt of life stage l were caught during time period p and year y, and N_{rpy} is the total number of sampling events in region r during time period p and year y. Next, the average annual frequency of delta smelt observation for each life stage and region was calculated as a simple average over all years.

We calculated the yearly observed density (Density; i.e. relative measure of abundance) of delta smelt for each life stage and region for all years by dividing the summed catches C of delta smelt for each life stage l, region r, time period p, and year y by the volume of water in cubic meters V that was sampled for each region and year, then multiplying by

10,000 to determine the catch per 10,000 m^3 of water for each life stage, region, and year as

$$Density_{lry} = (\Sigma C_{lry} / \Sigma V_{ry})\ (10000) \qquad (2)$$

Next, the average annual observed density for each life stage and region was calculated as a simple average over all years. To standardize these data, the average observed density for each life stage and region was then divided by the highest average annual observed density for that life stage and multiplied by 100.

While recognizing that the gear employed to sample Estuary fishes varies in catch efficiency, and that catch efficiency varies both between monitoring programs and within samples of each monitoring program depending on a variety of factors including the size of individual fish, we did not attempt to adjust the results reported here for catch efficiency. As a result, we did not attempt to draw conclusions regarding differences in densities between monitoring programs, or between life stages within a given monitoring program.

Our treatment of catch data was limited to frequency of observation and average observed density, rather than population estimates. The latter would have required estimates of the volume of the body of water and reliance on the assumption that samples are representative of the density of smelt in the targeted water body. The validity of such an assumption may be questionable in a variety of circumstances, particularly when using Beach Seine data since the demarcation between "beach habitat" and "open-water habitat" is difficult to specify.

To describe the temporal extent of the presence of each life stage across all years, we calculated the frequency of observation and observed density by month for each life stage. In so doing, we built upon the conceptual and analytical work of Bennett (2005), who provided a model of delta smelt life history that included the approximate months during which each life stage exists. The percentage of delta smelt caught in any individual month was calculated as the total number of smelt of that life stage caught in that month since 1995, divided by the total number of smelt of that life stage caught since 1995. Because we did not attempt to compare catch between monitoring programs, we reported this result separately for each monitoring program. We also reported the frequency with which each life stage was observed in each month in each monitoring program.

Results

Within the 21 identified regions of the San Francisco Estuary, we identified 289,401 survey events (a sampling event at a given location and time) at 624 monitoring stations. Of these, 444 (71%) were from IEP and 180 (29%) were from regional monitoring programs. The program with the single greatest number of monitoring stations was FMWT (136), followed by the Beach Seine (97), 20-mm (67), Kodiak (53), BMWT (52), and STN (39) (Table 1). Delta smelt were observed at 347 of the 444 (78%) IEP monitoring stations and at 83 of the 180 (46%) regional monitoring stations identified in this study.

Observed geographic extent.—Delta smelt were observed in all of the 21 regions covering an area of about 51,800 ha (Figure 2). Observations occurred as far west as Berkeley in San Francisco Bay, north on the Sacramento River to its confluence with the Feather River, and the San Joaquin River south of Stockton. Tributary observations included the Napa River, Cache Slough, the American River to the north, and the Mokelumne and

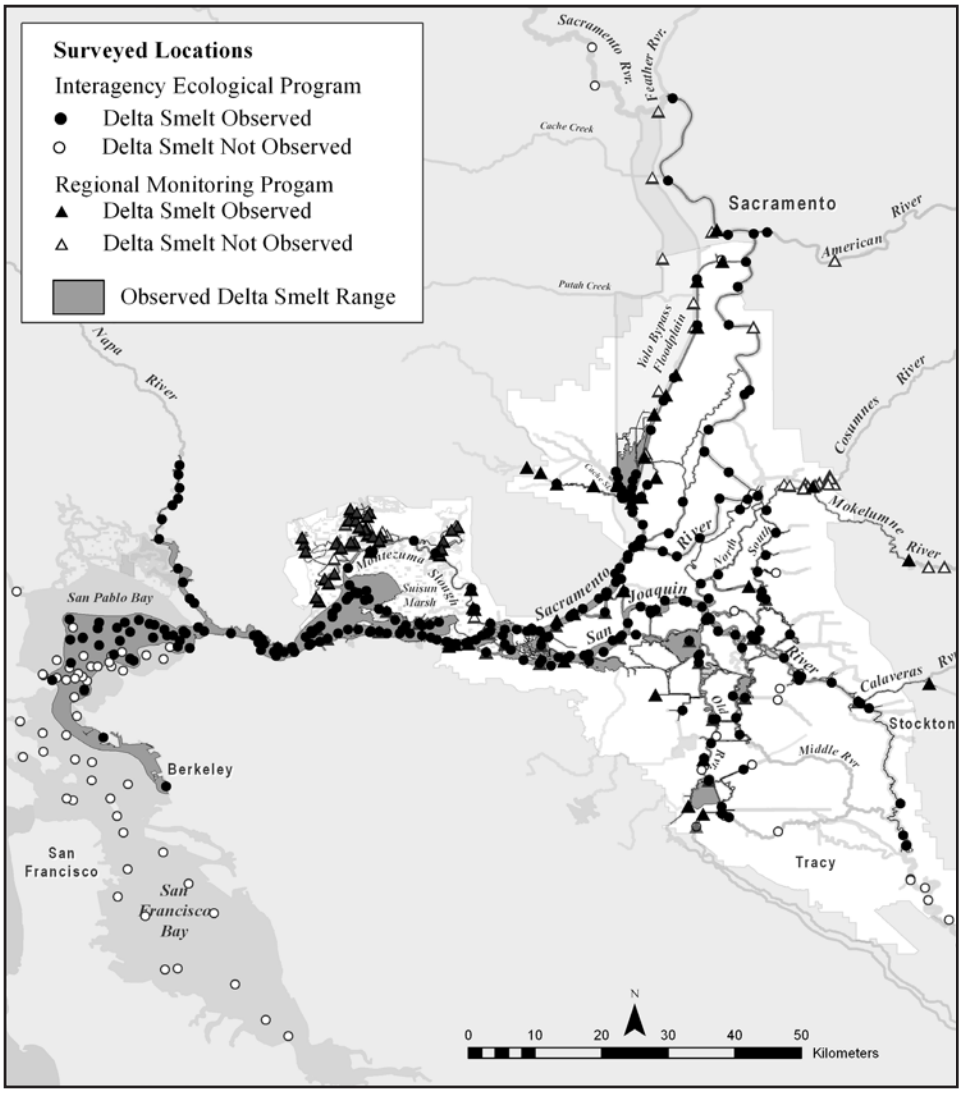

Figure 2.—Observations of delta smelt at monitoring stations of Interagency Ecological Program and Regional surveys. Circles indicate Interagency Ecological Program stations where delta smelt were observed (closed) or not observed (open). Triangles indicate Regional survey stations where delta smelt were observed (closed) or not observed (open). The outlined area represents the observed delta smelt range.

Calaveras rivers to the east. Delta smelt were also observed in seasonally-inundated habitat of the Yolo Bypass and the Cosumnes River at its confluence with the Mokelumne River.

No single IEP monitoring program sampled all of the 21 regions (Table 1) that make up the observed extent of range (Figures 3 to 5). The 20-mm and the FMWT had the highest coverage (80% of regions each). The STN covered 71% of the regions, while coverage among the other IEP surveys ranged from 57 to 76%.

Distribution by life stage.—Delta smelt larvae were observed in the Estuary from March through July, sub-juveniles during April through August, juveniles during May

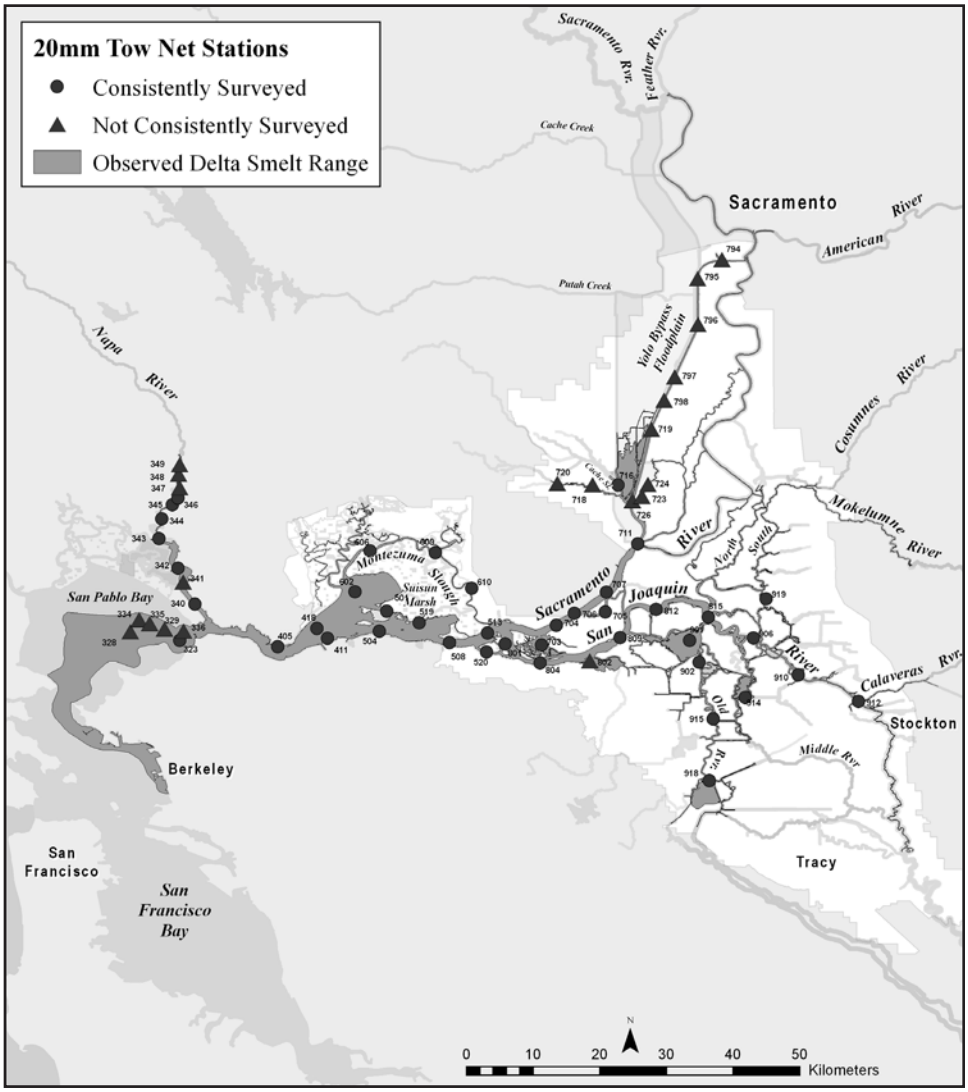

Figure 3.—Location of 20-mm Tow-Net survey stations in relation to the observed delta smelt range (outlined area). Circles represent stations consistently surveyed across all years (1995-2009). Triangles represent stations not consistently surveyed.

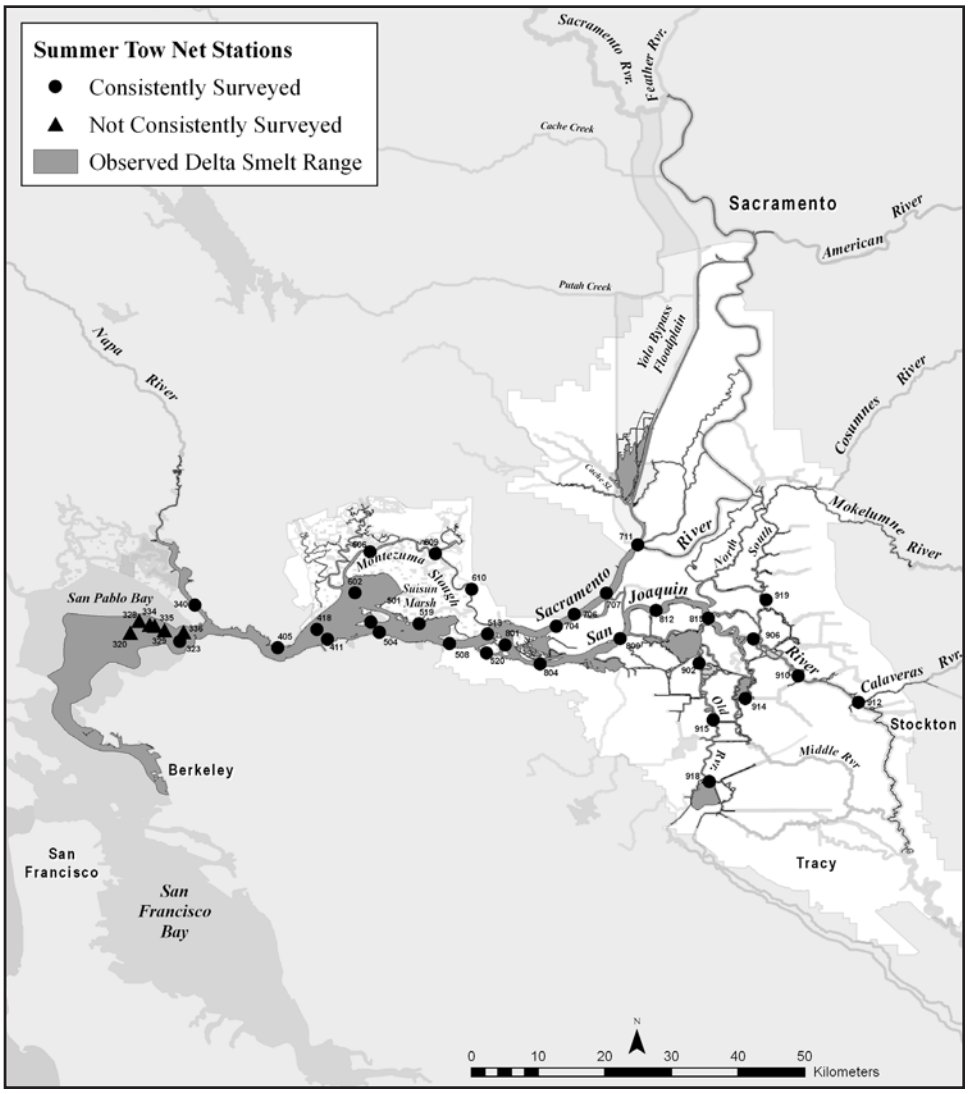

Figure 4.—Location of Summer Tow Net survey stations in relation to the observed delta smelt range (outlined area). Circles represent stations consistently surveyed across all years (1995-2009). Triangles represent stations not consistently surveyed.

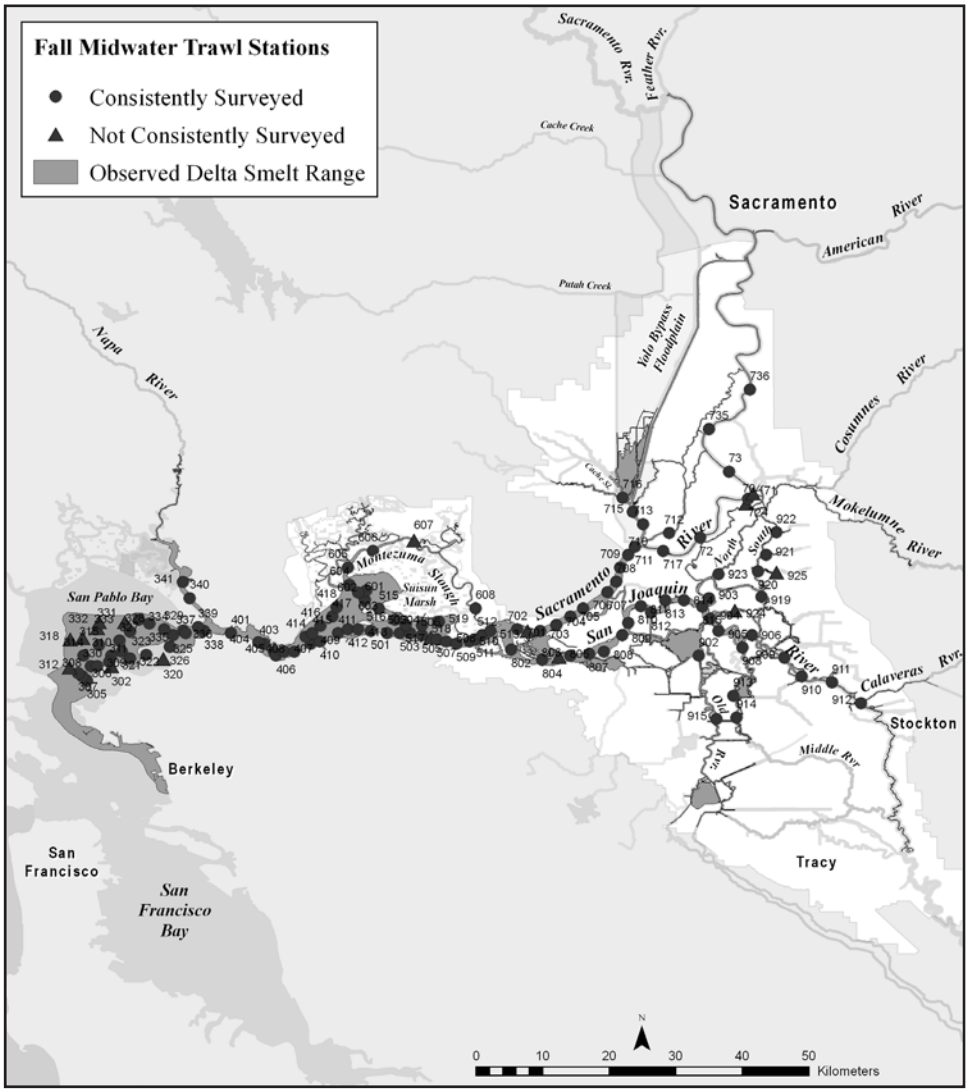

Figure 5.—Location of Fall Mid-Water Trawl survey stations in relation to the observed delta smelt range (outlined area). Circles represent stations consistently surveyed across all years (1995-2009). Triangles represent stations not consistently surveyed.

through December, sub-adults during September through December, and pre-spawning and spawning adults during January through May (Tables 5 and 6). For most life stages, delta smelt were observed most frequently near the center of their range — from Suisun Marsh down through Grizzly Bay and east Suisun Bay through the Confluence to the Lower

Table 5.—Percent of years delta smelt were observed in each month in at least one location in the Estuary by life stage and monitoring program (1995-2009). 20-mm = 20-mm Tow-Net, STN = Summer Tow-Net, FMWT = Fall Midwater Trawl, BS = Beach Seine, BMWT = Bay Midwater Trawl, and SKT = Spring Kodiak Trawl.

Life Stage	Monitoring Program	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Larvae	20-mm			64%	100%	100%	100%	43%	0%				
Sub-juvenile	20-mm			0%	93%	100%	100%	93%	50%				
Sub-juvenile	STN						100%	93%	58%				
Juvenile	20-mm			0%	7%	93%	100%	93%	50%				
Juvenile	STN						100%	100%	100%				
Juvenile	FMWT									87%	80%	73%	53%
Sub-adults	FMWT									100%	93%	93%	100%
Mature Adults	BS	69%	81%	94%	94%	93%						38%	56%
Mature Adults	BMWT	89%	80%	89%	92%	75%	58%	75%	100%	75%	8%	0%	18%
Pre-spawning	SKT	100%	100%	100%	100%	100%							
Spawning	SKT	43%	75%	100%	100%	50%							

Table 6.—Percent of total delta smelt catch occurring in each month by lifestage and monitoring program (1995-2009). 20-mm = 20-mm Tow-Net, STN = Summer Tow-Net, FMWT = Fall Midwater Trawl, BS = Beach Seine, BMWT = Bay Midwater Trawl, and SKT = Spring Kodiak Trawl.

Life Stage	Monitoring Program	Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Larvae	20-mm	1995-2009			2%	59%	29%	9%	1%					
Sub-juvenile	20-mm	1995-2009			0.0%	5%	43%	43%	9%	0.3%				
Sub-juvenile	STN	1995-2009						34%	56%	11%				
Juvenile	20-mm	1995-2009			0.0%	0.0%	5%	55%	38%	3%				
Juvenile	STN	1995-2009						18%	56%	26%				
Juvenile	FMWT	1995-2009									40%	37%	14%	9%
Sub-adults	FMWT	1995-2009									16%	34%	28%	22%
Mature Adults	BS	1995-2009	9%	10%	31%	21%	17%						2%	10%
Mature Adults	BMWT	1995-2006	20%	12%	17%	23%	7%	3%	9%	5%	3%	0.2%	0.0%	
Pre-spawning	SKT	2002-2009	45%	34%	16%	4%	1%							
Spawning	SKT	2002-2009	4%	23%	53%	17%	4%							

Sacramento River region, but also in the region of Cache Slough (Figure 6). Regions where delta smelt were observed most frequently (regions in the upper quartile of each column in Table 7) for any life stage were northeast Suisun Bay, Grizzly Bay, Suisun Marsh, Confluence, Lower Sacramento River, Upper Sacramento River, Cache Slough and Ship Channel, and

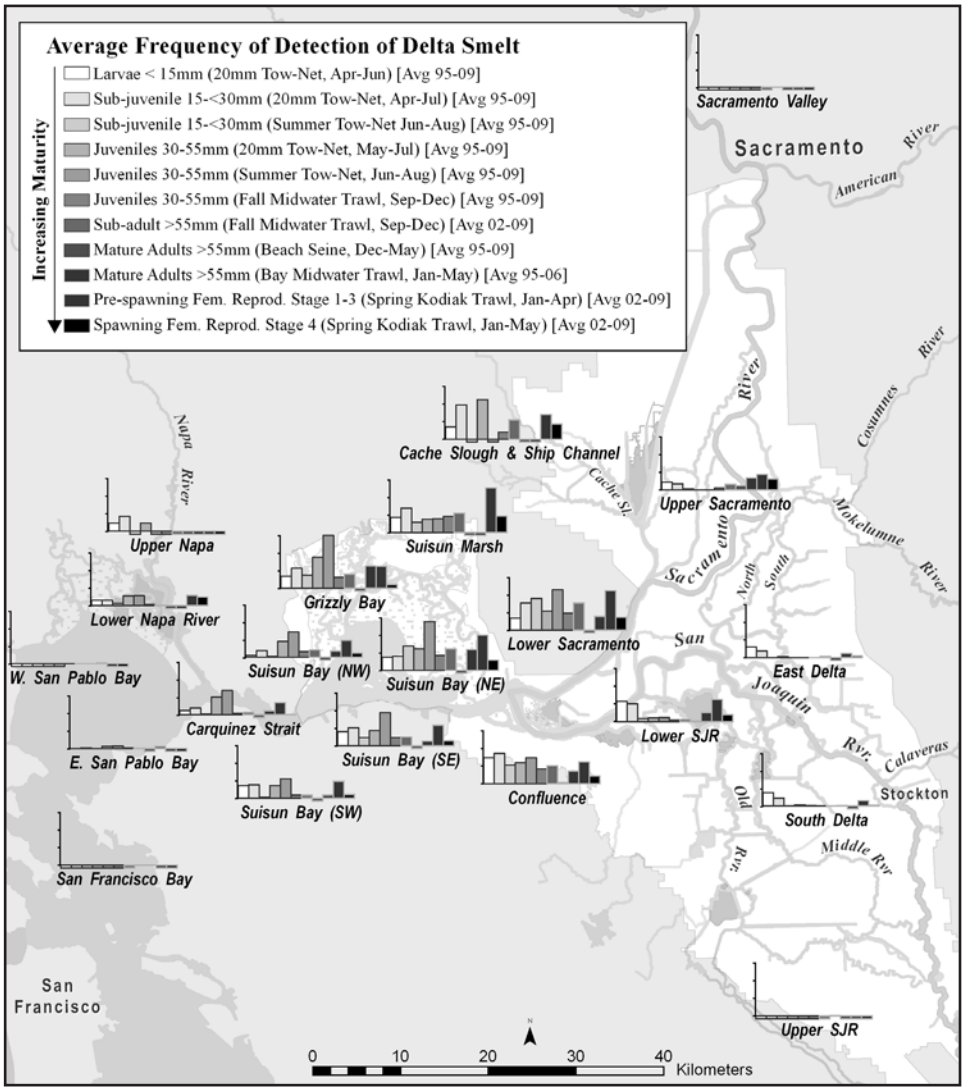

Figure 6.—Average annual frequency of delta smelt observation (percentage of sampling events where delta smelt were observed) by life stage and Region for Interagency Ecological Program surveys. Regions where the average frequency of detection for a given life stage was zero are indicated by no data column being present. Regions that were not sampled for a given life stage are indicated by a data column suspended slightly below the x-axis. Y-axis ticks indicate frequencies of 0, 25, 50, 75, and 100 percent.

Table 7.—Average annual frequency of delta smelt occurrence by life stage, IEP monitoring program, and region. 20-mm = 20-mm Tow-Net, STN = Summer Tow-Net, FMWT = Fall Midwater Trawl, BS = Beach Seine, BMWT = Bay Midwater Trawl, and SKT = Spring Kodiak Trawl. NS indicates no survey conducted in the given life-stage and region.

	Life-stage										
	Larvae	Sub-juvenile		Juvenile			Sub-adult	Mature Adults		Pre-spawning	Spawning
Monitoring Program	20-mm	20-mm	STN	20-mm	STN	FMWT	FMWT	Beach Seine	BMWT	Kodiak Trawl	Kodiak Trawl
Years of data used	95-09	95-09	95-09	95-09	95-09	95-09	95-09	95-09	95-06	02-09	02-09
Time period	Apr-Jun	Apr-Jul	Jun-Aug	May-Jul	Jun-Aug	Sep-Dec	Sep-Dec	Dec-May	Jan-May	Jan-Apr	Jan-May
San Francisco Bay	NS	NS	NS	NS	NS	NS	NS	0.0%	0.0%	NS	NS
West San Pablo Bay	NS	NS	NS	NS	NS	0.2%	0.0%	0.0%	1.2%	NS	NS
East San Pablo Bay	0.0%	1.0%	0.0%	2.8%	3.6%	0.7%	0.6%	NS	2.7%	NS	NS
Lower Napa River	7.3%	7.7%	3.3%	13.3%	14.0%	1.7%	0.8%	NS	NS	14.3%	11.8%
Upper Napa River	11.6%	21.2%	NS	12.0%	NS	NS	NS	NS	NS	NS	NS
Carquinez Strait	5.7%	9.3%	1.1%	24.4%	33.7%	1.9%	3.3%	NS	5.4%	16.7%	0.0%
Suisun Bay (SW)	17.8%	18.3%	1.3%	17.5%	26.9%	4.3%	4.3%	NS	4.3%	23.3%	5.6%
Suisun Bay (NW)	2.2%	8.9%	1.1%	21.7%	34.8%	7.3%	10.0%	NS	8.7%	23.3%	5.6%
Suisun Bay (SE)	19.5%	24.9%	11.0%	20.9%	45.7%	11.0%	12.1%	NS	6.5%	28.3%	6.9%
Suisun Bay (NE)	17.8%	19.2%	33.6%	29.7%	66.7%	20.3%	29.3%	NS	28.3%	48.3%	13.9%
Grizzly Bay	16.3%	27.6%	17.9%	42.9%	72.8%	15.0%	19.6%	NS	30.4%	30.0%	5.6%
Suisun Marsh	21.4%	33.6%	14.2%	18.5%	19.2%	22.8%	27.2%	NS	NS	62.0%	23.1%
Confluence	35.7%	41.6%	25.7%	29.2%	36.1%	20.2%	24.5%	1.8%	17.4%	30.0%	10.4%
Lower Sacramento River	16.5%	37.0%	43.3%	26.2%	55.5%	22.9%	37.1%	NS	18.8%	54.4%	17.8%
Upper Sacramento River	10.8%	8.2%	1.3%	0.0%	0.0%	2.7%	8.0%	5.8%	16.7%	21.7%	15.3%
Cache Slough & Ship Channel	17.2%	47.3%	NS	54.3%	NS	9.8%	26.7%	NS	NS	33.9%	21.1%
Lower San Joaquin River	28.0%	24.5%	4.1%	5.1%	5.6%	2.6%	3.5%	0.9%	12.6%	30.6%	9.7%
East Delta	14.6%	8.8%	0.0%	1.2%	0.0%	0.0%	0.0%	1.6%	NS	5.7%	2.3%
South Delta	18.4%	10.8%	0.0%	1.4%	0.3%	0.0%	0.0%	0.3%	NS	7.1%	1.1%
Upper San Joaquin River	NS	NS	NS	NS	NS	NS	NS	0.2%	NS	NS	NS
Sacramento Valley	NS	NS	NS	NS	NS	NS	NS	0.2%	NS	NS	NS

Lower San Joaquin River. Westward of Suisun Bay, the frequency of observation tended to decrease as the distance from Suisun Bay increased. San Pablo Bay typically had the lowest observed frequencies west of Suisun Bay. The East and South Delta regions generally had low observed frequencies relative to other regions for the same life stage. The exception was for larval delta smelt where these regions (with observed frequencies of 15% and 18%, respectively) were close to the median observed frequency of 16%.

Delta smelt were observed at higher densities near the center of their range — the same area where they were observed most frequently: from Suisun Marsh down through Grizzly Bay and east Suisun Bay through the Confluence to the Lower Sacramento River region, but also in the Cache Slough region (Figure 7). The regions where delta smelt were

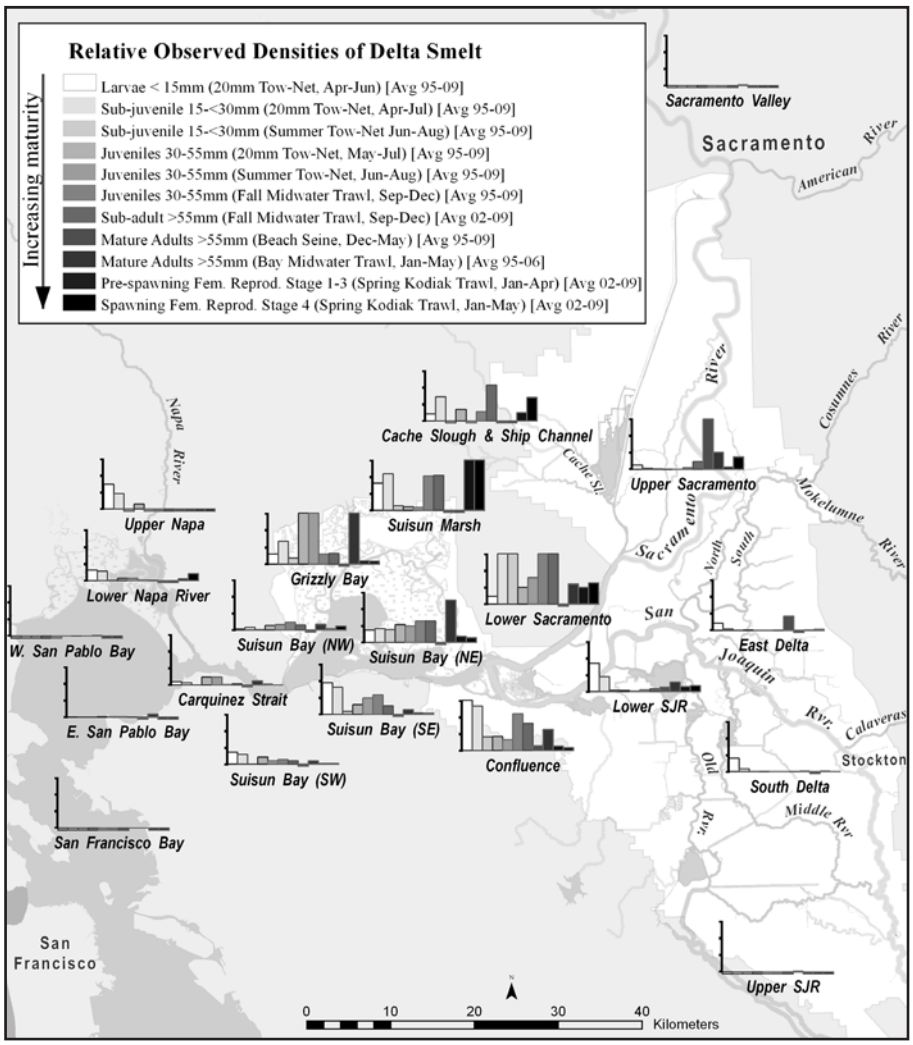

Figure 7.—Relative observed densities (average density for each life stage and region divided by highest average annual density observed for that life stage multiplied by 100) of delta smelt by life stage and region for Estuary-wide surveys. Regions where the relative observed density for a given life stage was zero are indicated by no data column being present. Regions that were not sampled for a given life stage are indicated by a data column suspended slightly below the x-axis. Y-axis ticks indicate 0, 25, 50, 75, and 100 percent of highest observed density.

observed in the greatest densities were the Confluence for larvae in the 20-mm; Lower Sacramento River for sub-juveniles in both the 20-mm and STN; Grizzly Bay for juveniles in the 20-mm and STN, but Lower Sacramento River for juveniles later in the year in the FMWT; Lower Sacramento River for sub-adults in the FMWT; Upper Sacramento River for mature adults in the Beach Seine; Grizzly Bay for mature adults in the BMWT; and Suisun Marsh for both pre-spawning and spawning adults in the Kodiak (Table 8). Regions with the highest average observed densities (regions in the upper quartile of each column in Table 8) for any life stage were northeast Suisun Bay, Grizzly Bay, Suisun Marsh, Confluence, Lower Sacramento River, and Upper Sacramento River. Delta smelt observed densities (for all but the earliest life stages) were low in the western Suisun Bay and regions further to the west, and in the east and south Delta, relative to other areas.

Discussion

Observed geographic extent.—Extent of habitat is a critical piece of information for assessing the conservation status of a species (e.g., Millsap et al. 1990, IUCN 1994, Lunney et al. 1996, Burgman and Fox 2003). The historical range of delta smelt was provided by Sweetnam and Stevens (1993) who described the species as existing as far upstream in the Sacramento River as the Feather River mouth (citing Wang 1991) and Mossdale on the San Joaquin River (citing Moyle et al. 1992), and downstream to western Suisun Bay.

We utilized recently available data from the 20-mm (since 1995) and Kodiak (since 2002), together with other IEP and regional monitoring programs (since 1995) to provide information on areas of the Estuary where identified delta smelt life stages have been observed. Though our study included additional portions of San Pablo Bay not detailed by Sweetnam and Stevens (1993), we identified essentially the same distribution of delta smelt on the Napa River, Cache Slough, Suisun Marsh tributaries, and San Joaquin River inferred by the earlier study.

Observations at the most upstream sampling stations in the Napa River, Cache Slough, and Sacramento and Calaveras rivers indicate that the extent of delta smelt distribution in these locations remains unknown. Recently, Cache Slough and its tributaries have been identified as key habitat for delta smelt across all life stages (DSC 2010). However, available survey data suggest the full distributional range of delta smelt in the Cache Slough drainage has not been identified by current sampling efforts. These observations suggest sampling locations beyond those covered by current IEP monitoring could yield further insights into distribution and habitat requirements of this endangered fish.

Distribution by life stage.—While numerous factors affect the distribution of delta smelt (EET 1997, Meng and Matern 2001, Bennett et al. 2002, Kimmerer 2002, Baskerville-Bridges et al. 2004, Dege and Brown 2004, Feyrer 2004, Grimaldo et al. 2004, Sommer et al. 2004, Bennett 2005, Feyrer et al. 2007, Baxter et al. 2008, Nobriga 2008), it was beyond the scope of this paper to relate distribution to causal factors. Nevertheless, important information can be gleaned from this review, which may inform conservation planning and lead to research into factors driving delta smelt distribution. For example, high frequency of observation and observed density of mature adults and early life stages are indicators of areas that could be spawning regions (Sommer et al. 2011). Spawning occurring upstream in freshwater has been supported elsewhere through high catches of larval delta smelt along the edges of rivers and in adjoining sloughs in the western Delta (Moyle et al. 1992). The

newer IEP monitoring programs provide potentially important information regarding general spawning locations. The relatively higher presence of spawning adults in Suisun Marsh, Cache Slough, and the Lower Sacramento River indicate possible proximity to spawning areas, a suggestion also supported by high relative observed densities of larval smelt in downstream areas. The Upper Napa River has relatively high observed densities of larvae, suggesting that this may also be an important area for spawning; considering their poor swimming ability, it is unlikely that larvae would have migrated up the Napa River from other locations. The Napa River, which at one time was considered to be a population sink for delta smelt, is now considered a contributor to the adult population (Hobbs et al. 2007).

An important rearing area appears to be the stretch of water between the Lower Sacramento River and Grizzly Bay, with Grizzly Bay supporting an increasing proportion of young delta smelt as they mature. The highest relative observed densities of juveniles in STN (with surveys from June to August) were found in Grizzly Bay. This is corroborated by data from the 20-mm, which also showed Grizzly Bay to have the highest relative observed densities of juveniles (May to July). By fall, the FMWT data indicate the highest relative observed juvenile densities usually are found further to the east in the Confluence and Lower Sacramento River regions — an area where sub-adults were also found in relatively high observed densities.

Spawning in the upstream regions of Napa River, Suisun Marsh, the Upper Sacramento River and Cache Slough, and maturing downstream in waters from Grizzly Bay upstream to the Lower Sacramento River is consistent with the well-noted migration of delta smelt (Grimaldo et al. 2009, Sommer et al. 2011). The data also suggest year-round populations in the central regions (Lower Sacramento River downstream to Suisun Marsh) and in the Cache Slough and Ship Channel region. Collectively, these observations, along with the report of Hobbs et al. (2007), are an indication of variability in the migratory patterns observed by Sommer et al. (2011).

Outside of the central regions, the Cache Slough and Ship Channel was the only region that yielded high catches of delta smelt relative to other regions across multiple life stages for years 1995-2009. Recent monitoring efforts have shown that delta smelt are utilizing the near-shore habitats of the Cache Slough and Ship Channel region (a restored tidal marsh) not only during the spawning season, but also on a year-round basis (DSC 2010). Many IEP studies are underway to understand the environmental mechanisms in Cache Slough that help create critical habitat for delta smelt.

A number of observations can be taken from these distributional data that could contribute to more effective conservation planning for delta smelt. First, some of the highest observed densities of delta smelt are found close to shore (Table 8), suggesting that some necessary or desired habitat conditions exist along the shoreline, possibly related to migration (Sommer et al. 2011) or spawning. Second, it could be inferred from subregional delta smelt observed densities that, under contemporary conditions, the fish seem to be exhibiting higher densities in areas that are most similar to historic habitat — deep channels that occur proximate to more extensive areas of shallow water (Whipple 2010), which may to some degree be insulated from the influences of anthropogenic environmental stressors. Third, it appears that the monitoring programs may be missing useful information at some life stages in areas potentially important for delta smelt (e.g., areas upstream of existing consistently monitored stations in the Napa River, around Cache Slough and the adjacent ship channel, and several other tributaries to the Sacramento River).

Table 8.—Average observed densities (number of fish per 10,000 m3) of delta smelt by life stage, Interagency Ecological Program monitoring program, and region. 20-mm = 20-mm Tow-Net, STN = Summer Tow-Net, FMWT = Fall Midwater Trawl, BS = Beach Seine, BMWT = Bay Midwater Trawl, and SKT = Spring Kodiak Trawl. NS indicates no survey conducted in the given life-stage and region.

	Life-stage										
	Larvae	Sub-juvenile		Juvenile			Sub-adult	Mature Adults		Pre-spawning	Spawning
Monitoring Program	20-mm	20-mm	STN	20-mm	STN	FMWT	FMWT	Beach Seine	BMWT	SKT	SKT
Years of Data Used	95-09	95-09	95-09	95-09	95-09	95-09	95-09	95-09	95-06	02-09	02-09
Time Period	Apr-Jun	Apr-Jul	Jun-Aug	May-Jul	Jun-Aug	Sep-Dec	Sep-Dec	Dec-May	Jan-May	Jan-Apr	Jan-May
San Francisco Bay	NS	NS	NS	NS	NS	NS	NS	0.0	0.0	NS	NS
West San Pablo Bay	NS	NS	NS	NS	NS	0.0	0.0	0.0	0.0	NS	NS
East San Pablo Bay	0.0	0.0	0.0	0.1	0.4	0.0	0.0	NS	0.1	NS	NS
Lower Napa River	2.0	3.6	0.2	1.2	3.3	0.1	0.0	NS	NS	1.1	0.4
Upper Napa River	4.6	6.0	NS	2.5	NS	NS	NS	NS	NS	NS	NS
Carquinez Strait	0.5	0.8	0.0	3.9	10.2	0.0	0.1	NS	0.1	0.4	0.0
Suisun Bay (SW)	2.3	3.7	0.1	3.4	4.6	0.4	0.3	NS	0.1	0.3	0.0
Suisun Bay (NW)	0.1	0.9	0.1	2.3	6.8	0.6	0.4	NS	0.1	0.6	0.2
Suisun Bay (SE)	5.9	10.4	0.9	4.8	22.1	1.6	0.7	NS	0.1	0.9	0.1
Suisun Bay (NE)	2.3	5.2	3.7	8.7	21.6	1.8	1.8	NS	1.0	3.0	0.3
Grizzly Bay	1.9	8.7	1.8	24.8	67.1	0.8	0.9	NS	1.2	1.6	0.2
Suisun Marsh	5.0	13.9	1.3	1.7	3.7	2.8	2.9	NS	NS	24.8	3.1
Confluence	9.4	17.0	3.9	7.0	14.8	3.1	2.3	3.9	0.5	2.2	0.2
Lower Sacramento River	1.4	19.3	14.7	8.3	35.1	4.2	4.2	NS	0.5	8.2	1.3
Upper Sacramento River	0.8	0.4	0.1	0.0	0.0	0.1	0.7	39.3	0.4	1.1	0.8
Cache Slough & Ship Channel	1.3	9.2	NS	5.7	NS	0.8	3.0	NS	NS	4.1	1.5
Lower San Joaquin River	5.2	5.6	0.4	0.4	0.4	0.1	0.2	3.4	0.2	2.4	0.4
East Delta	1.3	0.5	0.0	0.1	0.0	0.0	0.0	10.9	NS	0.1	0.0
South Delta	2.5	1.0	0.0	0.1	0.0	0.0	0.0	0.4	NS	0.2	0.0
Upper San Joaquin River	NS	NS	NS	NS	NS	NS	NS	0.4	NS	NS	NS
Sacramento Valley	NS	NS	NS	NS	NS	NS	NS	0.6	NS	NS	NS

According to Feyrer et al. (2007), one factor limiting the utility of delta smelt empirical data is that those data frequently pertain to a particular life stage or time period when sampling was conducted. Thompson et al. (2010) suggested a life history model linking the abundances of each life stage would provide a more continuous picture of the population and would capitalize more fully on available data. Martin et al. (2007) suggested that conservation of migratory species depends largely on understanding links between different periods of life cycles. These suggestions highlight the importance of, and the need for, a clearer understanding of the distribution of the various life stages of delta smelt.

Concepts regarding restoration of native fish habitat and buffering from potential environmental disaster within the San Francisco Estuary have evolved considerably in recent years, particularly the restoration of tidal wetlands and floodplain habitats (Moyle 2008). While significant issues include the management of flow, invasive species responses, and future climatic effects (Brown and May 2006), our review provides important information on the life stage-specific distribution of delta smelt that was made possible by monitoring programs implemented by the IEP and other agencies since 1995.

According to Holl et al. (2003), a common conclusion of many restoration efforts is that success varies substantially among sites. At least in part, varying success results from differences in hydrology, microclimate, and movement of plants, animals, and disturbance regimes. Our review of the spatial distribution of delta smelt highlights general regions that appear important for specific life stages. Such information will be useful when addressing management issues such as anthropogenic stressors, habitat restoration efforts, and testing the success of experimental approaches to achieving habitat objectives for desirable species (Moyle et al. 2010). This comprehensive review of delta smelt distribution within the San Francisco Estuary provides managers and scientists an improved depiction of the spatial and temporal extent of the delta smelt throughout its range, and lends itself to future analysis of population assessment and restoration planning.

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A state-space multi-stage lifecycle model to evaluate population impacts in the presence of density dependence: illustrated with application to delta smelt

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Abstract

Multiple factors acting on different life stages influence population dynamics and complicate the assessment and management of natural populations. To provide appropriate management advice, the available data should be used to determine which factors are important and what life stages they impact. It is also important to consider density dependent processes because they can modify the impact of some factors and the

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strength of density dependence can vary among life stages. We develop a state-space multi-stage life cycle model that allows for density dependence at multiple life stages and allows for factors to impact different life stages. The three parameter Deriso-Schnute stock-recruitment model is used to represent the transition between stages. We use AICc scores and AICc weights to rank models and provide an idea of the strength of evidence in the data about an a priori set of alternative hypothesis. We use a two-covariate-at-a-time stepwise model selection procedure based on model averaging to reduce the possibility of excluding factors that are detectable in combination, but not alone. Impact analysis with associated estimates of uncertainty is used to evaluate the impact of factors on the population. The framework is illustrated by application to delta smelt, a threatened species that is potentially impacted by multiple anthropogenic factors. The model is implemented using AD Model Builder. Our results indicate that density dependence and a few key factors impact the delta smelt population. Temperature, prey, and predators dominated the factors supported by the data and operated on different life stages. The included factors explain the recent declines in delta smelt abundance and may provide insight into the cause of the pelagic species decline in the San Francisco Estuary.

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Introduction

Multiple factors acting on different life stages influence population dynamics and complicate the assessment and management of natural populations. To provide appropriate management advice, the available data should be used to determine which factors are important and what life stages they impact. It is also important to consider density dependent processes because they can modify the impact of some factors and the strength of density dependence can vary among life stages. Management can then better target limited resources to actions that are most effective. Unfortunately, the relationships among potential factors, the life stages that they influence, and density dependence are often difficult to piece together through standard correlation or linear regression analyses.

Life cycle models are an essential tool in evaluating factors influencing populations of management concern (Buckland et al. 2007). They can evaluate multiple factors that simultaneously influence different stages in the presence of density dependence. They also link the population dynamics from one time period to the next propagating the information and uncertainty. This link allows information relating to one life stage (i.e., abundance estimates) to inform processes influencing other life stages and is particularly important when data is not available for all life stages for all time periods. The life cycle model should be fit to the available data to estimate the model parameters, including parameters that represent density dependence, and determine the data based evidence of the different factors that are thought to influence the population dynamics. Finally, the model should be used to direct research or provide management advice.

DRAFT

Deriso et al. (2008) present a framework for evaluating alternative factors influencing the dynamics of a population. It extends earlier work by Maunder and Watters (2003), Maunder and Deriso (2003), and Maunder (2004) and is similar to approaches taken by others (e.g., Besbeas et al. 2002; Clark and Bjornstad 2004; Rivot et al. 2004; Newman et al. 2006; Buckland et al. 2007). The Deriso et al. framework involves several components. First, the factors to be considered are identified. Second, the population dynamics model is developed to include these factors and then fitted to the data. Third, hypothesis tests are performed to determine which factors are important. Finally, in order to provide management advice, the impact of the factors on quantities of management interest, are assessed. They illustrate their framework using an age-structured fisheries stock assessment model fit to multiple data sets. Their application did not allow for density dependence in the population dynamics, except through the effect of density on the temporal variation in which ages are available to the fishery.

Inclusion of density dependence is important in evaluating the impacts on populations. Without density dependence, modeled populations can increase exponentially. This is unrealistic and can also cause computational or convergence problems in fitting population dynamics models to data. Density dependence can also moderate the effects of covariates. This is important because factors effecting density independent survival may be much less influential in the presence of density dependence compared to factors that affect carrying capacity (e.g., habitat). It is also important to correctly identify the timing of when the factors influence the population with respect to the timing of density dependence processes and available data. The approach also provides a framework for

DRAFT

amalgamating the two paradigms of investigating population regulation outlined by Krebs (2002); the density paradigm and the mechanistic paradigm.

Here we develop a life cycle model that allows for density dependence at multiple life stages and allows for factors to impact different life stages. We apply the framework of Deriso et al. (2008) where the first component also includes identifying the life stages that are impacted by each factor and where density dependence occurs. We illustrate the framework by applying it to Delta smelt. Delta smelt is an ideal candidate to illustrate the modeling approach because there are several long-term abundance time series for different life stages and a range of hypothesized factors influencing its survival for which covariate data is available. Life cycle models have been recommended to evaluate the factors effecting delta smelt (Bennett 2005; Mac Nally et al. 2010; Thomson et al. 2010).

Delta smelt is of particular management concern due to declines in abundance and the myriad of anthropogenic factors that could be causing the decline. Delta smelt is endemic to the San Francisco Estuary, which has multiple stressors including habitat modification, sewage outflow, farm runoff, and water diversions, to name just a few. Delta smelt was listed as threatened under the U.S. and California Endangered Species Acts in 1993. Several other pelagic species in the San Francisco Estuary have also experienced declines, but the factors causing the declines are still uncertain (Bennett 2005; Sommer et al. 2007). Recent studies have investigated the factors hypothesized to have caused the declines at both the species and ecosystem level, but the results were not conclusive (Mac Nally et al. 2010; Thomson et al. 2010).

Materials and Methods

Model

The model is stage based with consecutive stages being related through a function that incorporates density dependence. For simplicity and to be consistent with the predominant dynamics of delta smelt, we assume an annual life cycle. However, it is straightforward to extend the model to a multiple year life cycle or to stages that cover multiple years (i.e., adding age structure; e.g., Rivot et al. 2004; Newman and Lindley 2006). Within a year the number of individuals in each stage is a function of the numbers in the previous stage. The number of individuals in the first stage is a function of the numbers in the last stage in the previous year (i.e., the stock-recruitment relationship), except for the numbers in the first stage in the first year, which is estimated as a model parameter. The functions describing the transition from one stage to the next are modeled using covariates. A state space model (Newman 1998; Buckland et al. 2004; Buckland et al. 2007) is used to allow for annual variability in the equation describing the transition from one life stage to the next. Traditionally, state space models describe demographic variability (e.g., using a binomial probability distribution to represent the number of individuals surviving based on a given survival rate; e.g., Dupont 1983; Besbeas et al. 2002) however environmental variability generally overwhelms demographic variability (Buckland et al. 2007) so we model the process variability (e.g., Rivot et al. 2004; Newman and Lindley 2006) using a lognormal (LN) probability distribution (Maunder and Deriso 2003). Our approach differs from modeling the log abundance and assuming additive normal process variability (e.g., Quinn and Deriso 1999, page 103) and the population dynamics function models the expected value rather than the median. The

difference in the expectation will simply be a scaling factor ($\exp\left[-0.5\sigma^2\right]$) unless the variance of the process variability changes with time.

(1) $$N_{t,s} \sim LN\left(f\left(N_{t,s-1}\right), \sigma_{s-1}^2\right) \qquad s > 1$$

(2) $$N_{t,1} \sim LN\left(f\left(N_{t-1,nstages}\right), \sigma_{nstages}^2\right)$$

Where *t* is time, *s* is stage, *nstages* is the number of stages in the model, and σ_s is the standard deviation of the variation not explained by the model (process variability) in the transition from stage *s* to the next stage.

The three parameter Deriso-Schnute stock-recruitment model (Deriso 1980; Schnute 1985) is used to model the transition from one stage to the next. The Deriso-Schnute model is a flexible stock-recruitment curve in which the third parameter (γ) can be set to represent the Beverton-Holt ($\gamma = -1$) and Ricker ($\gamma \to 0$) stock-recruitment models (Quinn and Deriso 1999, page 95).

(3) $$f\left(N\right) = aN\left(1 - b\gamma N\right)^{\frac{1}{\gamma}}$$

DRAFT

where the parameter *a* can be interpreted as the number of recruits per spawner at low spawner abundance or the survival fraction at low abundance levels. In cases for which only the relative abundance at each stage can be modeled (as in the delta smelt example), *a* also contains a scaling factor from one survey to the next. The parameter *b* determines how the number of recruits per spawner or the survival rate decreases with abundance. Constraints can be applied to the parameters to keep the relationship realistic: $a \geq 0$, $b \geq 0$. The additional constraint $a \leq 1$ can be applied when the relationship is used to describe survival and the consecutive stages are modeled in the same units.

Covariates are implemented to influence the abundance either before density dependence or after density dependence. Although, when no density dependence is present the two methods are identical.

(4) $$f(N) = ag(N,x)\left(1 - b\gamma g(N,x)\right)^{\frac{1}{\gamma}} h(x)$$

(5) $$g(N,x) = N \exp\left[\sum \lambda x\right]$$

(6) $$h(x) = \exp\left[\sum \beta x\right]$$

For survival it might be important to keep the impact of the environmental factors within the range 0 to 1 and the logistic transformation can be used, e.g.,

$$g(N,x) = N\frac{\exp\left[\sum \lambda x\right]}{1+\exp\left[\sum \lambda x\right]} \tag{7}$$

If the covariate values are all positive, the negative exponential can be used, e.g.,

$$g(N,x) = N\exp\left[-\sum \lambda x\right] \qquad \lambda \geq 0 \quad x \geq 0 \tag{8}$$

A combination of the above three options may be appropriate depending on the application.

The importance of the placement of the covariates (i.e., before or after density dependence) relates to both the timing of density dependence and the timing of the surveys, which provide information on abundance. Covariates could be applied to the other model parameters. For example, covariates that are thought to be related to the carrying capacity (e.g., habitat) could be used to model *b*.

The model is fit to indices of abundance ($I_{t,s}$). The abundance indices are assumed to be normally distributed, but other sampling distributions could be assumed if appropriate. Typically, if the index of abundance is a relative index and not an estimate of the absolute abundance, the model is fit to the index by scaling the model's estimate of abundance using a proportionality constant (*q*, often called the catchability coefficient) (Maunder and Starr 2003).

DRAFT

(9) $$I_{t,s} \sim N\left(qN_{t,s}, \nu_{t,s}^2\right)$$

However, the scaling factor is completely confounded with the *a* parameter of the Deriso-Schnute model and therefore the population is modeled in terms of relative abundance that is related to the scale of the abundance indices for each life stage and only makes sense in terms of total abundance if the abundance indices are also in terms of total abundance. Therefore, the proportionality constant (*q*) should be set to one. Other data could also be used in the analysis if appropriate (e.g., information on survival from mark-recapture studies; Besbeas et al. 2002; Maunder 2004).

Model parameters to estimate

The model parameters estimated include the initial abundance of the first stage $N_{1,1}$, the parameters of the stock-recruitment model for each stage $\mathbf{a}, \mathbf{b}, \boldsymbol{\gamma}$, the coefficients of the covariates $\boldsymbol{\lambda}, \boldsymbol{\beta}$, the standard deviation of the process variability for each stage $\boldsymbol{\sigma}$, and the standard deviation of the likelihood for each index of abundance $\boldsymbol{\nu}$. The state space model can be implemented by treating the process variability as random effect parameters (de Valpine 2002). The likelihood function that is optimized is calculated by integrating over these parameters (Skaug 2002; Maunder and Deriso 2003). Therefore, they are not treated as parameters to estimate. However, realizations of the random effects can be estimated by using empirical Bayes methods (Skaug and Fournier 2006) so that the unexplained process variation can be visualized.

Parameters = $\{N_{1,1}, \mathbf{a}, \mathbf{b}, \boldsymbol{\gamma}, \boldsymbol{\lambda}, \boldsymbol{\beta}, \boldsymbol{\sigma}, \mathbf{v}\}$

Model selection

Model selection (Hilborn and Mangel 1997) can be used to determine if the data supports density dependence for a particular stage or the factors that impact the population dynamics. In our analysis different models are represented by different values of the model parameters. The relationship between one stage and the next is density independent if $b = 0$. Therefore, a test for density dependence tests if $b = 0$. When $b = 0$, $\boldsymbol{\gamma}$ has no influence on the results and unless a hypothesis about $\boldsymbol{\gamma}$ is made (i.e., Beverton-Holt, $\gamma = -1$ or Ricker, $\gamma \to 0$), testing between density independence and density dependence requires the estimation of two additional parameters ($b, \boldsymbol{\gamma}$). A factor has no influence on the model when its coefficient ($\boldsymbol{\lambda}, \boldsymbol{\beta}$) is fixed at zero. Therefore, testing a factor requires estimating one parameter for each factor tested. There are a variety of methods available for model selection and hypothesis testing, each with their own set of issues (e.g., Burnham and Anderson 1998; Hobbs and Hilborn 2006). Given these issues, we rely on Akaike information criteria adjusted for sample size (AICc) and AICc weights to rank models and provide an idea of the strength of evidence in the data about an a priori set of alternative hypotheses (factors) but they are not used as strict hypothesis tests (Andersen et al. 2000; Hobbs and Hilborn 2006).

The AIC is useful for ranking alternative hypotheses when multiple covariates and density dependence assumptions are being considered. The AICc (Burnham and Anderson 2002), is given by

$$AIC_c = -2\ln L + 2K + \frac{2K(K+1)}{n-K-1} \tag{10}$$

where L is the likelihood function evaluated at its maximum, K is the number of parameters, and n is the number of observations. A better model fit is one with a smaller AICc score.

Burnham and Anderson (1998 page 128) recommend the following model selection guidelines: For a comparison between two model fits, first the AICc score is calculated for each model fit then the difference in the AICc score from the minimum AICc score is denoted as Δ.

For any model with $\Delta \le 2$ *there is no credible evidence that the model should be ruled out . . .. For a model with* $2 < \Delta \le 4$ *there is weak evidence that the model is not the K-L [Kullback-Leibler] best model. If a model has* $4 < \Delta \le 7$ *there is definite evidence that the model is not the K-L best model, and if* $7 < \Delta \le 10$*, there is strong evidence that the model is not the K-L best model. Finally, if* $\Delta > 10$*, there is very strong evidence that the model is not the K-L best model.*

Burnham and Anderson (2002 page 131) note that when doing model selection by adding covariates, a Δ of two (higher for the AICc due to the additional term) is what is expected when a covariate with one coefficient is added to the model and does not explain any variation. Therefore, the rules of thumb presented above are somewhat inconsistent and

in fact a Δ of two, in the case of adding nested parameters to the model with the lowest AIC, suggests that there is very strong evidence that the model is not the K-L best model. This should be taken into consideration when conducting model selection and asymmetrical rules of thumb may be appropriate, with the rules presented above applied to models with fewer parameters than the model with the lowest AICc and values somewhere between 0 and 2 (or the appropriate value based on the extra term in the AICc) considered for nested models with more parameters than the model with the lowest AICc.

AIC weights are often used to provide a measure of the relative support for a model and to conduct model averaging (Hobbs and Hilborn 2006). AIC weights are essentially the rescaled likelihood penalized by the number of parameters, which is considered the likelihood for the model (Anderson et al. 2000).

$$w_i = \frac{\exp[-0.5\Delta_i]}{\sum_j \exp[-0.5\Delta_j]} \tag{11}$$

The correct modeling of observation and process variability (error) is important for hypothesis testing. If process variability is not modeled, likelihood ratio and AIC based tests are biased towards incorrectly accepting covariates (Maunder and Watters 2003). Other tests, such as randomization tests, should be used if it is not possible to model the additional process variability (e.g., Deriso et al. 2008). Incorrect sampling distribution assumptions (e.g., assumed values for the variance) can influence the covariate selection

DRAFT

process and the weighting given to each data set can change which covariates are chosen (Deriso et al 2007). If data based estimates of the variance are not available, estimating the variances as model parameters or using concentrated likelihoods is appropriate (Deriso et al. 2007). Missing covariate data need to be dealt with appropriately (Gimenez et al. 2009; Maunder and Deriso 2010).

Parameter estimation of population dynamics models generally requires iterative methods, which take longer than calculations based on algebraic solutions, and therefore limit the number of models that can be tested (Maunder at al. 2009). This is problematic when testing hypotheses because, arguably, all possible combinations of the covariates and density dependent possibilities should be evaluated. All possible combinations should be used because a covariate by itself may not significantly explain process variation, but in combination they do (Deriso et al. 2008) and some covariates may only be significant if density dependence is taken into consideration. However, modeling of process variability, as we suggest, may minimize this possibility. In many cases, time and computational resource limitations may prevent testing all possible combinations and therefore we suggest the following strategy. First, test all possible combinations of the density dependence parameters without the use of covariates. Choose the model with the lowest AICc. If more than one model has high relative support, more than one density dependent scenario may need to be carried on to the next stage that tests the different factors. Next run all possible one and two covariate models, select the one or two covariates that produce the lowest AICc and run an all possible one and two covariate models with the remaining covariates, and repeat the process until the support for the new

DRAFT

models is small compared to the lowest AICc model; we stop when the lowest AICc model in the current iteration is at least 4 AICc units higher than the model with the lowest overall AICc. The approach is based on a compromise between eliminating models for which *there is definite, strong, or very strong evidence that the model is not the K-L best model* ($4 \leq \Delta$)) and the fact that there is a maximum Δ when adding covariates to the lowest AICc model. We have chosen to carry out the selection process by using the sum of the AICc weights over all models that include the corresponding factor. This selection process chooses factors that have high support in general, work in combination with other factors, and are therefore less likely to preclude additional factors in subsequent steps. This approach embraces the multiple hypothesis weight of evidence framework and is somewhat consistent with model averaging. We also remove models for which any of the estimated covariate coefficients are the incorrect sign as assumed a priori. Modification of this procedure may be needed depending on the available computational resources, the number of covariates and model stages, and the relative difference in the weight of evidence among models. It might also be useful to reevaluate density dependence once covariates have been selected and to look at the confidence intervals of the included covariates to see if any include zero indicating that the covariate could be excluded from the model.

Burnham and Anderson (2002) note that in general, there are situations where choosing to make inferences using a model other than the lowest AICc model can be justified (page 330) based on professional judgment, but only after the results of formal selection methods have been presented (page 334). For example, model parameterizations that do

DRAFT

not make sense biologically. Burnham and Anderson (2002) give an example (page 197) where a quadratic model is rejected because it could not produce the monotonic increasing dose response that was desired. Sometimes AICc will select a model that fits to quirks or noise in the data and not provide a useful model. The selected best model is a type of estimate, and so like a parameter estimate it can sometimes be a poor estimate (Ken Burnham, Colorado State University, personal communication).

Parameter estimates from stock recruitment models in integrated assessments are often biased towards extremely strong density dependence (recruitment is independent of stock size) (Conn et al. 2010) and this is unrealistic for stocks that have obtained very low population sizes. We therefore identify values of the Deriso-Shnute stock-recruitment relationship (for the Beverton-Holt and Ricker special cases) *b* parameter that are realistic (see Appendix). We assume that recruitment (or the individuals surviving) can't be greater than 80% of that expected from the average population size when the population is at 5% of the average population size seen in the surveys during the period studied.

Impact analysis

Impact analysis is carried out by repeating the analysis with the coefficients of the covariates fixed at different values. This can be done either by running the model with all other parameters fixed at their estimates or if estimates of uncertainty are desired, the standard model and the model with the modified coefficients are run simultaneously while sharing parameter values (Deriso et al. 2008). The results are then compared for the quantities of interest, which may be a derived quantity other than the covariate's

DRAFT

coefficients. For example, if a covariate is related to some form of mortality, the coefficient is set to zero to determine what the abundance would have been in the absence of that mortality (e.g., Wang et al. 2009).

Implementation in AD Model Builder

Dynamic models like the multistage life cycle model described here can be computationally burdensome if they are carried out in a state-space modeling framework (i.e., integrating over the state-space or equivalently the process variability) and efficient parameter estimation is needed if multiple hypotheses are being tested. Implementation is facilitated by the use of Markov chain Monte Carlo and related methods (Newman et al. 2009) and their use has exploded in recent years (Lunn et al. 2009). However, this generally, but not necessarily, requires that the model be implemented in the Bayesian framework (Punt and Hilborn 1997). An alternative approach is to use the La Place approximation to implement the integration (Skaug 2002). AD Model Builder (http://admb-project.org/) has an efficient implementation of the La Place approximation using automatic differentiation (Skaug and Fournier 2006). The realizations of the random effects are estimated by using empirical Bayes methods adjusted for the uncertainty in the fixed effects (Skaug and Fournier 2006). ADMB was originally designed as a function minimizer and therefore likelihoods are implemented in terms of negative log-likelihoods and probability distributions are implemented in terms of negative log-probabilities.

DRAFT

The population is modeled using random effects to implement the state space model (de Valpine 2002)

(12) $$N_{t,s} = f\left(N_{t,s-1}\right)\exp\left[\sigma_{s-1}\varepsilon_{t,s-1} - 0.5\sigma_{s-1}^2\right]$$

(13) $$N_{t,1} = f\left(N_{t-1,nstages}\right)\exp\left[\sigma_{nstages}\varepsilon_{t-1,nstages} - 0.5\sigma_{nstages}^2\right]$$

(14) $$\varepsilon_{t,s} \sim N(0,1)$$

A penalty is added to the objective function to implement the random effects,

(15) $$\sum_{t,s}\varepsilon_{t,s}^2 \ .$$

The negative log-likelihood function for the abundance indices ignoring constants is

(16) $$-\ln[L] = \sum_{t,s}\ln\left[\nu_{t,s}\right] + \frac{\left(I_{t,s} - qN_{t,s}\right)^2}{2\nu_{t,s}^2}$$

Application to Delta smelt

DRAFT

The multi-stage lifecycle model is applied to delta smelt to illustrate the application of the model, covariate selection procedure, and impact analysis. Delta smelt effectively live for one year and one spawning season. Some adults do survive to spawn a second year, but the proportion is low (Bennett 2005) and we ignore them in this illustration of the modeling approach. The delta smelt life cycle is broken into three stages (Figure 1). The model stages are associated with the timing of the three main surveys, (1) 20mm trawl (20mm), (2) summer tow net (STN), and (3) fall mid-water tow (FMWT), and roughly correspond to the life stages larvae, juveniles, and adults, respectively. The reason for associating the model stages with the surveys is because the surveys are the only data used in the model and therefore information is only available on processes operating between the surveys. The population is modeled from 1972 to 2006 because these are the years for which data for most of the factors are available. The summer tow net abundance index is available for the whole time period. The fall mid-water tow abundance indices are available for the whole time period except for 1974 and 1979. The 20mm trawl is only available starting in 1995. Other survey data are available (e.g., the Spring Kodiak trawl survey), but they are not used in this analysis.

The FMW and STN survey indices of abundance are the estimates taken from Manly (2010b) tables 2.1 and 2.2. The standard errors were calculated by bootstrap procedures (Manly, 2010a). The 20mm survey indices were taken from Nations (2008). The index values and standard errors are given in Table 1. The results of the bootstrap analysis suggest that the abundance indices are normally distributed (Manly 2010a).

DRAFT

Two types of factors are used in the model (Table 2). The first are standard factors relating to environmental conditions. The second are mortality rates based on estimates of entrainment at the water pumps. The mortality rates are converted to the appropriate scale to use in the model. Let u represent the mortality fraction such that the survival fraction is $1-u=\exp[\beta x]$ and x will be used as a covariate in the model. Setting $\beta=1$ gives $x=\ln[1-u]$.

Several factors were chosen for inclusion in the model (Table 3). These factors are used for illustrative purposes only and they may differ in a more rigorous investigation of the factors influencing delta smelt. The environmental factors are taken as those proposed by Manly (2010b). The entrainment mortality rates are calculated based on Kimmerer (2008); the rates were obtained by fitting a piece-wise linear regression model of winter Old Middle River (OMR) flow to his adult entrainment estimates and his larval/juvenile entrainment estimates were fitted to a multiple linear regression model with spring OMR flow and spring low salinity zone (as measured by X2). The values from Kimmerer (2008) were used for years in which they are available and the linear regression predictions were used for the remaining years. Manly (2010b) provided several variables as candidates to account for the changes in delta smelt abundance from fall to summer and summer to fall. The fall to summer covariates could influence the adult and larvae stages, while the summer to fall covariates could influence the juvenile stage. The factors proposed by Manly (2010b) are those that are considered to act directly on delta smelt. There are many other proposed factors that act indirectly through these factors. We also include secchi disc depth as a covariate for water turbidity/clarity since it was identified

as a factor by Thomson et al. (2010). Exports were also identified as an important factor and were assumed to be related to entrainment. However, we chose to use direct measures of entrainment. Interactions among the factors were not considered in the application. However, some of the covariates implicitly include interactions in their definition and construction.

Some manipulation of the data was carried out before use in the model (the untransformed covariates values used in the model are given in Table 3). Delta smelt average length was missing for 1972-1974, 1976, and 1979, and was set to the mean based on Maunder and Deriso (2010). The factors were normalized (mean subtracted and divided by standard deviation) to improve model performance, except for the covariates relating to predator abundance, which were just divided by the mean, and the entrainment mortality rates, which were not transformed. These exceptions are factors that are hypothesized to have a have a unidirectional impact and setting their coefficients to zero is needed for impact analysis. Setting the coefficient for the entrainment mortality rate covariates to one can be used to determine the impact if the entrainment estimates are assumed to be correct.

The standard approach outlined above is applied to the delta-smelt application. The Ricker model was approximated by setting $\gamma = -\exp[-10]$. We also constrained $\gamma < 0$ to avoid computational errors. It is difficult to scale the survey data to absolute abundance, so they are all treated as relative abundance and are not on the same scale. The scaling parameter a is not limited to $a \leq 1$ and the exponential model is used for all covariates.

To illustrate the impact analysis, we implement three scenarios. In all scenarios a parallel population dynamics model is run simultaneously with the main model so that estimates of uncertainty can be obtained. The parameters are shared between the two models except the second model is modified as described in the scenario descriptions. In the first scenario, the covariates are all set to zero. This means that environmental conditions are average, predation is zero, and entrainment is zero. We implement the second scenario if one or both of the entrainment covariates are selected for inclusion in the model. In this case, only the entrainment coefficients are set to zero in the second population dynamics model. In the third scenario we take the final set of covariates and add the entrainment covariates (or substitute them if they we already included in the model) with their coefficients set to one and rerun the model. In this case, only the entrainment coefficients are set to zero in the second population dynamics model.

Results

AICc values and weights were calculated for all possible combinations of density dependence that included no density dependence (No), a Beverton-Holt Model (BH), a Ricker model (R), and estimation of both b and γ (DD) (Table 4). Density dependence was clearly preferred for survival from juveniles to adults (J), but it is not clear if the density dependence is Beverton-Holt, Ricker, or somewhere in between. The Beverton-Holt and Ricker models for juvenile survival appear to be influenced by three points (years 1976-1978) of high juvenile abundance with corresponding average adult abundance (Figures 2 and 3). The evidence for and against density dependence is about the same for the stock-recruitment relationship from adults to larvae (A). With slightly

more evidence for no density dependence if survival from juveniles to adults is Beverton-Holt and slightly more evidence for Beverton-Holt density dependence if the survival from juveniles to adults is Ricker. The evidence for no density dependence in survival from larvae to juveniles (L) is moderately (3 to 4 times) higher than for density dependence. Therefore, we proceed with four density dependence scenarios: (1) Beverton-Holt density dependence in survival from juveniles to adults; and (2) Beverton-Holt density dependence in survival from juveniles to adults and a Beverton-Holt stock-recruitment relationship from adults to larvae; (3) Ricker density dependence in survival from juveniles to adults; and (4) Ricker density dependence in survival from juveniles to adults and a Beverton-Holt stock-recruitment relationship from adults to larvae.

AICc weights were calculated separately for each step in the two factor analysis. The two factor analysis included all one factor and two factor combinations while including the factors that had already been selected in previous steps. To determine which two factors were to be retained for the next step in the analysis, the AICc weights were summed over all models that contained that factor and the two factors with the highest values were retained. We also remove models for which any of the estimated covariate coefficients are the incorrect sign and models for which the *b* parameter was too high (see Appendix) as assumed a priori.

The number and the type of factors supported by the data depended on the assumptions made about density dependence. The models with density dependence for both survival from juveniles to adults and a stock recruitment relationship for adults to larvae included

more covariates in the lowest AICc models (8 and 9 covariates for Beverton-Holt and Ricker density dependence in survival from juveniles to adults, respectively) than the models that included only density dependence for survival from juveniles to adults (5 covariates each) (Table 6). Several temperature, prey and predator covariates (TpAJ, EPAJ, EPJA, TpJul, Pred1) were selected in the first few steps and were included in all models. The April-June abundance of predators (Pred2) was selected in the first few steps in one model, but not selected at all in the others (Tables 5 and 6). The covariates selected based on simple one-covariate-at-a-time AICc scores (as far as possible given the two-covariate-at-a-time stepwise procedure) were generally the same as those selected by the two–covariate-at-a-time selection procedure (Tables 5 and 6). One obvious exception was the lowest AICc score for Pred2 as the first covariate in two of the models (Table 6) for which the two-covariate-at-a-time selection procedure never selected it (Table 5). While in another model it was selected by the two-covariate-at-a-time selection procedure but not by the AICc criteria.

Overall, the model with Ricker density dependence in survival from juveniles to adults and a Beverton-Holt stock-recruitment relationship from adults to larvae had better AICc scores than the other models (Table 6). This differs from the similarity in scores obtained when no covariates were included in the models (Table 4). For all density dependent assumptions, there were alternatives with more (or less) covariates than the lowest AICc model (within the models for that density dependence assumption), for which there was not *definite, strong, or very strong evidence that the model is not the K-L best model* ($4 \leq \Delta$) suggesting that these factors should also be considered as possible factors that

influence the population dynamics of delta smelt (Table 6). Although, the asymmetrical nature of the AICc scores for nested models should be kept in mind.

The magnitude and the sign of the covariate coefficients are generally consistent across models (Table 7). The covariates were standardized so that the size of the coefficients are generally comparable across covariates. The coefficients are similar magnitudes for most covariates except those for water clarity (Secchi) and, particularly, adult entrainment (Aent), which had much larger effects. These both occurred before the stock-recruitment relationship from adults to larvae, which had a very strong density dependence effect. Pred2 had a small effect. The confidence intervals on the coefficients support inclusion of the covariates in the lowest AICc models except for Pred2 (Table 7). The effects for Secchi and Aent appear to be unrealistically large and their coefficients have a -0.99 correlation. This may be a consequence of the unrealistically strong density dependence estimated in the stock-recruitment relationship from adults to larvae for those models.

The five lowest AIC_c models in step 6 of the two factors at a time procedure had a *b* parameter of the Beverton-Holt stock recruitment relationship from adult to larvae that was substantially greater than the critical value used to define realistic values of the parameter. The sixth model had an AIC of 812.53, which is worse than the lowest AICc model of step 5. The lowest AICc model with Beverton-Holt survival from juveniles to adults and Beverton-Holt stock recruitment relationship from adult to larvae also had an unrealistic *b* parameter and the next lowest AICc model had an AIC of 812.33. Therefore, the lowest AICc model after accounting for realistic parameter values is the lowest AICc

model from step 5 with Ricker survival from juveniles to adults and Beverton-Holt stock recruitment relationship from adult to larvae with one additional covariate (Table 6d, AICc = 808.47). The confidence intervals for the pred2 covariate for this model contained zero and removing the Pred2 covariate essentially had no effect on the likelihood. Therefore, we chose this model without the Pred2 covariate as the lowest AICc model (AICc = 806.63). Several models had an AICc score within 2 units of this model (after removing the Pred2 covariate), which according to the Burnham and Anderson guidelines "*there is no credible evidence that the model should be ruled out*". Therefore, to illustrate the sensitivity of results to the model choice we also provide results for the model with the fewest parameters that was within 2 AICc units of the lowest AICc model. This alternative model is that selected with two additional parameters in step 3 of the selection procedure (Table 6d, AICc=810.20). Removing the Pred2 covariate improved the AICc score (808.63) so we also eliminated the Pred2 covariate from this model.

The models fit the survey data well (Figures 4 and 5), in fact better than expected from the survey standard errors, indicating that most of the variation in abundance was modeled by the covariates or unexplained process variability. The unexplained process variability differed among the stages (Figures 6 and 7; Table 8). Essentially all the variability in survival between larvae and juveniles was explained by the covariates. The amount of variability in the survival from juveniles to adults explained was higher than in the stock-recruitment relationship, but they show similar patterns (Figures 6 and 7; Table 8).

DRAFT

The impact analysis of the selected covariates shows that the adult abundance under average conditions, with no predators, and entrainment mortality set to zero in Figure 8, differs moderately from that estimated in the original model (Figures 8 and 9). In particular, the recent decline is not as substantial under average conditions indicating that the covariates describe some of the decline, although there is still substantial unexplained variation and a large amount of uncertainty in the recent abundance estimates. Entrainment is estimated to have only a small impact on the adult abundance in either the lowest AICc model (Figure 10 which uses the estimated adult entrainment coefficient and the juvenile entrainment coefficient is zero) or the alternative model (Figure 11 in which both the juvenile and adult entrainment coefficients are set to one). The lowest AICc model with the two entrainment coefficients set at 1 did not converge and results are not shown for that analysis, although the results are expected to be similar.

Discussion

We developed a state-space multi-stage lifecycle model to evaluate population impacts in the presence of density dependence. Application to delta-smelt detected strong evidence for a few key factors and density dependence operating on the population. Both environmental factors (e.g., Deriso et al. 2008) and density dependence (e.g., Brook and Bradshaw 2006) have been detected in a multitude of studies either independently or in combination (e.g., Sæther 1997; Ciannelli et al. 2004). Brook and Bradshaw (2006) used long-term abundance data for 1198 species to show that density dependence was a

pervasive feature of population dynamics that holds across a range of taxa. However, the data they used did not allow them to identify what life stages the density dependence operates on. Ciannelli et al. (2004) found density dependence in different stages of walleye Pollock. In our application we found evidence against density dependent survival from larvae to juveniles, strong evidence for density dependence in survival from juveniles to adults, and weak evidence for density dependence in the stock-recruitment relationship from adults to larvae, which includes egg and early larval survival. Other studies have suggested that density dependence is more predominant at earlier life stages (e.g., Fowler 1987; Gaillard et al. 1998), although the life history of these species differs substantially from delta smelt. The density dependence in survival from juveniles to adults found in our study was probably heavily influenced by three consecutive years of data. Unfortunately, this is a common occurrence in which autocorrelated environmental factors cause autocorrelation in abundance within a stage and this likely influences other studies as well. We only allowed factors to influence density independent survival, either before or after density dependence, however the factors could also influence the strength or form of the density dependence (Walters 1987). For example, Ciannelli et al. (2004) found that high wind speed induced negative density dependence in the survival of walleye Pollock eggs. Our analysis is one of the few, but expanding, applications investigating both density dependent and density independent factors in a rigorous statistical framework that integrates multiple data sets within a life cycle model. The framework amalgamates the density and the mechanistic paradigms of investigating population regulation outlined by Krebs (2002) while accommodating the fact that most available data is observational rather than experimental. More detailed mechanistic

processes could be included in the model if the appropriate observational or experimental data are available.

One factor is often erroneously singled out as the only major cause of population decline (e.g., over fishing; Sibert et al. 2006). However, there is a substantial accumulation of evidence that multiple factors interact to cause population declines. Our analysis found support for a variety of factors that influence delta smelt population dynamics. We also showed that together these factors explain the decline in the delta smelt population. Deriso et al. (2008) also found support that multiple factors influenced the decline and suppression of the Prince William Sound herring population, including one or more unidentified factors related to a particular year.

Three of the first four factors included in the delta smelt application acted on the survival between larvae and juveniles. This is also the period where no density dependence in survival occurred. The final model estimates that the factors explain all the variability in survival from larvae to Juveniles. The 20mm trawl survey, which provides information on juvenile abundance, only starts in 1995 so there is less data to explain and this may be partly why the unexplained process variability variance goes to zero. The process variability for the other stages may partly absorb the variability in survival from larvae to juveniles.

Deriso et al. (2008) showed that multiple factors influence populations and that analysis of factors in isolation can be misleading. We also found that multiple factors influence

the dynamics of delta smelt and that evaluating factors in isolation can produce different results than evaluating them in combination. The type of density dependence assumed also impacted what factors were selected. Specifically, one predator covariate (Pred2) was the first selected covariate based simply on AICc for two of the density dependent assumptions, but was not selected by the two factor stepwise procedure or in subsequent steps based simply on AICc. However, this covariate was selected in the first step of the two factor stepwise procedure for another density dependent assumption, which happened to be the final model with the lowest AICc. In the final model the confidence intervals on the coefficient indicate that this factor should not be included in the model. Exploratory analysis showed that this covariate had about a 0.6 correlation with a temperature (TpAJ) and a prey covariate (EPAJ) that were consistently selected in the first or seconds steps, which operated on the same stage (larvae), when these covariates were combined together. We did find, to some extent, which other covariates were included in the model and the order in which they were included changed depending on the density dependence assumptions. However, apart from the one predator covariate, the four density dependence assumptions tended to select the same factors in the first few steps of the model selection procedure, although the order of selection differed.

The estimates of the *b* parameter of the Beverton-Holt stock-recruitment relationship between adults and larvae produced density dependence that was unrealistically strong in a few models. Consequently, this caused estimates of some coefficients that were also unrealistic (e.g., the coefficient for adult entrainment was nearly two orders of magnitude higher than expected). Even when a model was selected for which the *b* parameter was

DRAFT

considered reasonable, the coefficient for adult entrainment was still an order of magnitude greater than expected. This illustrates that naively following AICc model selection without use of professional judgment is not recommended. We could have retained all models by bounding the *b* parameter in the parameter estimation process, but we considered inference based on models with a parameter at the bound inappropriate. An alternative approach would be to use an informative prior for *b* (Punt and Hilborn 1997) to pull it away from unrealistic values, but we did not have any prior information that was considered appropriate.

Andersen et al. (2000) warn against data dredging as a method to test factors that influence population dynamics. In their definition of data dredging they include the testing of all possible models, unless, perhaps, if model averaging is used. This provides somewhat of a dilemma when using a multi-stage life cycle model because there are often multiple candidate factors for each life stage and they may only be detectable if included in the model together. For this reason, we use an approximation to all possible models and rely on AICc and AICc weights to rank models and provide an idea of the strength of evidence in the data about the models and do not apply strict hypothesis tests. Some form of model averaging using AICc weights might be applicable to the impact analysis, although the estimates of uncertainty would have to include both model and parameter uncertainty. The estimates of uncertainty in our impact analysis under estimate uncertainty because they do not include model selection uncertainty and use of model averaging might provide better estimates of uncertainty (Burnham and Anderson 2002). In addition, we use symmetric confidence intervals and approaches that provide

asymmetric confidence intervals may be more appropriate (e.g., based on profile likelihood or Bayesian posterior distribution).

Our results suggest that of all the factors that we tested, food abundance, temperature, predator abundance and density dependence are the most important factors controlling the population dynamics of delta smelt. Survival is positively related to food abundance and negatively related to temperature and predator abundance. There was also some support for a negative relationship with water clarity and adult entrainment, and a positive relationship with the number of days where the water temperature was appropriate for spawning. The first variables to be included in the model were those related to survival from larvae to juveniles, followed by survival from juveniles to adults, and finally the stock-recruitment relationship. Mac Nally et al. (2010) also found that high summer water temperatures had an inverse relationship with delta smelt abundance. Thomson et al. (2010) found exports and water clarity as important factors. We did not include exports, but included explicit estimates of entrainment. We found some support for adult entrainment, but it was not one of the main factors and the coefficient was unrealistically high and highly correlated with the coefficient for water clarity. Mac Nally et al. (2010) and Thomson et al. (2010) only used the FMWT data and did not look at the different life stages, which probably explains why the factors supported by their analyses differ from what we found.

We found strong evidence for density dependence in survival from juveniles to adults, some evidence for density dependence for the stock-recruitment relationship from adults

to larvae and evidence against density dependence in survival from larvae to juveniles. Previous studies only found weak evidence for a stock-recruitment relationship and suggested that density independent factors regulate the delta smelt population (e.g., Moyle et al. 1992). Bennett (2005) found that the strongest evidence for density dependence was between juveniles and pre-adults. Mac Nally et al. (2010) found strong support for density dependence, but Thomson et al. (2010) did not.

Several pelagic species in the San Francisco Estuary have also experienced declines, but the factors causing the declines are still uncertain (Bennett 2005; Sommer et al. 2007). Thomson et al. (2010) used Bayesian change point analysis to determine when the declines occurred and included covariates to investigate what caused the declines. They were unable to fully explain the decline and unexplained declines were still apparent in the early 2000s. The impact analysis we applied to delta smelt suggests that the factors included in the model explain the low levels of delta smelt in the mid 2000s. Although, there is still substantial annual variation in the delta smelt abundance and uncertainty in the estimates of abundance for these years.

The theory for state-space stage-structured life cycle models is well developed (Newman 1998; de Valpine, P. 2002; Buckland et al. 2004; Maunder 2004; Buckland et al. 2007), they have been promoted (Thomson et al. 2010; Mac Nally et al. 2010), they facilitate the use of multiple data sets (Maunder 2003), provide more detailed information about how factors impact a population, and we have shown that they can be implemented. Therefore,

we recommend that they are an essential tool for evaluating factors impacting species of concern such as delta smelt.

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DRAFT

Appendix: Calculating realistic values for the *b* parameter of the Beverton-Holt and Ricker versions of the Deriso-Schnute stock-recruitment model.

The third parameter (γ) of the Deriso-Schnute stock-recruitment model (Deriso 1980; Schnute 1985)

$$f(N) = aN(1 - b\gamma N)^{\frac{1}{\gamma}}$$

can be set to represent the Beverton-Holt ($\gamma = -1$) and Ricker ($\gamma \to 0$) models (Quinn and Deriso 1999, page 95), which correspond to

$$f(N) = \frac{aN}{1 + bN} \text{ and } f(N) = aN \exp[-bN]$$

The recruitment at a given reference abundance level (e.g., the carrying capacity N_0) can be calculated as

$$R_0 = \frac{aN_0}{1 + bN_0} \text{ and } R_0 = aN_0 \exp[-bN_0]$$

The recruitment when the abundance is at a certain fraction (p) of this reference level can be calculated as

$$R_p = \frac{apN_0}{1+bpN_0} \text{ and } R_p = aN_0 \exp\left[-bpN_0\right]$$

A standard reference in fisheries is the recruitment as a fraction of the recruitment in the absence of fishing (the carrying capacity) that is achieved when the abundance is 20% of the abundance in the absence of fishing (steepness).

$$h = \frac{R_{0.2}}{R_0} = \frac{1/N_0 + b}{5/N_0 + b} \text{ and } h = \frac{R_{0.2}}{R_0} = 0.2\exp\left[0.8bN_0\right]$$

To set *b* for a given steepness

$$b = \frac{5h-1}{N_0 - hN_0} \text{ and } b = \frac{\ln\left[5h\right]}{0.8N_0}$$

The 20% reference level was probably chosen because the objective of fisheries management has traditionally been to maximize yield and it is generally considered that when a population falls below 20% of its unexploited level the stock cannot sustain that level of yield. In the delta smelt application the concern is about low levels of population abundance and we do not estimate the unexploited population size. Therefore, a more appropriate reference level might be 5% of the average level observed in the surveys.

DRAFT

$$h_{0.05} = \frac{R_{0.05}}{R_{ave}} = \frac{1/N_{ave} + b}{20/N_{ave} + b} \text{ and } h_{0.05} = \frac{R_{0.05}}{R_{ave}} = 0.05\exp\left[0.95bN_{ave}\right]$$

$$b = \frac{20h_{0.05} - 1}{N_{ave} - h_{0.05}N_{ave}} \text{ and } b = \frac{\ln\left[20h_{0.05}\right]}{0.95N_{0.05}}$$

This specification is also more appropriate when considering both the Beverton-Holt and Ricker models because the Ricker model reduces at high abundance levels and the recruitment at an abundance level that is 20% of the carrying capacity could be higher than the recruitment at carrying capacity. We restrict the models to those that have *b* estimates such that the expected recruitment when the population is at 5% of its average level (over the survey period) is equal to or less than 80% of the recruitment expected when the population is at its average level (Table A1). This is equivalent to a Beverton-Holt $h_{0.2}$ = 0.95 based on the abundance reference level being the average abundance from the surveys, which is probably conservative is the sense of not rejecting high values of *b*.

DRAFT

Table A1. Maximum values of the parameter *b* for inclusion of models in the model selection process.

	Maximum *b*		
	Average abundance	Beverton-Holt	Ricker
20mm (larvae)	7.99	9.3867	0.3653
STN (juveniles)	6140	0.0122	0.0005
FMWT (adults)	459	0.1634	0.0064

DRAFT

Table 1. Indices of abundance and standard errors used in the delta smelt application.

	20mm		STN		FMW	
Year	value	SE	value	SE	value	SE
1972			20005	5577	1265	155
1973			11185	1722	1145	108.7
1974			12147	2175		
1975			8786	989	697	77.8
1976			24000	1802	328	67.7
1977			25965	2681	480	69.7
1978			31758	6867	572	41.2
1979			5484	853		
1980			7068	646	1654	235.6
1981			6300	1043	374	49.9
1982			7242	820	333	108.5
1983			1390	279	132	43.6
1984			779	147	182	35.2
1985			387	67	110	21.6
1986			3057	406	212	42.7
1987			2743	227	280	71
1988			764	129	174	40.7
1989			647	52	366	63.7
1990			747	125	364	83.3
1991			2486	334	689	108.8

DRAFT

1992			471	68	156	27.8
1993			5763	996	1078	226.6
1994			4156	380	102	45.4
1995	2.933692	0.563774	2490	307	899	132.6
1996	22.25453	2.437344	6162	701	127	31
1997	9.437214	1.371236	2362	353	303	55
1998	2.704639	0.526823	2209	694	420	67
1999	12.00716	1.428904	7478	1142	864	146.2
2000	14.02919	2.160034	4178	519	756	139.9
2001	10.10347	2.983169	2897	332	603	156.2
2002	4.63569	1.04671	1115	163	139	25.2
2003	6.043828	1.479269	1329	174	210	64.9
2004	3.380115	0.967356	649	113	74	19
2005	3.981609	0.693923	393	97	27	6.6
2006	4.372327	0.779492	352	117	41	11.9

DRAFT

Table 2. The variables used as candidates to account for the changes in delta smelt abundance from fall to summer. A = occurs between adult and larval stages, L = occurs between larval and juvenile stages, J = occurs between juvenile and adult stages. Norm = subtract mean and divide by standard deviation, Mean = divide by mean, Raw = not scaled. The covariate is attributed to after density dependence unless it is known to occur before density dependence. This is because density dependence generally reduces the influence of the covariate. *= the effect of entrainment on survival is negative, but the covariate is formulated so setting the coefficient to 1 assumed entrainment is known without error, so the coefficient should be positive.

Run	Name	Covar	Stage	B(efore)/ A(fter)	Sign	Description	Data scaling	Justification
1	SpDys	1	A	B	+	Days where temperature is in the range 11-20C	Norm	This measures the number of days of spawning—the longer the spawning season, presumably the better chance of survival.
2	TpAJ	2	L	B	- or +	Average water temperature	Norm	Temperature affects growth rate and survival of

DRAFT

						Apr-Jun in delta smelt habitat		early life stages.
3	TpAJ	2	A	A	- or +			
4	TpJul	3	L	A	-	Average water temperature July in delta smelt habitat	Norm	Higher water temperatures can be lethal. Could also include August temperature.
5	EPAJ	4	L	B	+	Minimum Eurytemera and psydodyoptimus density April-Jun	Norm	Measures height of food “gap” in spring, as Eury falls from spring maximum and Pseu rises from ~0.
6	EPAJ	4	A	A	+			
7	EPJul	5	L	A	+	Average eurytemera and psydodyoptimus density July	Norm	Measures food availability in summer until STN survey, identified as problem by Bennett based on smelt condition.
8	Pred1	6	J	A	-	Sep-Dec abundance other predators	Mean	Predation is a source of direct mortality, measured as the product of relative density from beach seine data with the square of average sechi depth

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9	Pred1	6	A	B	-			
10	Pred1	6	A	A	-			
11	StBass	7	J	A	-	Sep-Dec abundance striped bass	Mean	A major predator, whose abundance is measured as actual number of adults.
12	StBass	7	A	B	-			
13	StBass	7	A	A	-			
14	DSLth	8	L	A	+	Delta smelt average length	Norm	See Bennett 2005 for length vs fecundity relationship, ` linear for 1-year-olds.
15	DSLth	8	J	A	+			
16	DSLth	8	A	A	+			
17	TpJS	9	J	A	-	Maximum 2-week average temperature Jul-Sep	Norm	Measure of whether lethal temperature is reached in hot months.
18	EPJA	10	J	A	+	Average eurytemera and psydodyoptimus density July-August	Norm	Measures food availability in summer between STN and FMWT surveys, identified as problem by Bennett based on smelt condition.

DRAFT

19	Secchi	11	A	B	-	Jan-Feb Weighted Secchi depth	Norm	Protection from predators
20	Secchi	11	A	A	-			
21	Jent	12	L	A	+ *	Juvenile entrainment	Raw	Entrained in by water pumps
22	Aent	13	A	B	+ *	Adult entrainment	Raw	Entrained in by water pumps
23	Pred2	14	L	B	-	Apr-Jun abundance other predators	Mean	Predation is a source of direct mortality, measured as the product of relative density from beach seine data with the square of average sechi depth
24	Pred2	14	A	A	-			

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Table 3. Untransformed covariate values. See Table 2 for definitions.

Year	SpDys	TpAJ	TpJul	EPAJ	EPJul	Preds1	StBass	DSLth	TpJS	EPJA	Secci	JEnt	AEnt	Preds2
1972	110	17.8	21.3	1243.77	4725	586	36498		21.8	4303	50	0.28136	0.02626	354
1973	104	18.6	21.3	754.234	1547	1041	27596		21.9	2082	26	0.1174	0.02626	793
1974	85	17.7	21.0	614.313	4202	850	32314		22.5	3799	44	0.0814	0.02626	446
1975	92	17.2	20.1	479.507	1520	735	41650	65.1	21.5	1545	44	0.06449	0.02626	280
1976	130	17.6	21.4	666.081	4125	19410	65427		21.9	2895	74	0.31567	0.0952	6118
1977	118	17.0	21.1	581.151	4194	22324	40655	65.6	21.5	3972	59	0.35274	0.02626	7095
1978	110	17.8	21.1	1457.95	2082	14726	28399	65.3	22.4	1391	13	0	0.02626	8423
1979	90	18.0	21.0	516.84	947	37712	25761		22.1	722	34	0.15945	0.02626	18631
1980	137	16.8	20.5	428.147	548	20360	20254	70.3	22.5	647	11	0.03108	0.02626	15120
1981	108	18.7	21.8	787.671	922	22248	20621	67.2	22.8	724	42	0.22261	0.02626	17070
1982	105	17.0	20.6	19.4272	636	30605	21560	66.2	21.4	670	31	0.00746	0.02626	23570
1983	102	17.3	20.7	271.066	530	28422	31059	62.2	22.2	544	28	0	0.02626	13957
1984	100	18.3	22.4	251.49	1560	29082	35459	69.5	22.8	1545	50	0.20125	0.02626	20444

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1985	105	18.5	22.0	134.587	548	62483	46997	69.1	22.5	543	76	0.26546	0.06687	30364
1986	122	18.1	21.2	648.516	626	30255	22752	68.1	21.5	534	60	0	0.02626	22921
1987	102	19.0	20.6	534.328	392	42089	41144	64.8	21.3	519	65	0.26078	0.02626	26771
1988	125	17.8	22.4	119.215	364	36828	30207	69.5	23.1	360	46	0.3583	0.16922	26668
1989	108	17.9	21.1	383.708	2558	38551	29441	67.8	21.7	3641	67	0.27032	0.13226	24067
1990	100	18.4	22.0	200.219	3616	57128	32336	63.9	22.7	3837	46	0.36378	0.22385	26671
1991	108	17.2	21.3	150.931	2542	63209	39881	62.5	21.8	3059	87	0.3181	0.02626	23754
1992	99	19.2	21.3	531.604	2733	89736	44102	57.9	22.5	2828	82	0.28653	0.04369	42138
1993	112	17.8	21.5	602.607	1184	48487	27938	54.7	22.2	1425	23	0.06506	0.05702	25301
1994	102	17.8	21.1	1112	965	61942	32635	62.9	21.4	856	75	0.21454	0.02626	53729
1995	142	17.0	21.5	573.935	2366	59091	34966	58.5	22.0	1431	27	0	0.18	38412
1996	115	18.3	21.4	380.924	533	72056	44927	55.1	22.6	731	38	0.01	0.025	52547
1997	104	19.3	21.2	369.14	590	64436	56551	57.6	21.8	800	22	0.14	0.025	33056
1998	117	16.3	21.3	271.886	1002	25623	32979	59.3	22.6	842	30	0	0.01	21106
1999	112	17.3	21.3	751.657	1308	29853	42465	59.1	22.0	1091	56	0.07	0.03	21961
2000	118	18.9	20.8	411.035	825	74907	60639	59.3	22.2	1007	64	0.13	0.05	50114
2001	73	19.5	21.3	423.892	758	81186	48811	63.5	22.0	484	57	0.19	0.05	50992

DRAFT

2002	108	18.6	21.8	105.105	641	75565	32632	62.2	22.2	462	36	0.26	0.16	59540
2003	106	18.0	22.2	136.244	787	86509	40081	58.6	23.2	1525	35	0.17	0.22	56424
2004	108	19.1	21.3	153.943	354	109036	82253	62.0	22.3	1012	37	0.21	0.19	50151
2005	123	18.1	22.0	57.0556	849	119419	58943	59.6	22.8	466	49	0.03	0.09	68310
2006	95	17.8	22.6	121.846	1321	116848	41977	58.0	23.7	884	39	0	0.03	53328

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Table 4. AIC weights for all possible density dependence models without covariates.

		J-No	J-BH	J-R	J-DD	Sum
L-No	A-No	0.000	0.079	0.062	0.027	0.168
	A-BH	0.000	0.075	0.067	0.026	0.168
	A-R	0.000	0.059	0.052	0.020	0.131
	A-DD	0.000	0.069	0.064	0.023	0.156
	Sum	0.000	0.281	0.245	0.096	0.622
L-BH	A-No	0.000	0.022	0.017	0.007	0.047
	A-BH	0.000	0.020	0.018	0.007	0.045
	A-R	0.000	0.016	0.014	0.005	0.035
	A-DD	0.000	0.018	0.017	0.006	0.040
	Sum	0.000	0.076	0.066	0.025	0.167
L-R	A-No	0.000	0.022	0.017	0.007	0.047
	A-BH	0.000	0.020	0.018	0.007	0.045
	A-R	0.000	0.016	0.014	0.005	0.035
	A-DD	0.000	0.018	0.017	0.006	0.040
	Sum	0.000	0.076	0.066	0.025	0.167
L-DD	A-No	0.000	0.006	0.005	0.002	0.013
	A-BH	0.000	0.005	0.005	0.002	0.012
	A-R	0.000	0.004	0.004	0.001	0.009
	A-DD	0.000	0.004	0.004	0.001	0.010
	Sum	0.000	0.020	0.017	0.006	0.043

DRAFT

Table 5a. AIC weights for each step in the two factor analysis for the model with Beverton-Holt survival from juvenile to adult. In the Stage column A=Adults, L=Larvae, and J=Juveniles. In the B/A column B=before density dependence and A=after density dependence. # = not included in AIC weights calculation because it was selected in previous step. * = not included in AIC weights calculation because a similar covariate was selected in previous step. The shaded cells indicate the two models chosen to retain in subsequent tests.

Run	Name	Stage	B/A	1st	2nd	3rd	4th	5th
1	SpDys	A	B	0.01	0.05	0.17	0.33	#
2	TpAJ	L	B	0.63	#	#	#	#
3	TpAJ	A	A	0.02	0.04	0.08	0.15	0.25
4	TpJul	L	A	0.31	0.68	#	#	#
5	EPAJ	L	B	0.56	#	#	#	#
6	EPAJ	A	A	0.01	0.00	0.00	0.00	0.00
7	EPJul	L	A	0.01	0.03	0.12	0.30	#
8	Pred1	J	A	0.13	0.43	#	#	#
9	Pred1	A	B	0.00	0.00	0.00	0.00	0.00
10	Pred1	A	A	0.00	0.00	0.00	0.00	0.00
11	StBass	J	A	0.01	0.06	0.08	0.17	0.25
12	StBass	A	B	0.00	0.00	0.00	0.00	0.00
13	StBass	A	A	0.00	0.00	0.00	0.00	0.00
14	DSLth	L	A	0.00	0.03	0.09	0.19	0.24
15	DSLth	J	A	0.00	0.03	0.00	0.00	0.00
16	DSLth	A	A	0.00	0.00	0.00	0.00	0.00
17	TpJS	J	A	0.00	0.02	0.06	0.00	0.00

DRAFT

18	EPJA	J	A	0.06	0.27	0.41	#	#
19	Secchi	A	B	0.01	0.08	0.23	#	#
20	Secchi	A	A	0.01	0.08	0.23	*	*
21	Jent	L	A	0.01	0.00	0.00	0.00	0.00
22	Aent	A	B	0.01	0.03	0.08	0.16	0.33
23	Pred2	L	B	0.18	0.06	0.10	0.18	0.25
24	Pred2	A	A	0.00	0.03	0.06	0.00	0.00

DRAFT

Table 5b. AIC weights for each step in the two factor analysis for the model with Beverton-Holt survival from juvenile to adult and a Beverton-Holt stock-recruitment relationship. In the Stage column A=Adults, L=Larvae, and J=Juveniles. In the B/A column B=before density dependence and A=after density dependence. # = not included in AIC weights calculation because it was selected in previous step. * = not included in AIC weights calculation because a similar covariate was selected in previous step. The shaded cells indicate the two models chosen to retain in subsequent tests.

Run	name	Stage	B/A	1st	2nd	3rd	4th	5th
1	SpDys	A	B	0.00	0.01	0.04	0.08	0.26
2	TpAJ	L	B	0.40	#	#	#	#
3	TpAJ	A	A	0.02	0.03	0.06	0.07	0.14
4	TpJul	L	A	0.05	0.71	#	#	#
5	EPAJ	L	B	0.89	#	#	#	#
6	EPAJ	A	A	0.04	0.03	0.11	0.13	0.17
7	EPJul	L	A	0.01	0.03	0.15	0.37	#
8	Pred1	J	A	0.09	0.32	#	#	#
9	Pred1	A	B	0.00	0.00	0.01	0.05	0.04
10	Pred1	A	A	0.01	0.04	0.10	0.22	0.23
11	StBass	J	A	0.01	0.06	0.07	0.09	0.15
12	StBass	A	B	0.00	0.00	0.00	0.00	0.00
13	StBass	A	A	0.00	0.00	0.00	0.00	0.00
14	DSLth	L	A	0.00	0.02	0.07	0.09	0.18
15	DSLth	J	A	0.00	0.02	0.00	0.00	0.00
16	DSLth	A	A	0.00	0.00	0.00	0.01	0.08
17	TpJS	J	A	0.00	0.02	0.05	0.00	0.00

DRAFT

18	EPJA	J	A	0.04	0.28	0.36	#	#
19	Secchi	A	B	0.01	0.06	0.24	#	#
20	Secchi	A	A	0.01	0.06	0.16	*	*
21	Jent	L	A	0.01	0.00	0.00	0.00	0.00
22	Aent	A	B	0.01	0.07	0.14	0.37	#
23	Pred2	L	B	0.34	0.10	0.11	0.13	0.19
24	Pred2	A	A	0.02	0.06	0.12	0.12	0.10

DRAFT

Table 5c. AIC weights for each step in the two factor analysis for the model with Ricker survival from juvenile to adult. In the Stage column A=Adults, L=Larvae, and J=Juveniles. In the B/A column B=before density dependence and A=after density dependence. # = not included in AIC weights calculation because it was selected in previous step. * = not included in AIC weights calculation because a similar covariate was selected in previous step. The shaded cells indicate the two models chosen to retain in subsequent tests.

Run	name	Stage	B/A	1st	2nd	3rd	4th	5th
1	SpDys	A	B	0.01	0.03	0.18	#	#
2	TpAJ	L	B	0.39	0.91	#	#	#
3	TpAJ	A	A	0.01	0.04	0.08	0.13	0.26
4	TpJul	L	A	0.17	0.50	#	#	#
5	EPAJ	L	B	0.44	#	#	#	#
6	EPAJ	A	A	0.00	0.00	0.00	0.00	0.00
7	EPJul	L	A	0.01	0.02	0.11	0.24	#
8	Pred1	J	A	0.02	0.16	0.38	#	#
9	Pred1	A	B	0.00	0.00	0.00	0.00	0.00
10	Pred1	A	A	0.00	0.00	0.00	0.00	0.00
11	StBass	J	A	0.01	0.03	0.09	0.00	0.00
12	StBass	A	B	0.00	0.00	0.00	0.00	0.00
13	StBass	A	A	0.00	0.00	0.00	0.00	0.00
14	DSLth	L	A	0.00	0.02	0.11	0.17	0.27
15	DSLth	J	A	0.00	0.04	0.17	0.15	0.26
16	DSLth	A	A	0.00	0.00	0.00	0.00	0.00
17	TpJS	J	A	0.00	0.00	0.00	0.00	0.00

DRAFT

18	EPJA	J	A	0.53	#	#	#	#
19	Secchi	A	B	0.01	0.04	0.18	0.26	#
20	Secchi	A	A	0.01	0.04	0.18	0.26	*
21	Jent	L	A	0.01	0.01	0.00	0.00	0.00
22	Aent	A	B	0.01	0.02	0.08	0.14	0.30
23	Pred2	L	B	0.37	0.09	0.11	0.18	0.26
24	Pred2	A	A	0.00	0.01	0.04	0.00	0.00

DRAFT

Table 5d. AIC weights for each step in the two factor analysis for the model with Ricker survival from juvenile to adult and a Beverton-Holt stock-recruitment relationship. In the Stage column A=Adults, L=Larvae, and J=Juveniles. In the B/A column B=before density dependence and A=after density dependence. # = not included in AIC weights calculation because it was selected in previous step. * = not included in AIC weights calculation because a similar covariate was selected in previous step. The shaded cells indicate the two models chosen to retain in subsequent tests.

Run	name	Stage	B/A	1st	2nd	3rd	4th	5th	6th	7th
1	SpDys	A	B	0.00	0.02	0.04	0.03	0.23	#	#
2	TpAJ	L	B	0.32	0.38	#	#	#	#	#
3	TpAJ	A	A	0.01	0.04	0.05	0.08	0.12	0.48	#
4	TpJul	L	A	0.04	0.09	0.61	#	#	#	#
5	EPAJ	L	B	0.78	#	#	#	#	#	#
6	EPAJ	A	A	0.03	0.02	0.07	0.19	0.18	0.00	0.00
7	EPJul	L	A	0.01	0.03	0.06	0.21	0.61	#	#
8	Pred1	J	A	0.01	0.13	0.30	#	#	#	#
9	Pred1	A	B	0.00	0.00	0.00	0.00	0.06	0.00	
10	Pred1	A	A	0.01	0.00	0.04	0.11	0.10	0.00	
11	StBass	J	A	0.00	0.04	0.08	0.00	0.00	0.00	0.00
12	StBass	A	B	0.00	0.00	0.00	0.00	0.00	0.17	0.00
13	StBass	A	A	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	DSLth	L	A	0.00	0.00	0.02	0.08	0.12	0.23	#
15	DSLth	J	A	0.00	0.04	0.09	0.09	0.10	0.20	0.54
16	DSLth	A	A	0.00	0.00	0.00	0.00	0.00	0.17	0.00
17	TpJS	J	A	0.00	0.00	0.00	0.00	0.00	0.00	0.00

DRAFT

18	EPJA	J	A	0.35	0.89	#	#	#	#	#
19	Secchi	A	B	0.01	0.09	0.17	0.37	#	#	#
20	Secchi	A	A	0.00	0.04	0.09	0.15	*	*	*
21	Jent	L	A	0.00	0.03	0.00	0.00	0.00	0.00	0.00
22	Aent	A	B	0.01	0.07	0.15	0.23	#	#	#
23	Pred2	L	B	0.39	#	#	#	#	#	#
24	Pred2	A	A	0.01	0.00	0.05	0.10	0.04	0.05	0.53

DRAFT

Table 6a. AICc values and covariates included for each step in the two factor analysis for the model with Beverton-Holt survival from juvenile to adult. y = covariate included in lowest AICc model, # = covariate selected in previous step, * = covariate not considered because it is similar to another covariate.

					test1		test2		test3		test4		test5	
					covar1	covar2	covar1	covar2	covar1	covar2	covar1	covar2	covar1	covar2
				AICc	841.06	833.44	827.58	824.00	823.01	823.30	824.61	825.95	828.28	831.08
				Δ	18.05	10.43	4.57	0.99	0.00	0.28	1.60	2.94	5.27	8.07
Run	name	Stage	B/A											
1	SpDys	A	B								y	y	#	#
2	TpAJ	L	B			y	#	#	#	#	#	#	#	#
3	TpAJ	A	A											y
4	TpJul	L	A				y	y	#	#	#	#	#	#
5	EPAJ	L	B			y	#	#	#	#	#	#	#	#
6	EPAJ	A	A											
7	EPJul	L	A									y	#	#
8	Pred1	J	A					y	#	#	#	#	#	#
9	Pred1	A	B											
10	Pred1	A	A											
11	StBass	J	A											
12	StBass	A	B											

DRAFT

13	StBass	A	A								
14	DSLth	L	A								
15	DSLth	J	A								
16	DSLth	A	A								
17	TpJS	J	A								
18	EPJA	J	A			y	y	#	#	#	#
19	Secchi	A	B				y	#	#	#	#
20	Secchi	A	A				*	*	*	*	*
21	Jent	L	A								
22	Aent	A	B							y	y
23	Pred2	L	B	y							
24	Pred2	A	A								

DRAFT

Table 6b. AICc values and covariates included for each step in the two factor analysis for the model with Beverton-Holt survival from juvenile to adult and a Beverton-Holt stock-recruitment relationship. y = covariate included in the lowest AICc model, # = covariate selected in previous step, * = covariate not considered because it is similar to another covariate.

					test1		test2		test3		test4		test5	
					covar1	covar2	covar1	covar2	covar1	covar2	covar1	covar2	covar1	covar2
				AICc	832.46	824.68	818.25	815.18	813.92	814.32	814.17	811.85	812.33	814.75
				AICc-min(AICc)	20.60	12.83	6.40	3.33	2.06	2.46	2.32	0.00	0.48	2.90
Run	name	Stage	B/A											
1	SpDys	A	B											y
2	TpAJ	L	B			y	#	#	#	#	#	#	#	#
3	TpAJ	A	A											y
4	TpJul	L	A				y	y	#	#	#	#	#	#
5	EPAJ	L	B		y	y	#	#	#	#	#	#	#	#
6	EPAJ	A	A											
7	EPJul	L	A								y	y	#	#
8	Pred1	J	A					y	#	#	#	#	#	#
9	Pred1	A	B											
10	Pred1	A	A										y	
11	StBass	J	A											
12	StBass	A	B											
13	StBass	A	A											

DRAFT

14	DSLth	L	A								
15	DSLth	J	A								
16	DSLth	A	A								
17	TpJS	J	A								
18	EPJA	J	A				y	y	#	#	#	#
19	Secchi	A	B					y	#	#	#	#
20	Secchi	A	A						*	*	*	*
21	Jent	L	A									
22	Aent	A	B							y	#	#
23	Pred2	L	B									
24	Pred2	A	A									

DRAFT

Table 6c. AICc values and covariates included for each step in the two factor analysis for the model with Ricker survival from juvenile to adult. y = covariate included in lowest AICc model, # = covariate selected in previous step, * = covariate not considered because it is similar to another covariate.

					test1		test2		test3		test4		test5	
					covar1	covar2	covar1	covar2	covar1	covar2	covar1	covar2	covar1	covar2
				AICc	841.80	833.67	826.25	821.40	820.00	821.10	822.58	823.71	826.26	828.86
				Δ	21.81	13.68	6.25	1.40	0.00	1.11	2.58	3.72	6.26	8.86
Run	name	Stage	B/A											
1	SpDys	A	B							y	#	#	#	#
2	TpAJ	L	B				y	y	#	#	#	#	#	#
3	TpAJ	A	A											y
4	TpJul	L	A					y	#	#	#	#	#	#
5	EPAJ	L	B				#	#	#	#	#	#	#	#
6	EPAJ	A	A											
7	EPJul	L	A									y	#	#
8	Pred1	J	A						y	y	#	#	#	#
9	Pred1	A	B											
10	Pred1	A	A											
11	StBass	J	A											
12	StBass	A	B											

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13	StBass	A	A										
14	DSLth	L	A										
15	DSLth	J	A										
16	DSLth	A	A										
17	TpJS	J	A										
18	EPJA	J	A		y	#	#	#	#	#	#	#	#
19	Secchi	A	B							y	y	#	#
20	Secchi	A	A							*	*	*	*
21	Jent	L	A										
22	Aent	A	B									y	y
23	Pred2	L	B	y	y								
24	Pred2	A	A										

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Table 6d. AICc values and covariates included for each step in the two factor analysis for the model with Ricker survival from juvenile to adult and a Beverton-Holt stock-recruitment relationship. y = covariate included in lowest AICc model, # = covariate selected in previous step, * = covariate not considered because it is similar to another covariate. Additional covariates increased the AICc by more than 4 units and are not shown.

					test1		test2		test3		test4		test5		test6		test7	
					covar1	covar2	covar1	covar2	covar1	covar2	covar1	covar2	covar1	covar2	covar1	covar2	covar1	covar2
				AICc	833.16	824.93	817.96	814.72	811.60	810.20	810.72	810.38	808.47	809.23	810.86	813.39	817.03	820.83
				AICc-min(AICc)	24.68	16.46	9.49	6.25	3.12	1.73	2.25	1.91	0.00	0.75	2.38	4.92	8.55	12.36
Run	name	Stage	B/A															
1	SpDys	A	B											y	#	#	#	#
2	TpAJ	L	B			y		y	#	#	#	#	#	#	#	#	#	#
3	TpAJ	A	A												y	y	#	#
4	TpJul	L	A						y	y	#	#	#	#	#	#	#	#
5	EPAJ	L	B		y	y	#	#	#	#	#	#	#	#	#	#	#	#
6	EPAJ	A	A															
7	EPJul	L	A										y	y	#	#	#	#
8	Pred1	J	A							y	#	#	#	#	#	#	#	#
9	Pred1	A	B															
10	Pred1	A	A															

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11	StBass	J	A													
12	StBass	A	B													
13	StBass	A	A													
14	DSLth	L	A											y	#	#
15	DSLth	J	A												y	y
16	DSLth	A	A													
17	TpJS	J	A													
18	EPJA	J	A		y	y	#	#	#	#	#	#	#	#	#	#
19	Secchi	A	B						y	y	#	#	#	#	#	#
20	Secchi	A	A								*	*	*	*	*	*
21	Jent	L	A													
22	Aent	A	B							y	#	#	#	#	#	#
23	Pred2	L	B		#	#	#	#	#	#	#	#	#	#	#	#
24	Pred2	A	A													y

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Table 7. Estimates of coefficients from the lowest AICc models for each density dependence assumption.

Run	name	Stage	B/A	JBH	JBHABH	JR	JRABH	JRABH no Pred2	Alternative
1	SpDys	A	B						
2	TpAJ	L	B	-0.32 (-0.46, -0.18)	-0.21 (-0.36, -0.07)	-0.32 (-0.45, -0.19)	-0.20 (-0.34, -0.06)	-0.22 (-0.36, -0.09)	-0.31 (-0.44, -0.18)
3	TpAJ	A	A						
4	TpJul	L	A	-0.29 (-0.50, -0.08)	-0.30 (-0.49, -0.12)	-0.28 (-0.49, -0.07)	-0.28 (-0.47, -0.09)	-0.32 (-0.50, -0.13)	-0.30 (-0.50, -0.11)
5	EPAJ	L	B	0.39 (0.15, 0.63)	0.40 (0.18, 0.62)	0.37 (0.13, 0.61)	0.32 (0.09, 0.55)	0.36 (0.14, 0.58)	0.47 (0.23, 0.71)
6	EPAJ	A	A						
7	EPJul	L	A		0.32 (0.07, 0.58)		0.31 (0.05, 0.56)	0.33 (0.07, 0.59)	
8	Pred1	J	A	-0.45 (-0.84, -0.06)	-0.49 (-0.90, -0.08)	-0.37 (-0.71, -0.03)	-0.42 (-0.77, -0.07)	-0.44 (-0.78, -0.09)	-0.40 (-0.75, -0.05)
9	Pred1	A	B						
10	Pred1	A	A						
11	StBass	J	A						
12	StBass	A	B						
13	StBass	A	A						
14	DSLth	L	A						
15	DSLth	J	A						
16	DSLth	A	A						

DRAFT

17	TpJS	J	A						
18	EPJA	J	A	0.21 (0.00, 0.42)	0.22 (0.00, 0.45)	0.44 (0.21, 0.66)	0.46 (0.22, 0.69)	0.46 (0.22, 0.69)	0.46 (0.23, 0.69)
19	Secchi	A	B		-1.08 (-1.97, -0.19)		-1.24 (-2.27, -0.22)	-1.15 (-2.11, -0.20)	
20	Secchi	A	A						
21	Jent	L	A						
22	Aent	A	B		9.50 (0.62, 18.38)		10.97 (0.93, 21.01)	10.32 (0.99, 19.65)	
23	Pred2	L	B				-0.19 (-0.52, 0.13)		
24	Pred2	A	A						

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Table 8. Estimates of standard deviation of the process variation and the percentage of the process variation explained by the covariates for the lowest AICc model.

	Standard deviation without covariates	Standard deviation with covariates	%variation explained
Larvae	0.72	0.00	100%
Juvenile	0.63	0.48	43%
Adult	0.71	0.62	24%

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Figure captions

Figure 1. Life cycle diagram of delta smelt with survey, entrainment, and density dependence timing.

Figure 2. Relationship among stages in the model for the lowest AICc model that has Ricker survival from juveniles to adults and a Beverton-Holt stock-recruitment relationship. Points are the model estimates of abundance, lines are the estimates from the stock recruitment models without covariates or process variation, crosses are the estimates without covariates.

Figure 3. Relationship among stages in the alternative model that has Ricker survival from juveniles to adults and a Beverton-Holt stock recruitment relationship. Points are the model estimates of abundance, lines are the estimates from the stock recruitment models without covariates or process variation, crosses are the estimates without covariates.

Figure 4. Fit to the survey abundance data for the lowest AICc model that includes Ricker survival between juveniles and adults and a Beverton-Holt stock-recruitment relationship.

Figure 5. Fit to the survey abundance data for the alternative model that includes Ricker survival from juveniles to adults and a Beverton-Holt stock recruitment relationship.

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Figure 6. Estimates of the realizations of the process variation random effects ($\exp\left[\sigma_s \varepsilon_{t,s} - 0.5\sigma_s^2\right]$) for the lowest AICc model that includes Ricker survival between juveniles and adults and a Beverton-Holt stock-recruitment relationship.

Figure 7. Estimates of the realizations of the process variation random effects ($\exp\left[\sigma_s \varepsilon_{t,s} - 0.5\sigma_s^2\right]$) for the alternative model that includes Ricker survival between juveniles and adults and a Beverton-Holt stock-recruitment relationship.

Figure 8. Estimates of abundance with and without covariates (model run with parameter estimates fixed at those from the model with covariates and the coefficients of the covariates set to zero) (top) and ratio of the two with 95% confidence intervals (bottom, y-axis limited to show details) the from the lowest AICc model that has Ricker survival from juveniles to adults and a Beverton-Holt stock-recruitment relationship.

Figure 9. Estimates of abundance with and without covariates (model run with parameter estimates fixed at those from the model with covariates and the coefficients of the covariates set to zero) (top) and ratio of the two with 95% confidence intervals (bottom, y-axis limited to show details) the from the alternative model that has Ricker survival from juveniles to adults and a Beverton-Holt stock-recruitment relationship.

Figure 10. Estimates of the adult abundance with and without adult entrainment (top) (as estimated) and the ratio of adult abundance without adult entrainment to with adult

entrainment (bottom, y-axis limited to show details) from the lowest AICc model with Ricker survival from juveniles to adults and a Beverton-Holt stock-recruitment relationship.

Figure 11. Estimates of the adult abundance with and without entrainment (entrainment coefficients set to one) (top) and the ratio of adult abundance without to with entrainment (with confidence intervals) (bottom, y-axis limited to show details) from the alterative model with Ricker survival from juveniles to adults and a Beverton-Holt stock-recruitment relationship.

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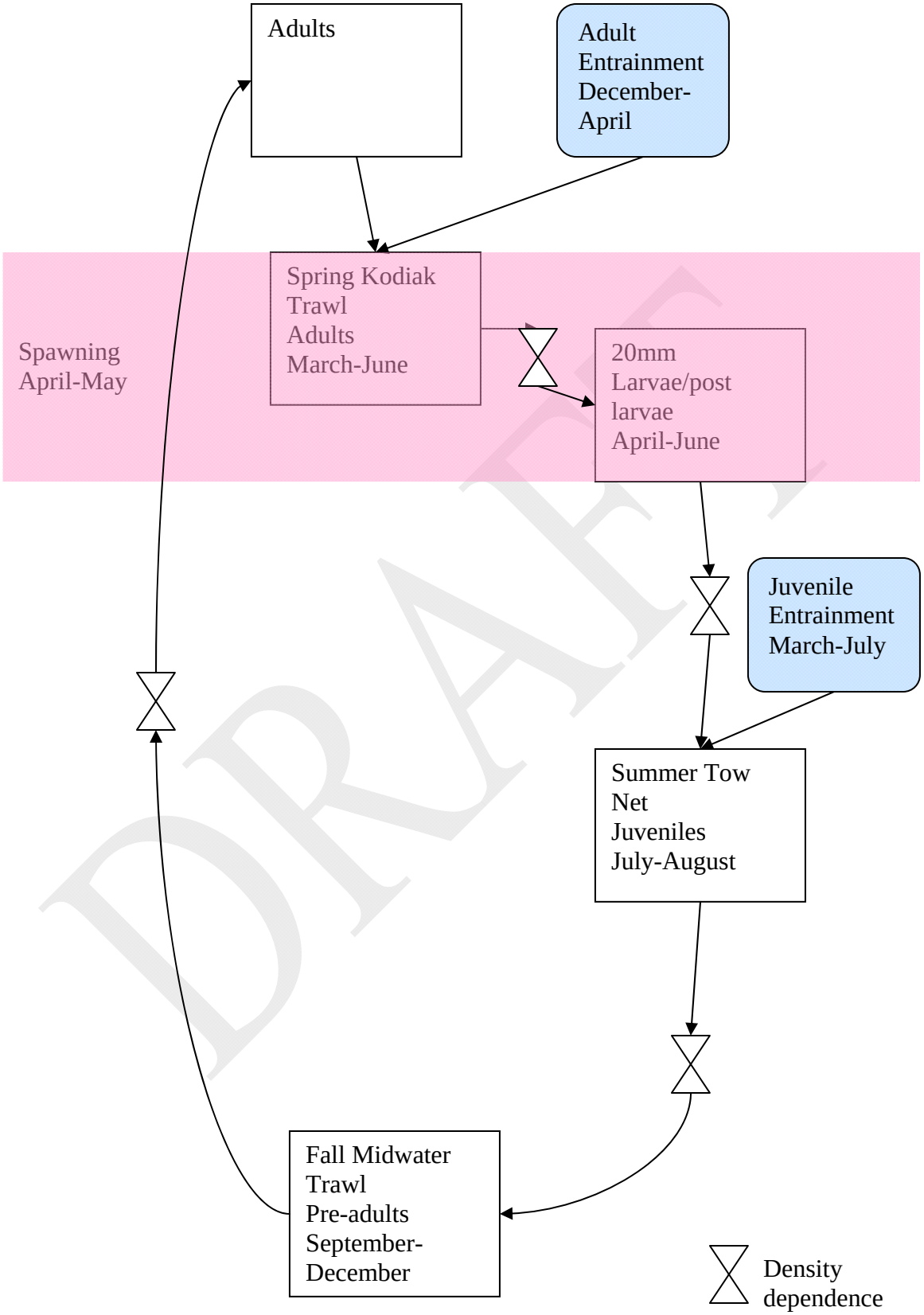
Adults
Adult Entrainment December-April
Spawning April-May
Spring Kodiak Trawl Adults March-June
20mm Larvae/post larvae April-June
Juvenile Entrainment March-July
Summer Tow Net Juveniles July-August
Fall Midwater Trawl Pre-adults September-December
Density dependence

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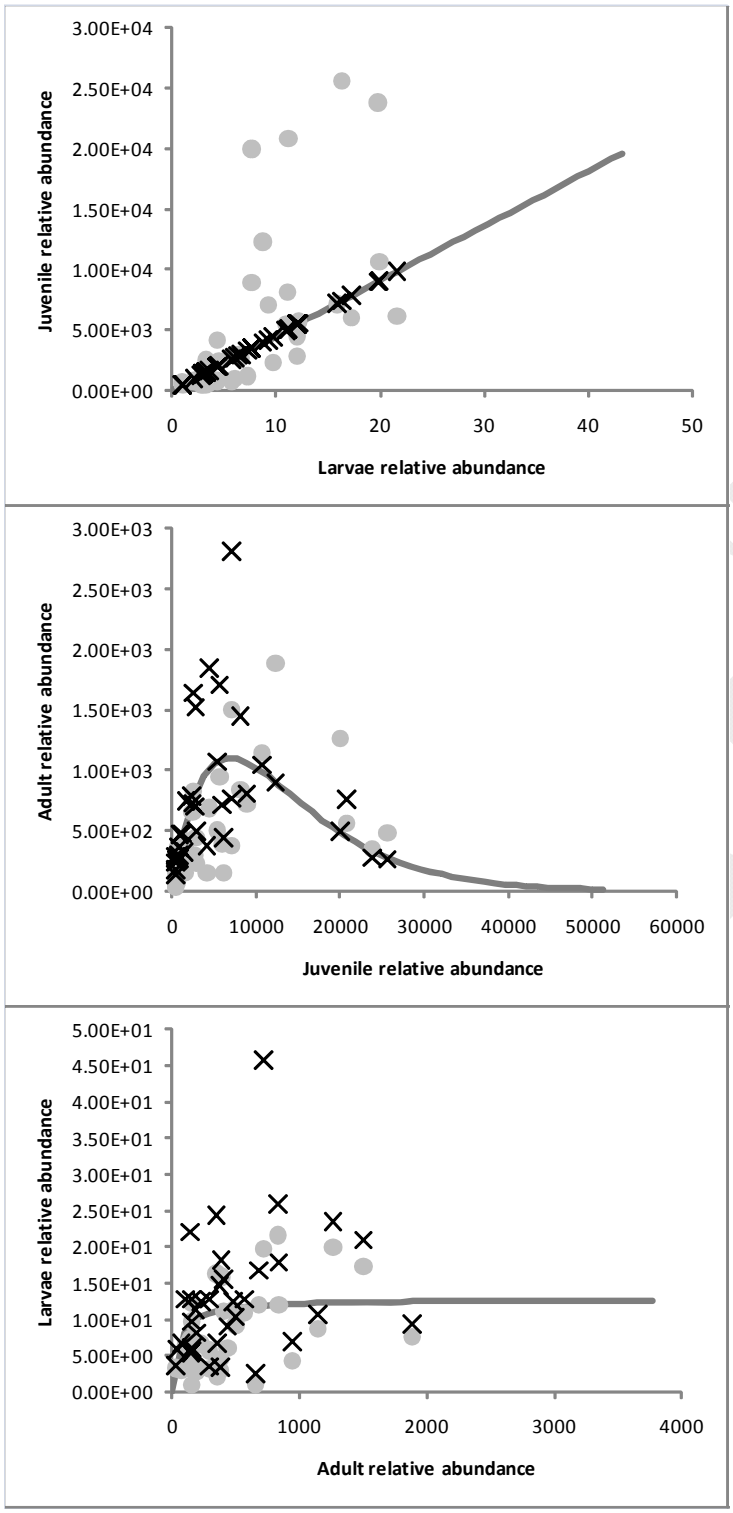

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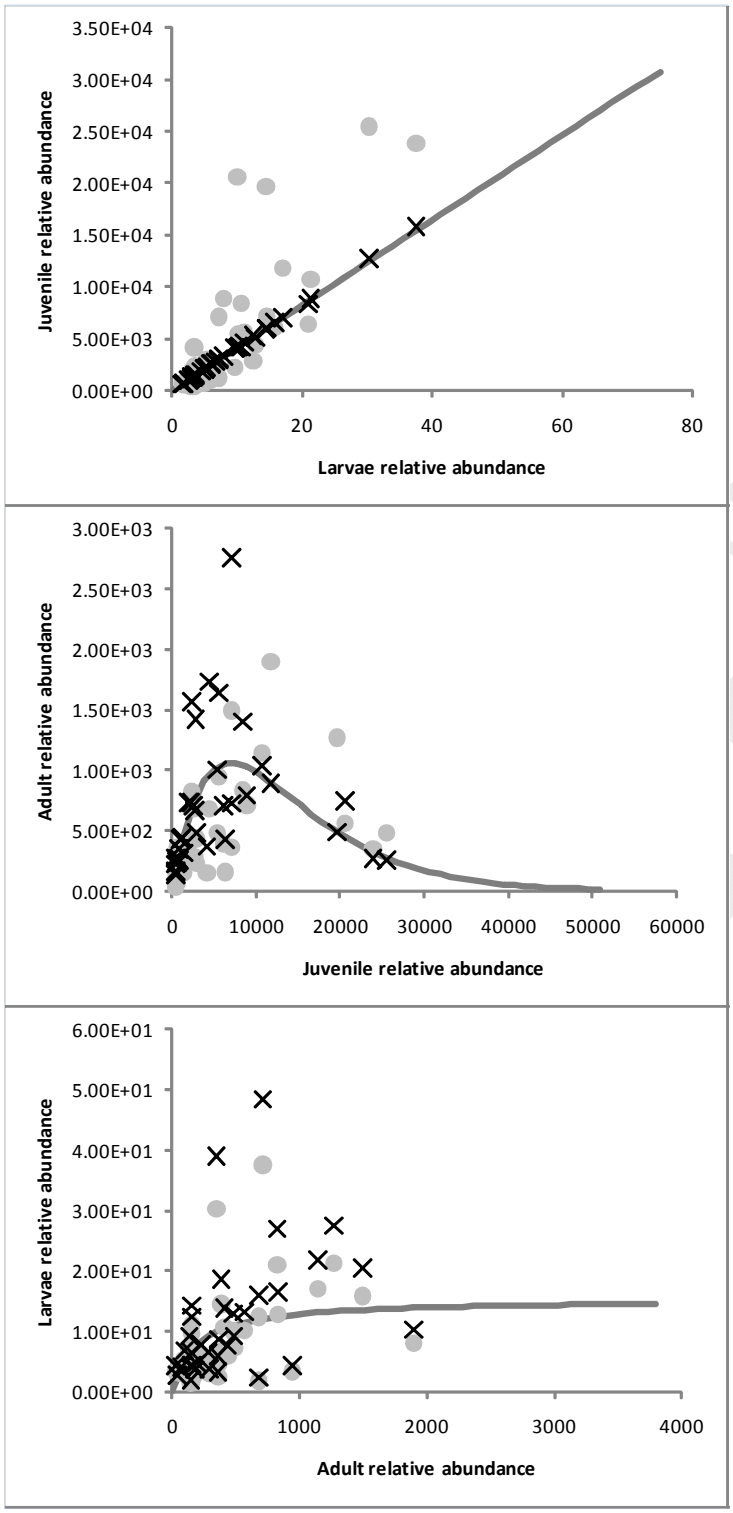

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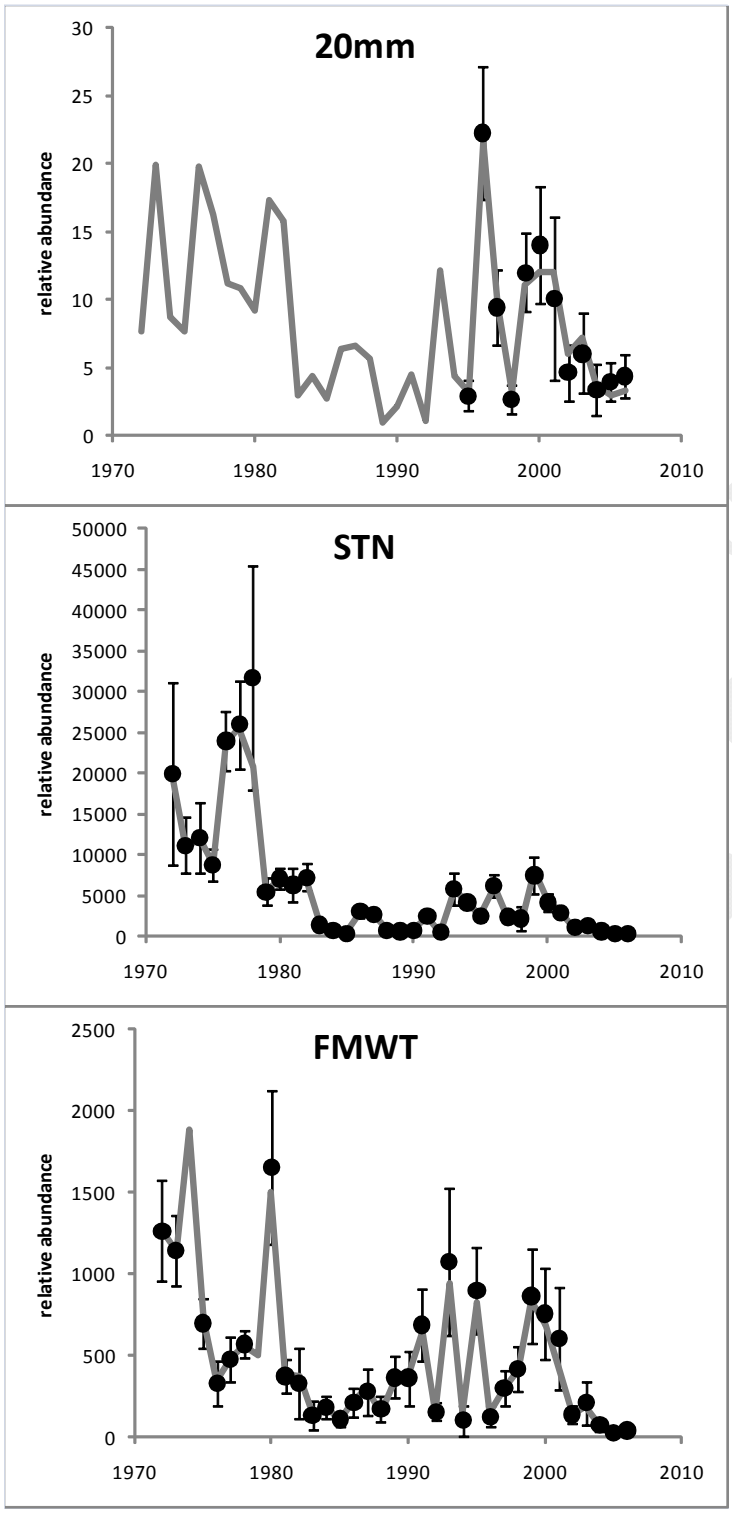

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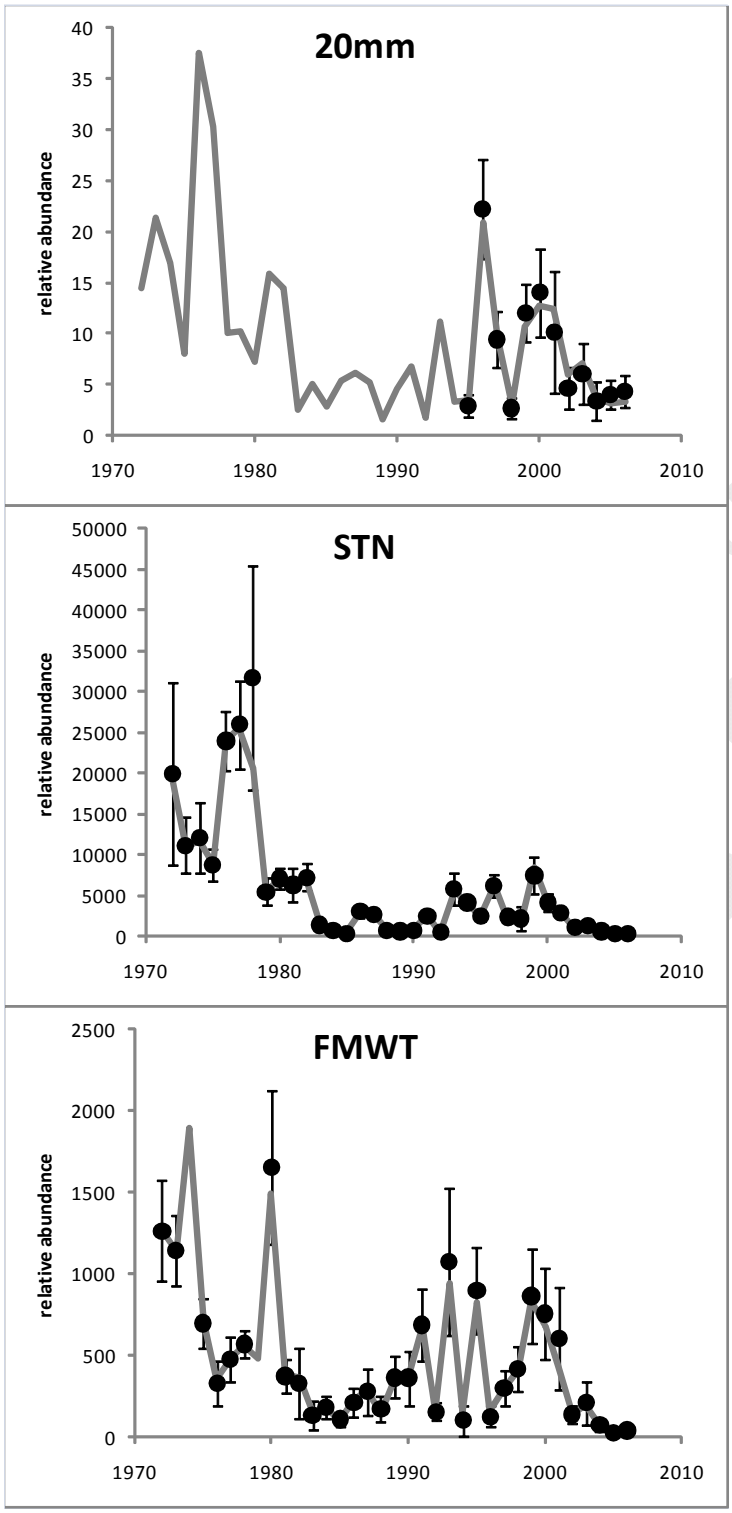
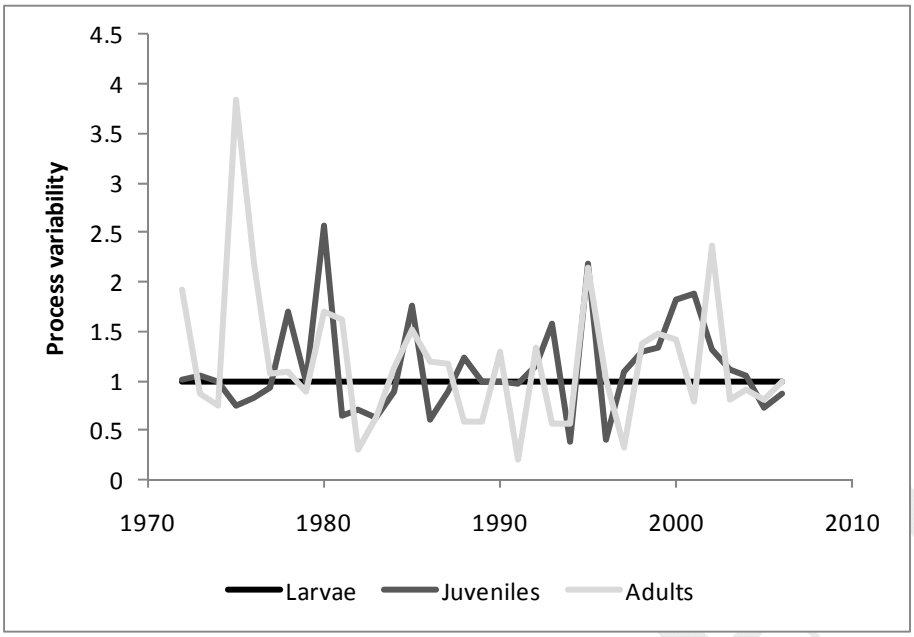


Figure 5. Fit to the survey abundance data for the alternative model that includes Ricker survival from juveniles to adults and a Beverton-Holt stock recruitment relationship.



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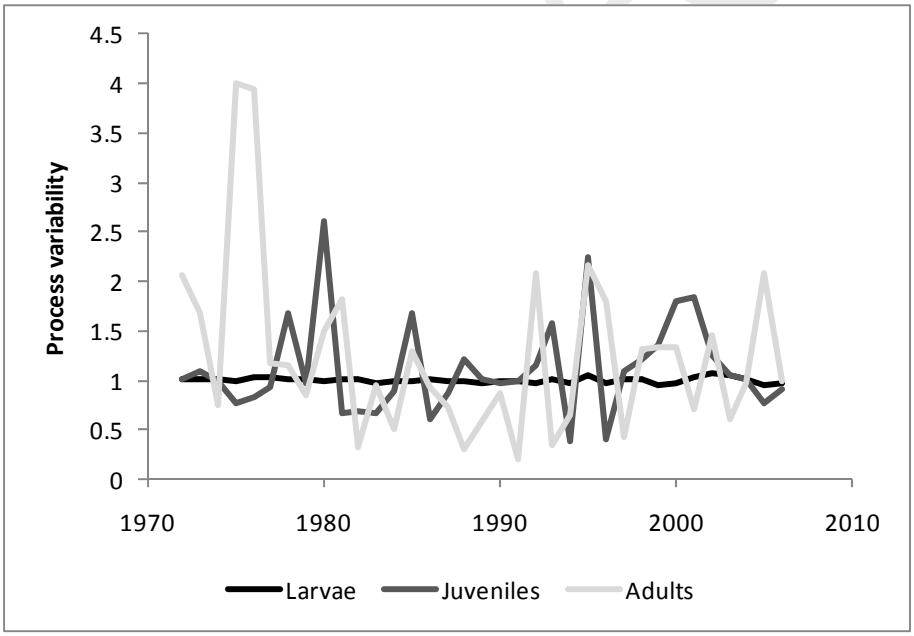

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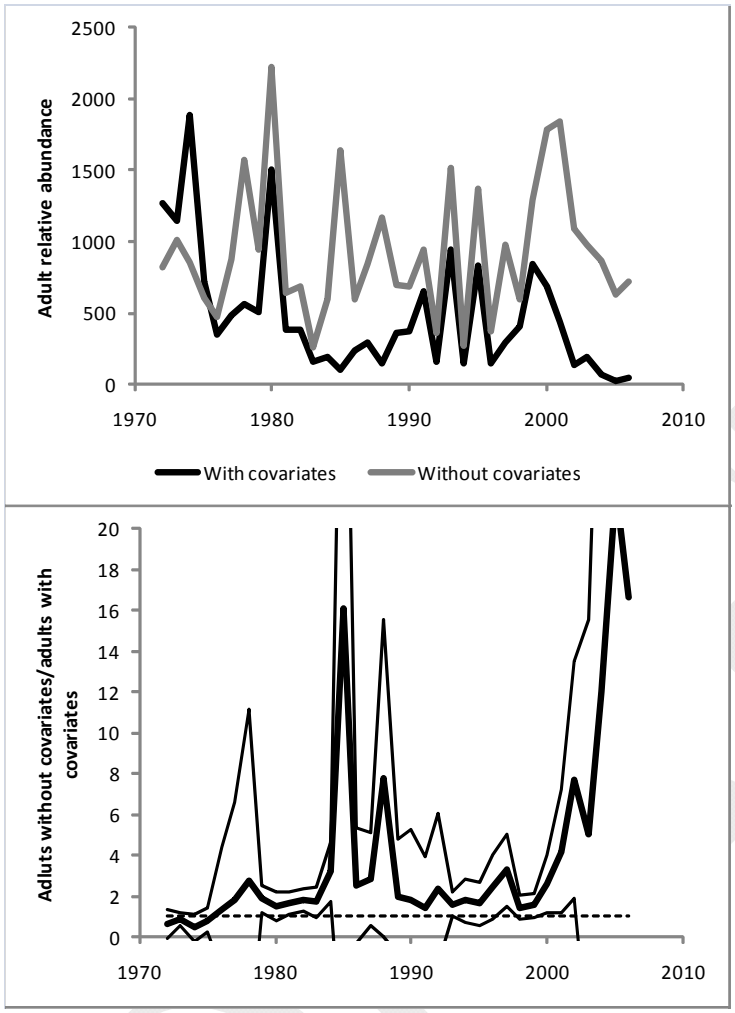

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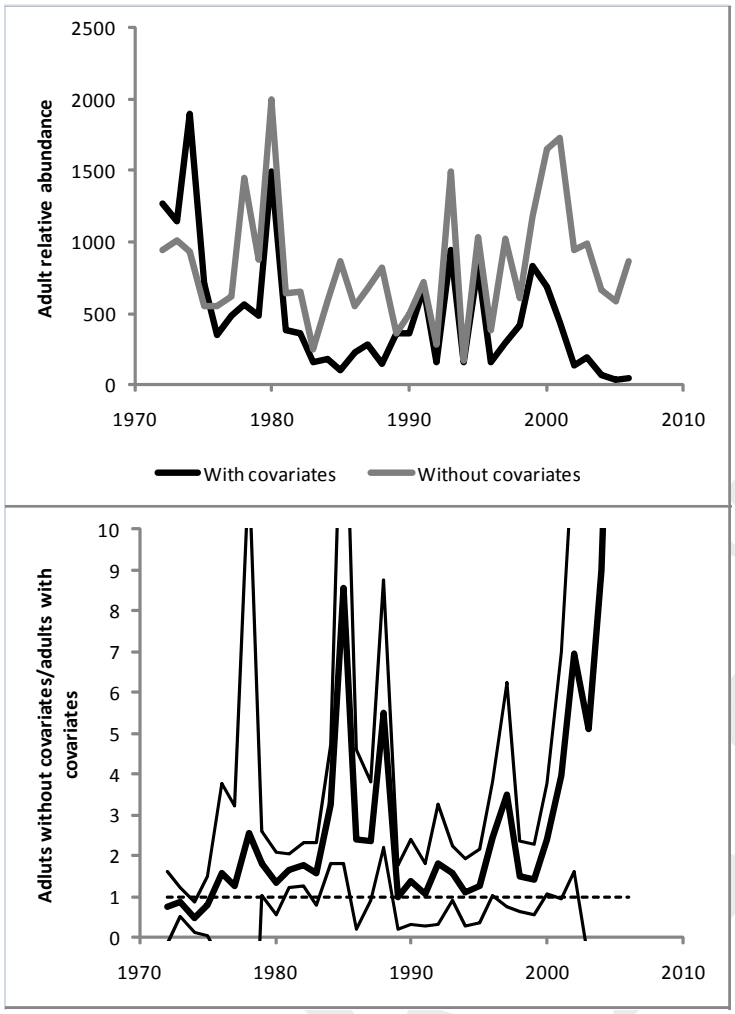

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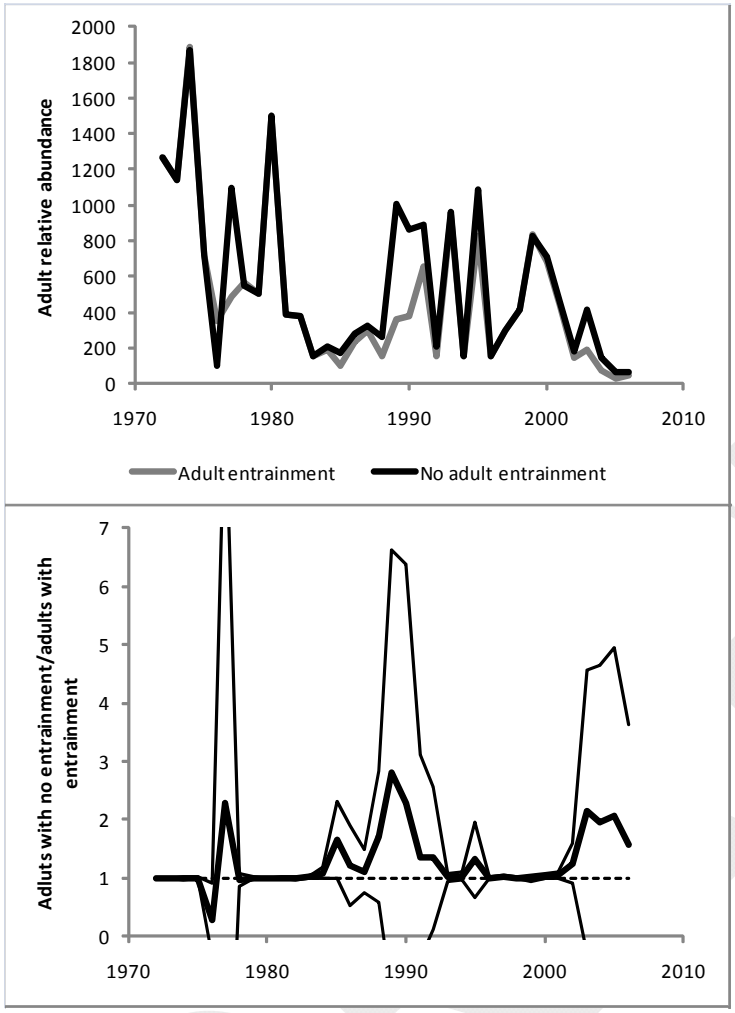

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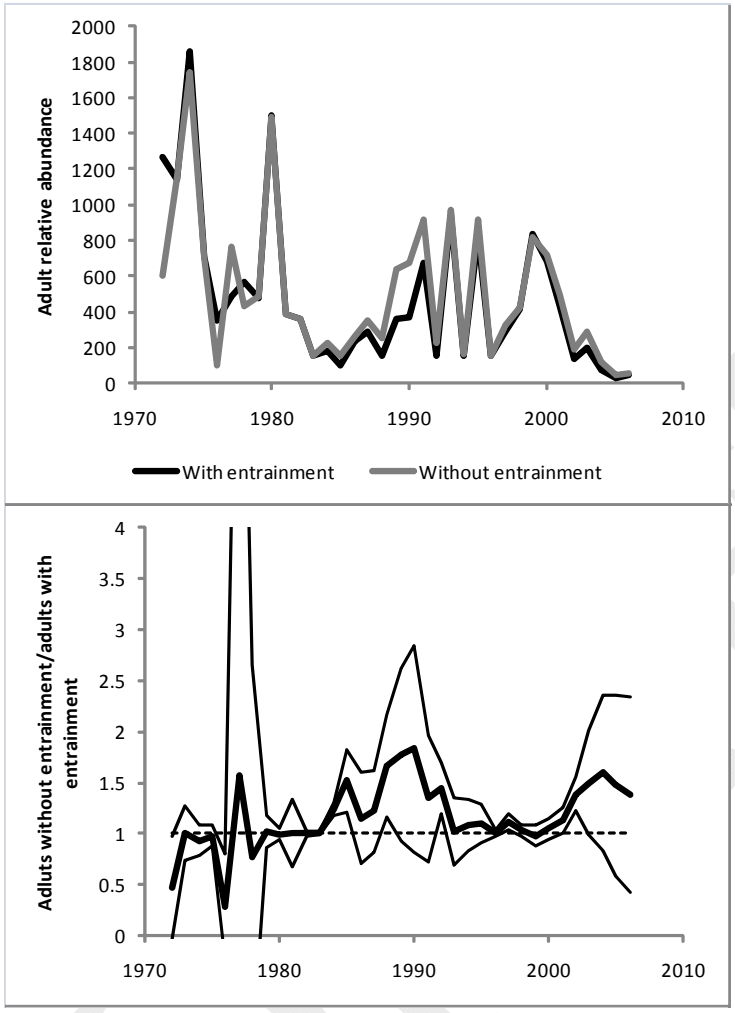

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Supplementary material table

Table S1. Parameter estimates, standard deviations, and steepness ($h_{0.05}$, see Appendix) estimates from the lowest AICc model and alternative model.

	Lowest AICc		Alternative	
Parameters	Value	sd	Value	sd
ln(a_Larvae)	6.12	0.09	6.02	0.09
ln_a_Juvenile	-0.84	0.27	-0.89	0.27
ln(b_Juvenile)	-8.85	0.15	-8.85	0.15
$h_{0.05}$_Juvenile	0.12		0.11	
ln(a_Adult)	-1.40	0.87	-2.52	0.52
ln(b_Adult)	-3.95	1.01	-5.25	0.83
$h_{0.05}$_Adult	0.34		0.15	
ln(Ninit)	2.03	0.42	2.67	0.39
ln(sd_Larvae)	-10.30	3891.30	-2.32	1.50
ln(sd_Juvenile)	-0.74	0.16	-0.76	0.16
ln(sd_Adult)	-0.48	0.13	-0.34	0.13

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Bayesian change point analysis of abundance trends for pelagic fishes in the upper San Francisco Estuary

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Abstract. We examined trends in abundance of four pelagic fish species (delta smelt, longfin smelt, striped bass, and threadfin shad) in the upper San Francisco Estuary, California, USA, over 40 years using Bayesian change point models. Change point models identify times of abrupt or unusual changes in absolute abundance (step changes) or in rates of change in abundance (trend changes). We coupled Bayesian model selection with linear regression splines to identify biotic or abiotic covariates with the strongest associations with abundances of each species. We then refitted change point models conditional on the selected covariates to explore whether those covariates could explain statistical trends or change points in species abundances. We also fitted a multispecies change point model that identified change points common to all species. All models included hierarchical structures to model data uncertainties, including observation errors and missing covariate values. There were step declines in abundances of all four species in the early 2000s, with a likely common decline in 2002. Abiotic variables, including water clarity, position of the 2‰ isohaline (X2), and the volume of freshwater exported from the estuary, explained some variation in species' abundances over the time series, but no selected covariates could explain statistically the post-2000 change points for any species.

Key words: change point; delta smelt; hierarchical Bayes; longfin smelt; Sacramento–San Joaquin Delta, California, USA; striped bass; threadfin shad; upper San Francisco Estuary, California, USA.

Introduction

Declines in ecological condition across large areas are increasingly common around the world (e.g., Sala et al. 2000, Palmer et al. 2008, Cunningham et al. 2009), reflecting the increase in scope and intensity of human land use during the past century. The condition of estuaries has declined as a result of changing levels of terrestrial, freshwater, and marine stressors, including toxicants, nutrient enrichment, reduction of freshwater inputs, commercial and recreational harvest, dredging, and invasions of nonnative species (Lotze et al. 2006). The San Francisco Estuary, California, USA, experiences all of these stressors, and populations of many aquatic species have declined since intensive human activities began in the mid-1800s (Bennett and Moyle 1996, Brown and Moyle 2005).

The San Francisco Estuary is the largest estuary on the Pacific coast of North America and consists of four major regions: San Francisco Bay, the most seaward region; San Pablo Bay and Suisun Bay, two intermediate brackish regions; and the generally freshwater Sacramento–San Joaquin Delta (Fig. 1). The Delta is at the core of a massive system of dams and canals that store and divert water from the estuary for agricultural, industrial, and domestic use in central and southern California (Nichols et al. 1986). The water diversion facilities export ~30% of the freshwater flow into the Delta on average, although that percentage has exceeded 60% during many recent summers (Kimmerer 2004).

The social, economic, and ecological effects of freshwater flows and diversions throughout the San Francisco Estuary have received tremendous attention. About 25 million Californians and 12 000 km^2 of agricultural land rely on water diversions from the Delta. Annual agricultural revenue from California's Central Valley, which accounts for about half of the

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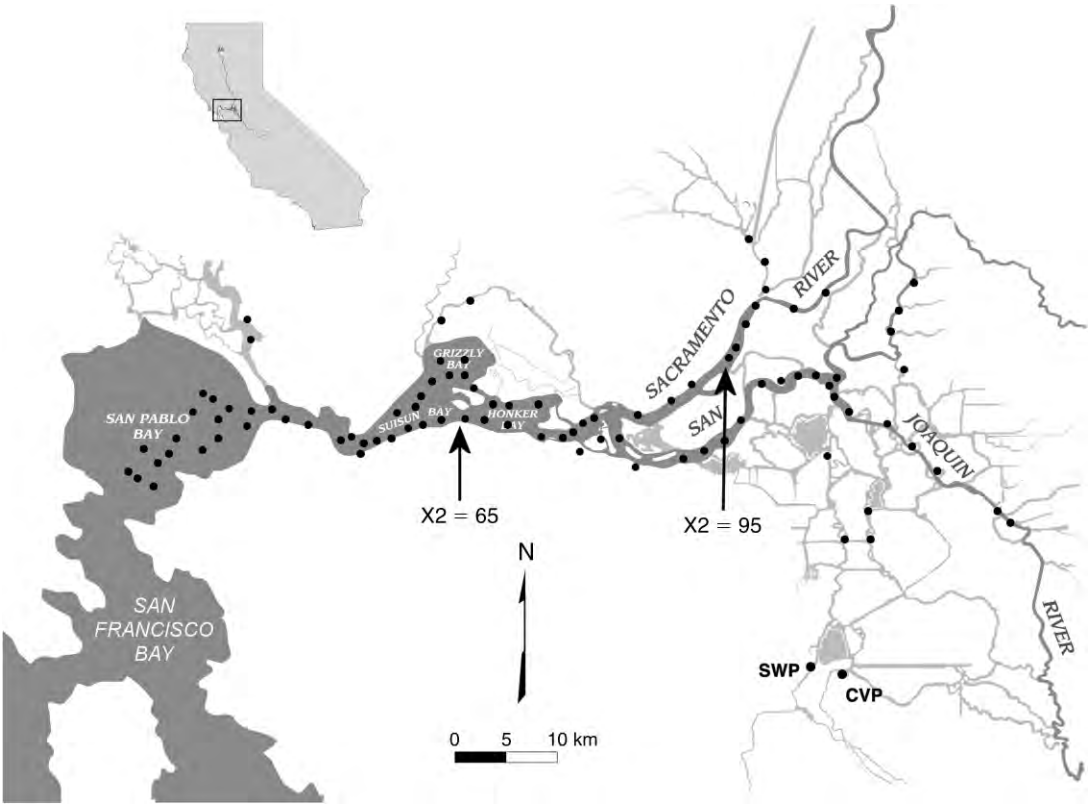

FIG. 1. Location and physiography of the upper San Francisco Estuary, California, USA. Solid circles denote sampling locations of the autumn midwater trawl surveys; arrows indicate two representative positions of the 2‰ isohaline (X2); SWP (State Water Project) and CVP (Central Valley Project) are locations of water exports from the estuary.

production of fruits and vegetables in the United States, frequently approaches US$15 billion. Regulations on water diversions, including standards for the position of the 2‰ isohaline (a measure of the physical response of the estuary to freshwater flow; Jassby et al. 1995), locally termed X2, have become increasingly stringent.

Conflicts over water management in the Delta have intensified because of the apparently precipitous decline in abundance of four species of pelagic fish (delta smelt [*Hypomesus transpacificus*], longfin smelt [*Spirinchus thaleichthys*], striped bass [*Morone saxatilis*], and threadfin shad [*Dorosoma petenense*]) since ca. 2000 (Sommer et al. 2007). Delta smelt was listed as threatened under the U.S. and California Endangered Species Acts in 1993 and the listing was revised to endangered under the California act in 2009. Recent litigation to protect the species resulted in court orders to halt water diversions temporarily (Wanger 2007*a*, *b*). Longfin smelt was listed as threatened under the California Endangered Species Act in 2009 and was proposed but declined for federal listing.

Analyses of existing data and new field investigations have identified various factors that may help to explain the declines, but the relative importance of these factors, particularly water diversions, is unclear (Sommer et al. 2007). Identification of the processes causing declines and their relative effects is critical because the solutions under consideration include major investments in infrastructure, changes in water management, and rehabilitation of species' habitats that collectively will cost billions of dollars. Although an experimental evaluation of potential drivers is impossible for a system of this size, multi-decadal sets of data exist on abundances of pelagic fishes and biotic and abiotic characteristics of their environment, allowing for a robust correlative analysis.

There is interest in determining whether the recent declines in species' abundances are the continuation of longer term trends or more abrupt changes in population dynamics, which we refer to as ecological "change points" (Beckage et al. 2007). If the latter, identifying when these changes occurred and if and when similar changes have occurred previously is an important step toward understanding their causes and possible mitigation. We define a change point as a point in time when an abrupt change occurred in the functional relationship between the mean abundance of a species and time. A change point may be either a step change, which is an abrupt change in abundance; a trend change, which is an abrupt change in the temporal trend in abundance; or both. Manly and Chotkowski (2006) used a bootstrap approach to explore the timing of one or more change

points in the abundance of delta smelt. But no method has been applied to detect objectively multiple change points for all four species, whether individually or as a group. Neither has there been a rigorous examination of factors that might explain statistically specific change points.

Here, we characterize abundance trends of delta smelt, longfin smelt, striped bass, and threadfin shad over the period of record (1967–2007), identify change points for species individually and collectively, and examine whether biotic and abiotic covariates are related to those trends or change points. To identify statistically the number, timing, and magnitude of any changes in abundance trajectories and to integrate uncertainties into parameter estimates and inference, we constructed models based on Bayesian change point techniques (Beckage et al. 2007). We used hierarchical model structures to separate explicitly observation error from natural process variation, to handle missing data, and to fit a multispecies change point model. Hierarchical Bayesian models are ideally suited to the complexity of analyzing ecological time series (Webb and King 2009) because they can integrate multiple sources of information and uncertainty to provide more robust inferences about parameters and processes of interest (Cressie et al. 2009).

Biological background

Delta smelt are endemic to the San Francisco Estuary. They reach 60–70 mm standard length (SL), feeding throughout their life on mesozooplankton (Bennett 2005). Delta smelt are weakly anadromous. Upstream migration begins in mid-December and spawning occurs from March through May in freshwater. Most delta smelt spawn 12–15 months after birth. A small percentage live two years, possibly spawning in one or both years (Bennett 2005). Young delta smelt move downstream in early summer and remain in the low-salinity zone (0.5–10 on the practical salinity scale) until they migrate for spawning.

Longfin smelt also are native to the San Francisco Estuary. Longfin smelt reach 90–110 mm SL with a maximum size of 120–150 mm SL (Moyle 2002, Rosenfield and Baxter 2007). Longfin smelt are anadromous. They spawn at age-2 in freshwater in the Delta from approximately December to April. Young longfin smelt occur from the low-salinity zone seaward throughout the estuary and into the coastal ocean. Longfin smelt feed on copepods as larvae and primarily on mysids as juveniles and adults.

Striped bass were deliberately introduced to the Delta from the east coast of the United States in 1879 and now support a popular sport fishery (Moyle 2002). The striped bass is a large (>1 m), long-lived (>10 years) anadromous species. Females begin to spawn at age-4 in the Sacramento River and to a lesser extent in the San Joaquin River from April through June. Their semi-buoyant eggs hatch as they drift with the current. The larvae drift into the low-salinity zone where they grow, later dispersing throughout the estuary. Adults occur throughout the estuary to the coastal ocean, except during spawning migrations. Age-0 striped bass feed mainly on copepods, later switching to macroinvertebrates and then to fish.

Threadfin shad was introduced into California reservoirs as a forage fish in 1954 and eventually spread to the Delta (Moyle 2002). Adult threadfin shad are typically <100 mm total length and primarily inhabit freshwater. They switch between filter feeding and particle feeding, consuming phytoplankton, zooplankton, and detritus. Most threadfin shad spawn in their second summer of life, although some may spawn at the end of their first year. Spawning occurs mainly in June and July. Threadfin shad is the most abundant pelagic fish in the upper San Francisco Estuary and is important as prey for piscivorous species.

Statistical analyses

We used a Bayesian framework to fit a series of log-linear models to explore temporal patterns in species abundances and relationships with biotic and abiotic covariates. First, we used piecewise regression models (Denison et al. 1998, Fearnhead 2006) to characterize temporal trends in abundance of each species and to identify change points in either the absolute abundance (step changes) or in the rate of change in abundance (trend changes). Next, we used Bayesian model selection (Green 1995) to identify covariates with the strongest associations with abundances of each species. We then fitted change point models conditional on the selected variables to explore whether those covariates could account statistically for changes detected by the trend model or lead to detection of other change points. We also fitted a multispecies change point model to determine whether there were years in which all species collectively experienced abrupt changes in abundance not explained by the selected covariates.

Hierarchical log-linear trend models

For each species, we fitted a log-linear trend model using piecewise linear splines (Denison et al. 1998) that allow for changes in the intercept or slope parameters at particular times (i.e., change points). We used a hierarchical model to account explicitly for sampling error. For each species, the observations (y_t) were the mean number of individuals captured during autumn trawl surveys conducted each year from 1967 to 2007 (Stevens and Miller 1983). The mean for each year was based on monthly (September, October, November, December) samples from 100 different locations; thus, the yearly average was based on ~400 observations (data and station details *available online*)[10]. We assumed that the observations were unbiased estimates of the true

[10] ⟨http://knb.ecoinformatics.org/knb/metacat/nceas.958.8/nceas/⟩

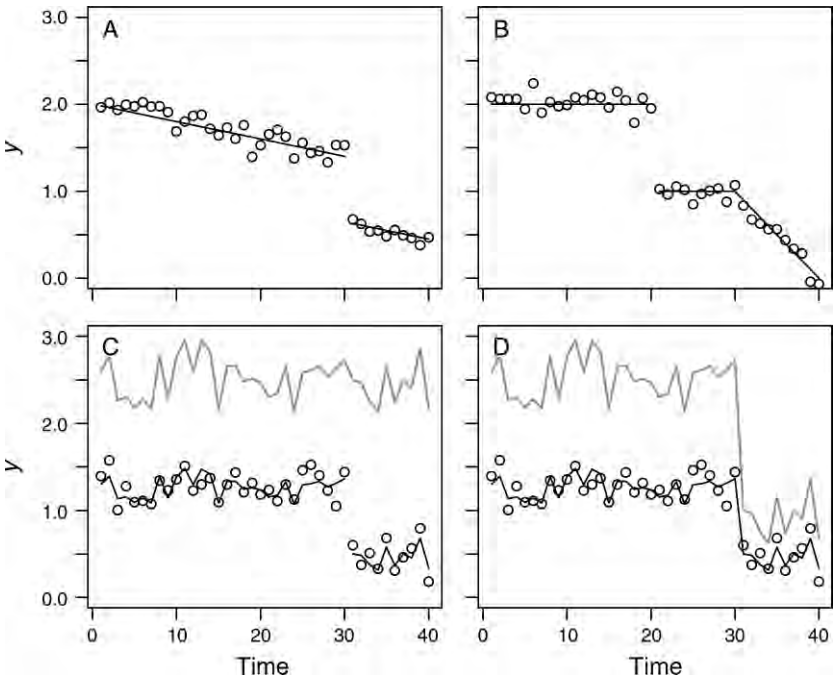

FIG. 2. Examples of change point models. All examples show a hypothetical time series y (circles) and corresponding piecewise linear models (dark lines): (A) a step change at time 31, modeled by $y_t = 2 - 0.75I(t \geq 31) - 0.02t + \varepsilon_t$; (B) a step change at time 21 and trend change at time 31, modeled by $y_t = 2 - 1I(t \geq 21) - 0.03(t - 31)I(t \geq 31) + \varepsilon_t$; (C) a covariate model with step change at time 31, modeled by $y_t = 0 - 0.75I(t \geq 31) + 0.5x_t + \varepsilon_t$; (D) a covariate model with no change points (change point at time 31 in panel C is predicted by covariate), modeled by $y_t = 0 + 0.5x_t + \varepsilon_t$. In panels (C) and (D), gray lines show the time series of the covariate x. For all models, ε_t is the residual error, and all other parameters are as defined in Eqs. 1–3.

mean abundance (n_t) in a standard trawl sample over the four-month period in year t and that the 100 sampling stations are an adequate spatial representation of the estuary. The resulting hierarchical model for observations and true abundances was

$$y_t \sim \text{Normal}\left(n_t, \sigma^2_{\text{O}t}\right) \tag{1}$$

$$n_t \sim \text{Lognormal}\left(\alpha_t + f_t(t), \sigma^2_{\text{p}}\right). \tag{2}$$

Simultaneously estimating observation noise, $\sigma_{\text{O}t}$, and process variation, σ_{p}, is difficult for such hierarchical models (e.g., Dennis et al. 2006). Therefore, we substituted the observed standard errors of trawl samples as estimates of $\sigma_{\text{O}t}$ in the fitting procedure.

The parameters of the state process model, α_t and $f_t(t)$ in Eq. 2, allowed for abrupt changes in the (log) abundances and changes in the relationship between abundance and time, respectively. The following submodel accounted for abrupt changes to the intercept, or step changes:

$$\alpha_t = \alpha_1 + \sum_{j=1}^{k_\alpha} \chi_j I(t \geq \delta_j). \tag{3}$$

In this submodel, α_1 is the initial log abundance of a given species, k_α is the number of step changes in abundance, δ_j is the timing of the jth step change, and χ_j is the value of the change. $I(t \geq \delta_j)$ is an indicator function that equals 1 when $t \geq \delta_j$ and is 0 otherwise. To illustrate, we present an example of the state process model (Eq. 2) fitted to abundance data with a single step change and constant linear trend (Fig. 2A).

We modeled the temporal trend, $f_t(t)$, as a piecewise linear regression with an unknown number k_β of changes in slope (trend changes) and a corresponding set of times θ_j of trend changes, or "knots" (Harrell 2001):

$$f_t(t) = \beta_1 t + \sum_{j=1}^{k_\beta} \beta_{[j+1]}(t - \theta_j)_+. \tag{4}$$

The term $(t - \theta_j)_+$ equals $I(t \geq \theta_j)(t - \theta_j)$. Given a particular intercept, the term $f_t(t)$ is a piecewise linear and continuous function of time, but when the intercept α_t varies, the combination $\alpha_t + f_1(t)$ is a discontinuous piecewise linear model (Fig. 2B).

Given uncertainty about when or if step or trend changes occurred, we treated the numbers, k_α and k_β, and timing, δ_j and θ_j, of change points as unknown parameters to be estimated as part of the model. We used a Bayesian framework with reversible jump Markov chain Monte Carlo sampling (MCMC; Lunn et al. 2006, 2008) to evaluate the posterior model probabilities (i.e., evidence) for all possible models, or

combinations of change points. The range of models considered possible is specified in the prior distributions, which are detailed here. The resulting posterior distributions allow for probabilistic inferences about the occurrence of change points in particular years, accounting for uncertainties in both data and other model parameters (including magnitudes and timing of other change points). The posterior probability that a change point occurred in year y is the summed posterior probabilities of all models that include a change point in year y (e.g., of all values of δ that include y as an element).

Prior distributions for parameters

In Bayesian analysis, prior distributions must be specified for the unknown parameters (Gelman et al. 2004). Our prior distributions limited the number of step and trend changes to a maximum of four each and included the possibility of zero change points: $k \sim$ Binomial(4, 0.5). This prior reflects our expectation that, in a system subjected to increasing anthropogenic influence over the period of record, there may have been multiple changes in abundance trends. The prior explicitly limits the number of change points so the larger and more abrupt changes are highlighted (see the Appendix for further discussion of priors). The priors were uninformative with respect to the timing of change points, with equal prior probability [$p_0 = (0.5 \times 4)/39 = 0.05$] of change points in each year (Appendix). With this prior, a posterior probability $p_1 > 0.14$ for a change point in year y corresponds to an odds ratio of 3, which is a threefold increase from the prior odds [$p_0/(1 - p_0)$] to the posterior odds [$p_1/(1 - p_1)$]. Odds ratios are measures of the evidence in the data in favor of one hypothesis (change point in year y) over an alternative (no change point in year y), and values >3 are generally considered to indicate "substantial" evidence (Jeffreys 1961).

We specified normal prior distributions with zero mean and standard deviations equal to [$\ln(y_{\max}) - \ln(y_{\min})$]/1.96 and $0.25 \times$ [$\ln(y_{\max}) - \ln(y_{\min})$]/1.96 for the magnitude of step (χ) and rate (β) changes, respectively. These priors imply that step changes greater than the observed data range are unlikely (prior probability < 0.05) and that the greatest change in slope in one year is unlikely to be greater than one-quarter of the range of log values of the observed data. We used several uninformative prior distributions for the unknown parameters (numbers and magnitudes of change points) to assess sensitivity to the choice of priors (Appendix). Although absolute values of model posterior probabilities sometimes were sensitive to choice of priors, the relative probabilities, and hence inferences about change point times, were consistent.

Covariate effects

We undertook a series of steps to identify biotic or abiotic variables that may explain temporal patterns in species' abundances and to determine how those variables affected inferences about change points. First, a set of Q (12–15) candidate covariates was selected for each species on the basis of previously published work and unpublished analyses (Table 1). Next, we used Bayesian model selection to identify which of the Q candidate variables had the strongest associations with variation in the (log) abundances of each species (see *Variable selection model*, below). We then fitted change point models conditioned on the selected variables by replacing the trend component $f_t(t)$ in Eq. 2 with covariate effects $f_x(X)$. These covariate-conditioned change point models identify abrupt changes in abundance that would not be expected given the covariate values and estimated species–covariate relationships. Changes in species' abundance that are identified as change points in covariate-conditioned models are unlikely to be related to the included covariates. But if the inclusion of a covariate reduces the evidence for a previously identified change point (i.e., one identified in a trend model or model conditioned on other covariates), then a causal relationship between that covariate and the change point is plausible.

Variable selection model

The variable selection model allowed nonlinear covariate effects and temporal autocorrelation. Covariates were standardized (mean 0, SD 1) prior to model fitting and missing values were assigned normal prior distributions, which were not updated during model fitting, with mean 0 and SD 1. The model was

$$n_t \sim \text{Lognormal}\Big(\alpha + \sum_{j=1}^{Q}\sum_{m=1}^{k_j} \beta_{jm}(x_{jt} - \phi_{jm})_+ + \rho \log n_{t-1}, \sigma_{\text{p}}^2\Big). \quad (5)$$

This model has up to Q covariates with effects fitted as piecewise linear splines with k_j slope parameters $\boldsymbol{\beta}_j$ and free knots $\boldsymbol{\phi}_j$. If $k_j = 0$, variable j has zero effect; if $k_j = 1$, variable j is included as a linear effect (for $x_j > \phi_{j1}$); and if $k_j > 1$, variable j is included as a nonlinear effect. We used a categorical prior for k_j such that the prior probabilities of values 0, 1, 2, and 3 were 0.5, 0.3, 0.1, and 0.1, respectively. Thus, the prior probability that variable j was included in the model, $\Pr(k_j > 0)$, was 0.5, and linear effects were more probable a priori than were nonlinear effects. The knots were assigned uniform discrete priors with 10 possible positions evenly spaced along the range of x_j.

The relative importance of each of the covariates in model 5 was measured by the posterior probability of inclusion for each variable, $\Pr(k_j > 0)$, which is the sum of the posterior model probabilities of all models that include a particular variable. We considered $\Pr(k_j > 0) > 0.75$, corresponding to an odds ratio of 3 [(0.75/0.25)/(0.5/0.5)], to be sufficient evidence to include variables

TABLE 1. Definitions of variables used in change point models, years for which data were available, and ranges of values for variables.

Variable	Years (missing)	Range
Response variables		
Delta smelt (*Hypomesus transpacificus*) 1	1967–2007 (3)	0.06–4.02
Longfin smelt (*Spirinchus thaleichthys*) 2	1967–2007 (3)	0.03–113.16
Striped bass (*Morone saxatilis*) 3	1967–2007 (3)	0.12–59.38
Threadfin shad (*Dorosoma petenense*) 4	1967–2007 (3)	1.36–31.21
Covariates		
Calanoid copepods, spring (cal.sp)	1972–2007 (1)	0.98–43.87
Calanoid copepods, summer (cal.s)	1972–2007 (1)	2.93–27.62
Mysids (mysid)	1972–2007 (0)	0.42–35.05
Northern anchovy (*Engraulis mordax*) (Ancho.)	1980–2006 (1)	0.22–490.42
"Other zooplankton," spring (zoop)	1972–2006 (0)	3.79–56.86
Spring chlorophyll *a* in low-salinity zone (chlo.sp)	1975–2006 (0)	1.12–21.32
Cyclopoid copepod *Limnoithona tetraspina* (Limno.)	1972–2006 (0)	0–7.78
Inland silverside (*Menidia beryllina*) (silver.)	1994–2006 (0)	19.88–116.54
Largemouth bass (*Micropterus salmoides*) (lm.bass)	1994–2006 (0)	0.02–8.00
Spring X2 (X2.sp)	1967–2006 (0)	48.53–91.74
Autumn X2 (X2.aut)	1967–2006 (0)	60.24–93.18
Water clarity (clarity)	1967–2006 (0)	0.44–11.00
Winter exports (expt.w)	1967–2006 (0)	0.13–12.00
Spring exports (expt.s)	1967–2006 (0)	0.37–13.00
Duration of spawning window for delta smelt (15-20C)	1975–2007 (0)	24–85
Mean summer water temperature (temp)	1967–2006 (0)	20.45–23.65
Winter Pacific Decadal Oscillation (PDO.w)	1967–2007 (0)	−1.90–1.89
Summer Pacific Decadal Oscillation (PDO.s)	1967–2007 (0)	−1.11–2.52
Striped bass egg supply (eggs)	1970–2006 (0)	0.02–0.40

Notes: "Candidate" indicates the species (by number; see numbers following species) for which each covariate was included as a candidate predictor in variable selection models. Abbreviated names for covariates used in Figs. 3C, 4C, 5C, and 6C are shown in parentheses. Biomass was measured as mg C/m^3. The low-salinity zone was determined to be at 0.5–10‰. The X2 position was measured in km upstream from the Golden Gate Bridge. The data, along with further details and explanations, are *available online* (see footnote 10). See also Mac Nally et al. (2010: Table 2).

in subsequent covariate-conditioned change point models.

With all models (combinations of variables) equally probable a priori (prior $\Pr(k_j > 0) = 0.5$), posterior model probabilities reflect differences in marginal likelihoods, which intrinsically penalize model complexity (Kass and Raftery 1995, Beal et al. 2005). The amount of penalty depends on the prior distributions for model parameters (more diffuse priors favor fewer model parameters; George and Foster 2000), so posterior model probabilities, hence $\Pr(k_j > 0)$, can be sensitive to the choice of priors. We used a half-Cauchy prior (Gelman 2006) for the standard deviation σ_β of nonzero covariate effects, scaled so that ~90% of the resulting prior probability mass of each linear coefficient β_{jm} was in the interval (−1, 1) and 95% was in the interval (−2, 2). This prior placed most weight on more plausible coefficients (a linear coefficient of 1 equates to a 2.7-fold change in abundance for 1 SD change in the predictor) while still allowing larger effects ($e^2 = 7.4$-fold change in abundance per 1 SD change in predictor). We also fitted models with a range of alternative prior specifications and generally obtained similar results (Appendix). Any variables for which $\Pr(k_j > 0)$ values were sensitive to priors are identified in *Results*.

We fitted the variable selection model (Eq. 5) with and without the autocorrelation term ρn_{t-1} and with a conditional prior on $\rho[\rho \mid k_{Q+1} = 1 \sim \text{Normal}(0, \sigma_\beta^2); k_{Q+1} \sim \text{Bernoulli}(0.5)]$ testing for the importance of the autocorrelation term (i.e., treating n_{t-1} as a candidate predictor). $\Pr(k_j > 0)$ values for covariates were largely unaffected by the treatment of ρ, so we present results only for the models that treated n_{t-1} as a candidate predictor.

Covariate-conditioned change point model

We fitted change point models that accounted for the effects of covariates identified as probable predictors (those with $\Pr(k_j > 0) > 0.75$) to examine whether those covariates could account for changes detected by the trend model or detect other change points. The

TABLE 1. Extended.

Candidate	Definition
	autumn (Sep–Dec) midwater trawl, mean total catch (no. individuals) per trawl
	autumn (Sep–Dec) midwater trawl, mean total catch per trawl
	autumn (Sep–Dec) midwater trawl, mean age-0 catch per trawl
	autumn (Sep–Dec) midwater trawl, mean total catch per trawl
all	mean biomass of calanoid copepodites and adults during spring (Mar–May) in low-salinity zone
all	mean biomass of calanoid copepodites and adults during summer (Jun–Sep) in low-salinity zone
2, 3	mean biomass of mysid shrimp during Jun–Sep in low-salinity zone
1, 2, 3	mean catch per trawl of northern anchovy in the Bay Study midwater trawl (Jun–Sep) in low-salinity zone
4	mean biomass of other zooplankton (not including crab and barnacle larvae, cumaceans) during spring (Mar–May) in the freshwater zone (<0.5‰)
all	mean chl *a* (mg/m^3) during spring (Mar–May) in low-salinity zone
1, 2, 4	mean biomass of *Limnoithona* copepodites and adults during summer (Jun–Sep) in the low-salinity zone
all	mean catch per seine haul of inland silverside in the USFWS survey during Jul–Sep (for stations within the delta)
all	mean catch per seine haul of largemouth bass in the USFWS survey during Jul–Sep (for stations within the delta)
1, 2, 3	mean Mar–May position of the 2‰ isohaline (X2)
4	mean during Sep–Dec position of the 2‰ isohaline (X2)
all	mean Secchi depth (m) for the autumn midwater trawl survey
1, 2, 4	total volume of water (km^3) exported by the California State Water Project and Central Valley Project during Dec–Feb
all	total volume of water (km^3) exported by the California State Water Project and Central Valley Project during Mar–May
1	no. days for which mean temperature was between 15° and 20°C (range of water temperatures that best induce spawning by delta smelt [15°C] and limit larval survivorship [20°C]), mean of five continuous monitoring stations throughout Suisun Bay and the Sacramento–San Joaquin Delta
all	mean water temperature (°C), mean of five continuous monitoring stations throughout Suisun Bay and the Sacramento–San Joaquin Delta during Jun–Sep
2, 3	Dec–Feb
1, 2, 3	Jun–Sep
3	estimated striped bass egg supply, calculated as the sum of age-specific fecundity based on the population estimates generated by the California Department of Fish and Game (Kimmerer et al. 2000)

covariate-conditioned change point model with $q < Q$ covariates was

$$n_t \sim \text{Lognormal}\left(\alpha_t + \sum_{j=1}^{q}\sum_{m=1}^{k_j}\beta_{jm}(x_{jt} - \phi_{jm})_+ + \rho\log(n_{t-1}), \sigma_\text{p}^2\right). \quad (6)$$

In this model, k_j had minimum value = 1 and a prior distribution given by $k_j = 1 + \kappa_j$, where $\kappa_j \sim$ Binomial(3, 0.3), the first knot ϕ_{j1} was fixed at min(x_j), and remaining knots had continuous uniform priors. The autocorrelation term was included only if results of the variable selection model indicated that ρ probably was nonzero (i.e., when $\Pr(k_{Q+1} = 1) > 0.75$) (n.b., we confirmed that including ρ when $\Pr(k_{Q+1} = 1) < 0.75$ had no effect on other parameters in Eq. 6).

In Eq. 6, the covariate effects,

$$\sum_{j=1}^{q}\sum_{m=1}^{k_j}\beta_{jm}(x_{jt} - \phi_{jm})$$

replace the trend component $f_t(t)$ in Eq. 2. Including step change(s) in the intercept allowed for abrupt changes in abundance conditional on the covariates, that is, changes that would not be expected given the covariate values and estimated species–covariate relationships (Fig. 2C). If a step change in n_t was explained by a step change in the covariate, then the model intercept would remain constant (i.e., no change point; Fig. 2D).

Multispecies model

We searched for common change points among species by fitting covariate-conditioned change point models (Eq. 6) for all species simultaneously, with an additional step change submodel that was common to all species. In the multispecies model, the time-dependent intercept for species s, α_{st}, was modeled as

$$\alpha_{st} = \alpha_{s1} + \sum_{j=1}^{k_{s\alpha}}\chi_{sj}I(t \geq \delta_{sj}) + \sum_{l=1}^{k_{C\alpha}}\psi_l I(t \geq \zeta_l). \quad (7)$$

Here, $k_{C\alpha}$ is the number of step changes common to all four species, with magnitude and timing given by vectors $\boldsymbol{\psi}$ and $\boldsymbol{\zeta}$, respectively. The other parameters in Eq. 7 define species-specific change points as in Eq. 3, with subscript s in Eq. 7 denoting species-specific parameters. The full model for each species was identical in all other respects to Eq. 6.

The multispecies model identified any year(s) in which abundances of all species changed unexpectedly given the values of relevant covariates. We fitted the model once with prior distributions that allowed only common change points ($k_{s\alpha} = 0$, $k_{C\alpha} \sim$ Binomial(4, 0.5)) and once with prior distributions that allowed both common and species-specific change points ($k_{s\alpha} \sim$ Binomial(2, 0.5), $k_{C\alpha} \sim$ Binomial(2, 0.5)). We also examined combinations of fewer species to determine whether results of the four-species models were overly influenced by one species.

Implementation

All models were estimated using the reversible jump MCMC add-on (Lunn et al. 2006, 2008) for WinBUGS version 1.4 (Lunn et al. 2000) with three chains of 200 000 iterations each after 50 000 iteration burn-in periods. The MCMC mixing and convergence were established by inspection of chain histories, autocorrelation plots, and Brooks-Gelman-Rubin statistics. We used the cut() function in WinBUGS (Lunn et al. 2000) to prevent updating the prior distributions for missing values, which otherwise may be tuned to fit the model, leading to selection of covariates with many missing values as predictors. This treatment of missing values allowed all available data to be used in the analysis, rather than omitting years in which any covariate values were missing (Carrigan et al. 2007). We did not use imputation methods to estimate missing values because these methods assume values are missing at random, which generally was not the case (e.g., values for the first six years of surveys were missing for some variables).

WinBUGS code for all models is available in the Supplement.

Results

Overview of results relevant to recent declines

The trend models identified probable step or trend changes in the early 2000s for delta smelt (trend change 2000–2002; Fig. 3A), striped bass (step decline 2002; Fig. 4A), and threadfin shad (step decline 2002; Fig. 5A). Longfin smelt abundances also declined after 2000, but this decline was modeled as a continuation of a long-term declining trend that was interrupted by sudden increases in the late 1970s and mid-1990s (Fig. 6A).

The species-specific, covariate-conditioned change point models indicated step declines in abundances (i.e., abrupt declines that could not be modeled by the included covariates) of delta smelt and longfin smelt in 2004 (Figs. 3B and 6B) and of striped bass (Fig. 4B) and threadfin shad (Fig. 5B) in 2002.

In the multispecies change point models, there was strong evidence of a common change point in 2002, regardless of whether species-specific change points were allowed (Fig. 7). Evidence for step declines in abundance of delta smelt and longfin smelt in 2004 remained in the multispecies model that allowed species-specific change points (Fig. 7). Similar results were obtained from multispecies models fitted with any combination of three species, so the high probability of a common change point in 2002 is not driven by any single species.

To ensure that our variable selection criterion ($\Pr(k_j > 0) > 0.75$) had not excluded variables that could explain the post-2000 declines, we refitted covariate-conditioned change point models including all variables with $\Pr(k_j > 0) > 0.5$ (i.e., variables with some evidence of effects). We also fitted models with variables that had strong effects in a multivariate autoregressive (MAR) analysis of an expert-elicited model of this system (up to six variables per species; see Mac Nally et al. 2010 for details). With one possible exception (detailed in *Species-specific results: Striped bass* below), inclusion of additional variables had no substantive effects on posterior probabilities of post-2000 change points in single- or in multispecies models.

Water clarity emerged as a likely predictor of the abundance of delta smelt, longfin smelt, and striped bass, but the other variables with $\Pr(k_j > 0) > 0.75$ were unique to each species (Table 2). No species had more than two variables with $\Pr(k_j > 0) > 0.75$. All of the covariates with $\Pr(k_j > 0) > 0.75$ had monotonic effects, and most were modeled adequately by a single linear coefficient ($k_j = 1$).

The autocorrelation coefficient, ρ, had low probability of inclusion (low $\Pr(k_{Q+1} = 1)$), and was close to zero when included, for all species except striped bass (Figs. 3C, 4C, 5C, and 6C and Table 2). Low values of ρ may indicate that the mean abundance from September through December is poorly correlated with abundance of spawning adults in a given year.

Species-specific results

Delta smelt.—In the variable-selection model for delta smelt, water clarity and winter exports had high probability of inclusion ($\Pr(k_j > 0) > 0.75$; Fig. 3C). Both variables had negative effects (Table 2). The effect of winter exports was approximately linear, but marginal effects of water clarity were greatest at high values. The probability of inclusion for winter exports was sensitive to the prior distribution specified for linear coefficients. Priors that weighted large effect sizes (e.g., absolute linear coefficients > 0.5) more heavily yielded low $\Pr(k_j > 0)$ values for winter exports. This sensitivity indicates that the data support relatively small effects of winter exports ($|\beta| < 0.5$), but models with larger export coefficients fitted the data poorly. The estimated mean linear coefficient in the step change model ($\beta = -0.25$; Table 2) implies that an increase of one standard deviation in volume of winter exports ($= 0.62$ km^3) would be associated with a 22% decline (95% posterior interval = −45% to +9%) in abundance of delta smelt, assuming other factors were constant.

Evidence for change points in the periods 1981–1983 and 2000–2002 was weaker in the covariate-conditioned

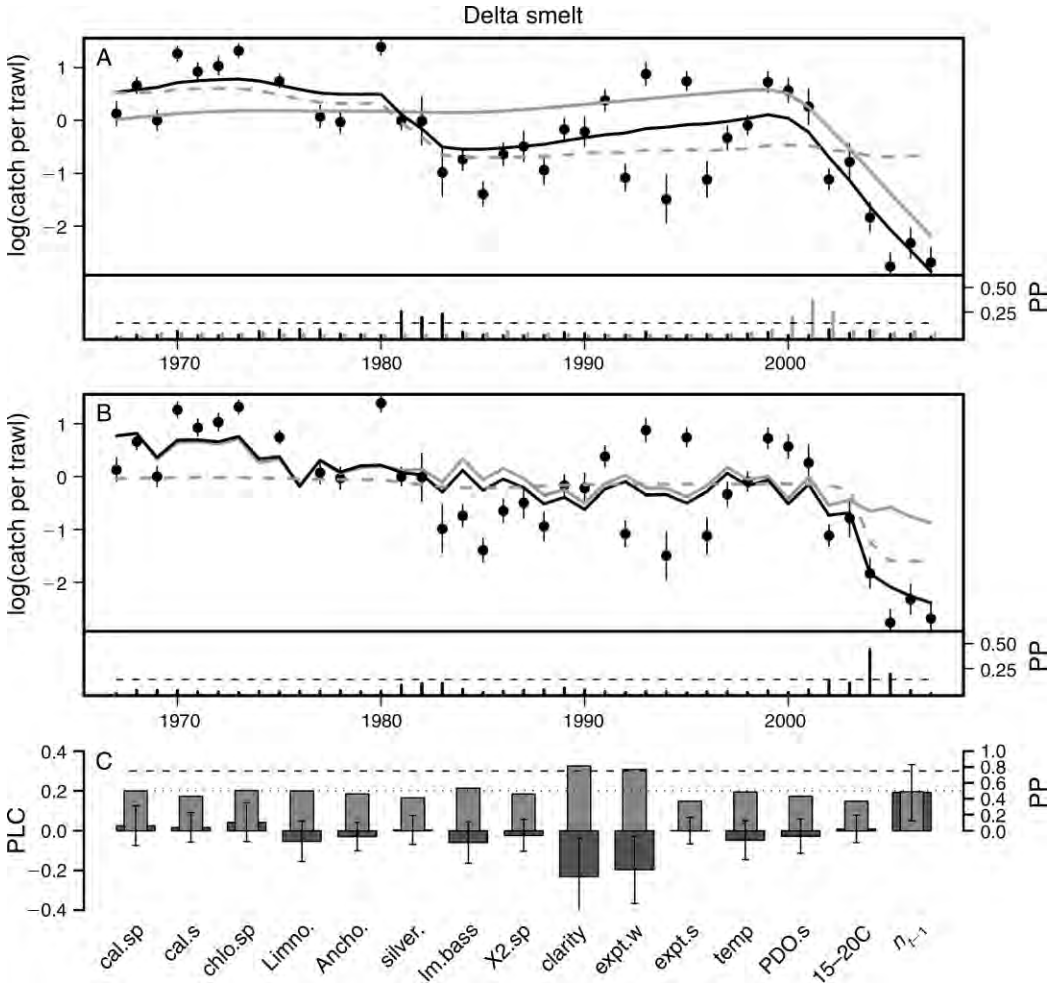

FIG. 3. (A) Results of the trend model (Eq. 2) for delta smelt. The fitted trend is shown as a black line, and observed values [log(catch per autumn trawl), mean ± SE] are shown as data points. Intercept (α_t) values are shown as dashed gray lines, and the trend component [$f_t(t)$] is shown as a solid gray line. The lower panel shows posterior probabilities (PP) of step changes (black) or trend changes (gray) in each year for the trend model (Eq. 2). (B) Results of the covariate-conditioned change point model (Eq. 6) for delta smelt. Fitted values are shown as a black line, the intercept (α_t) as a dashed gray line, and the covariate component [f(water clarity) + f(winter exports), where $f(\,)$ is a linear spline] as a solid gray line. The posterior probabilities of step changes (abrupt changes unexplained by covariates) for each year are shown in the lower panel. (C) Results of the covariate selection model (Eq. 5) for delta smelt. Posterior probabilities of variable inclusion (light gray bars, right axis) and posterior mean (±SE) linear coefficients (PLC; dark gray bars, left axis) are shown for each candidate predictor. The variable n_{t-1} is the previous year's abundance; see Table 1 for explanations of other covariate abbreviations. Mean linear coefficients were calculated as the mean slope of the fitted linear-spline model over the data range. In all panels, the horizontal dashed lines show posterior probabilities corresponding to odds ratios of 3 (0.14 for change points, 0.75 for variable inclusion), which we consider substantial evidence for a change point occurring in a year (panels A and B) or for a variable having an effect on abundance (panel C). In panel (C) the prior probability of inclusion (0.5) is shown as a dotted line.

model (Fig. 3B) than in the trend model (Fig. 3A), suggesting that those declines in abundance may have been associated with combined effects of increasing water clarity and high winter exports (Fig. 8). However, there was evidence of an unexplained decline in 2004 in the single-species model (Fig. 3B) and of unexplained declines in 2002 and 2004 in the multispecies model (Fig. 7). The mean effect of winter exports was slightly less negative in the multispecies model than in the single-species model (Table 2) because the multispecies model assigned more weight to an unexplained step decline in 2002, reducing the estimated effect of high winter exports in that year.

Longfin smelt.—In the variable-selection model for longfin smelt, water clarity and spring X2 had high probability of inclusion ($\Pr(k_j > 0) > 0.75$). Both variables had negative effects that were approximately linear (Fig. 6C, Table 2).

The change point model conditioned on spring X2 and water clarity indicated unexpected declines in

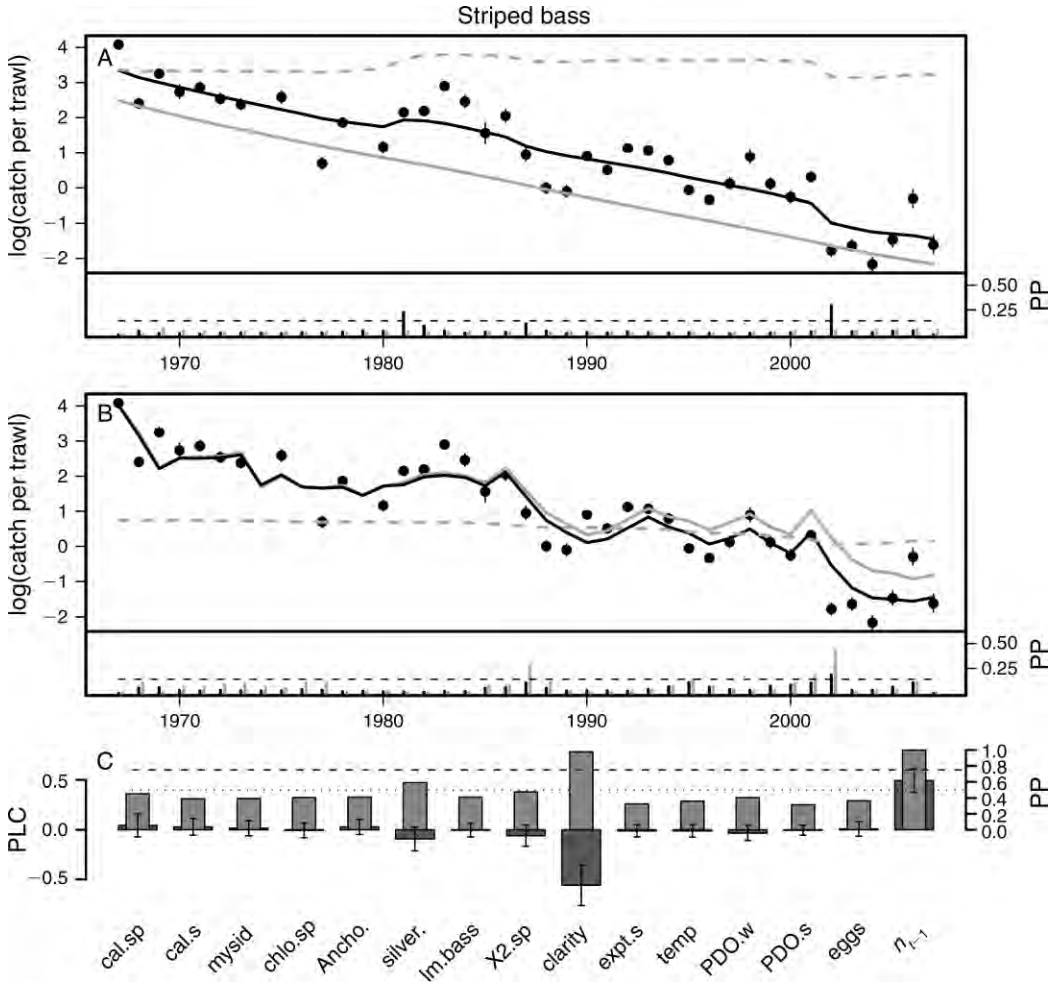

FIG. 4. Results of the models for striped bass. Panel details are as in Fig. 3. In panel (B), the covariate component (solid gray line) represents f(water clarity) + $\rho \log(n_{t-1})$. The gray bars in panel (B) show the posterior probabilities of change points in each year if $\rho = 0$; $\rho \log(n_{t-1})$ is the temporal autocorrelation term in Eq. 6 (see *Statistical analyses: Covariate-conditioned change point model*).

abundance from 1989 to 1991 and in 2004 (Fig. 6B). The sharp increases in longfin smelt abundance in 1978 and 1995, identified as step increases in the trend model, were modeled as responses to sharp declines in X2 (increases in outflow; Fig. 8) in the covariate-conditioned change point model. The estimated relationship between water clarity and longfin smelt abundance was weaker in the single-species change point model than in the multispecies change point model (Table 2). This disparity relates mainly to differences in the way the models explained abundance from 1988 through 1992. A sharp decline in longfin abundance in that period was largely modeled as an unexplained step decline in the single-species model, but, when species-specific change points were given lower prior probability in the multispecies model, that decline was partially attributed to increasing water clarity (Fig. 8). If change points were omitted, as in the variable-selection model, the water clarity effect was very strong. These results suggest that the relationship between longfin smelt abundance and water clarity, after accounting for a strong effect of spring X2, generally was weak throughout the time series and that the strong relationship identified in the variable-selection model was driven largely by data for the period 1988–1992.

Striped bass (age-0).—In the variable-selection model for striped bass, water clarity and the autocorrelation term had $\Pr(k_j > 0) > 0.75$. Water clarity had an approximately linear negative effect (Table 2).

Evidence for a step decline in striped bass abundance in 2002 was lower in the covariate-conditioned change point model (Fig. 4B) than in the trend model (Fig. 4A) and was lower still (odds ratio < 3) in a model that included the biomass of inland silverside (*Menidia beryllina*; $\Pr(k_j > 0) = 0.59$; Fig. 4C). These results suggest that high water clarity (Fig. 8) or biomass of inland silverside could have contributed to the 2002 step decline in striped bass abundance. However, the

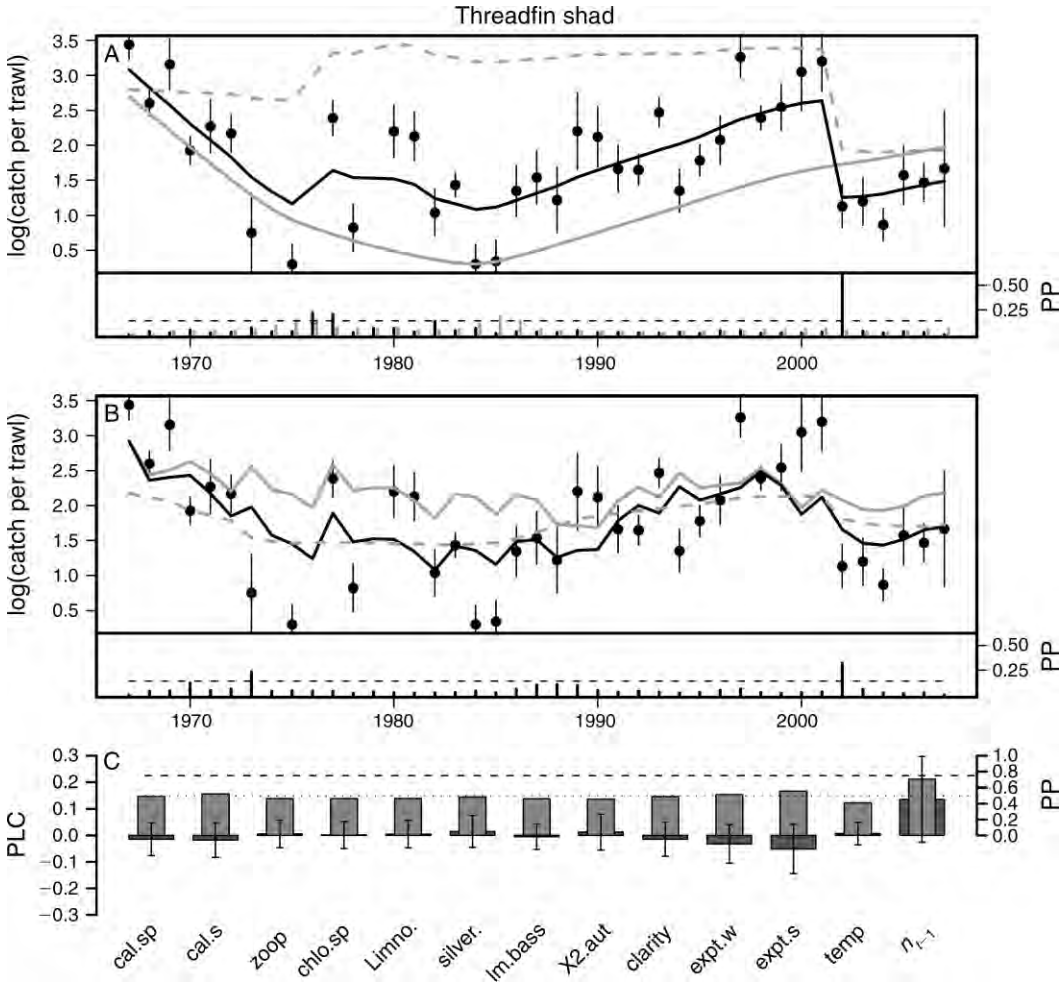

FIG. 5. Results of the models for threadfin shad. Panel details are as in Fig. 3. In panel (B), the covariate component (solid gray line) represents f(winter exports) + f(spring exports), and the dashed gray line represents the time-dependent intercept α_t plus a nonlinear trend $f(t)$.

presence of partial autocorrelation ($0 < \rho < 1$) complicated change point detection in these log-linear models because the interpretation of α, and hence appropriate prior distributions for change points, depends on ρ (see Appendix). When autocorrelation was omitted from covariate-conditioned, change point models for striped bass, regardless of the inclusion of inland silverside biomass, the posterior probability of a step change in 2002 was >0.4 (Fig. 4B).

In all covariate-conditioned models for striped bass, relatively low water clarity in 1981 accounted for the apparent step increase in abundance in that year (Fig. 4A vs. Figs. 4B and 7).

Threadfin shad.—No variables had high probability of inclusion in the threadfin shad variable selection model. The highest-ranked variables, other than the autocorrelation term, were biomass of summer calanoids in the low-salinity zone and winter and spring export volumes, which each had posterior probability of inclusion marginally higher than the prior probability (Fig. 5C), indicating only weak evidence of effects. However, probabilities of inclusion for winter and spring exports were sensitive to the prior distribution for the linear coefficients, and priors that put more weight on smaller coefficients yielded $\Pr(k_j > 0) > 0.75$ for both variables; no other variables showed this level of sensitivity to priors. Therefore, we included winter and spring exports in covariate-conditioned change point models for threadfin shad. We also included time as a covariate in the single-species model for threadfin shad because the model with export volumes alone fit too poorly ($R^2 = 0.33$) to make meaningful inferences about change points (i.e., unusual departures from "expected" abundance given covariate values).

The estimated relationship between log(abundance) of threadfin shad and spring exports was similar in form and magnitude to the relationship between log(abundance) of delta smelt and winter exports (Table 2) and was consistent among single- and multispecies models with and without time included as a covariate. An

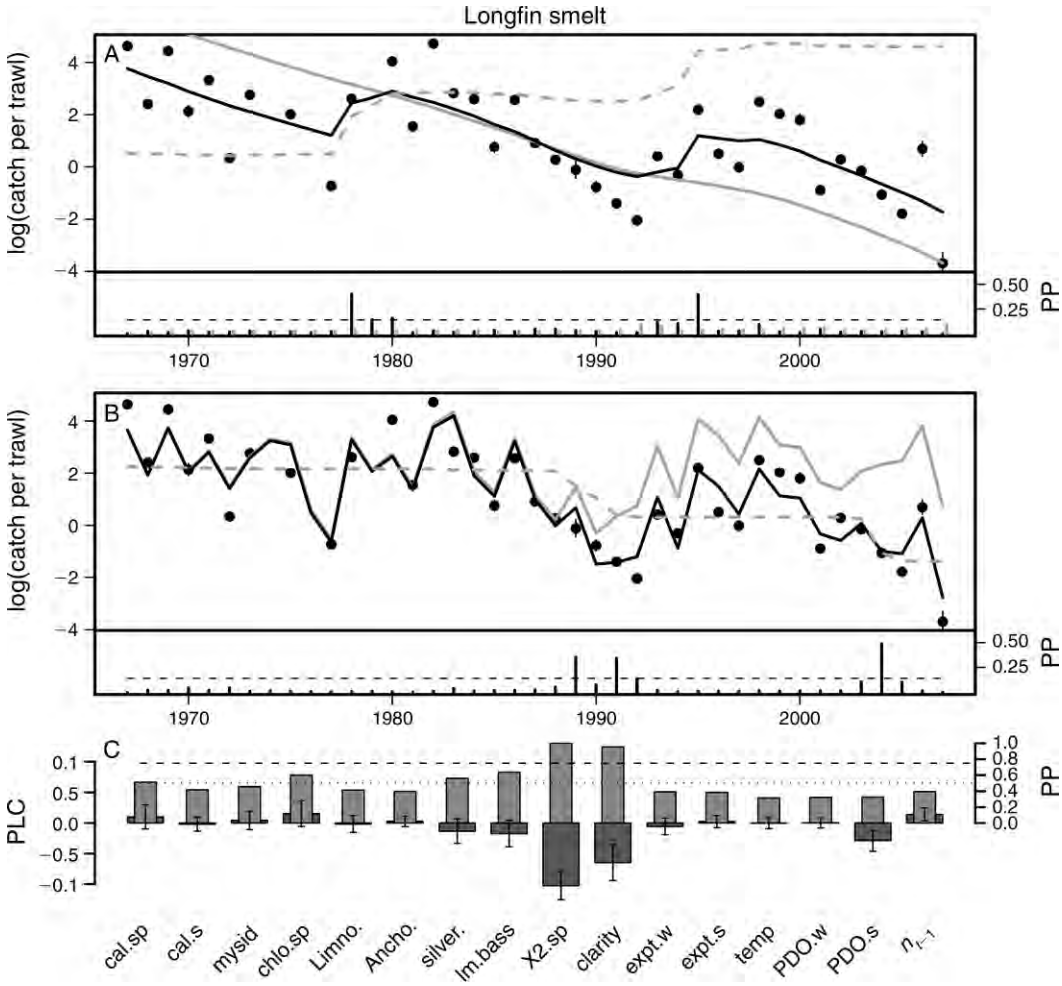

FIG. 6. Results of the models for longfin smelt. Panel details are as in Fig. 3. In panel (B), the covariate component (solid gray line) represents f(water clarity) + f(spring X2), but f(water clarity) was near zero, and including only f(spring X2) results in essentially the same figure as this.

apparent step increase in threadfin shad abundance in 1977 (Fig. 5A) was modeled as a response to low spring exports in that year (Fig. 8) in the covariate-conditioned models (note near-zero change point probabilities for 1977 in Figs. 5B and 7). The estimated relationship between winter exports and threadfin was weak in all models (Table 2), especially in the multispecies model that weighted 2002 step changes more heavily. The inclusion of summer calanoid biomass and an autoregressive term (both variables had $0.5 < \Pr(k > 0) < 0.75$) had no effect on posterior probabilities of change points for threadfin shad (estimated coefficients were close to zero in both cases).

DISCUSSION

Different model structures, particularly models for individual species compared with multiple species, yielded somewhat different sets of the more likely change points, but all models indicated sharp declines in abundance of delta smelt, longfin smelt, threadfin shad, and striped bass in the early 2000s. Post-2000 change points were evident in all covariate-conditioned models for all species, indicating that the covariates identified as the strongest predictors of abundance could not explain fully the recent declines. However, there was some evidence that increasing water clarity, winter exports, and spring X2 may have contributed to post-2000 declines in abundance of some species.

Inferences about declines in abundance after 2000 depend partially on whether species were considered jointly or separately. When delta smelt and longfin smelt were modeled individually, the best-supported models largely associated the 2002 decline in abundance of delta smelt with high winter exports and the 2001 decline in abundance of longfin smelt with spring X2. In these models, sharp, unexplained declines in abundance did not occur until 2004. However, in the multispecies model all four species experienced unexplained declines in 2002, and the estimated effects of winter exports and spring X2 on delta smelt and longfin smelt, respectively,

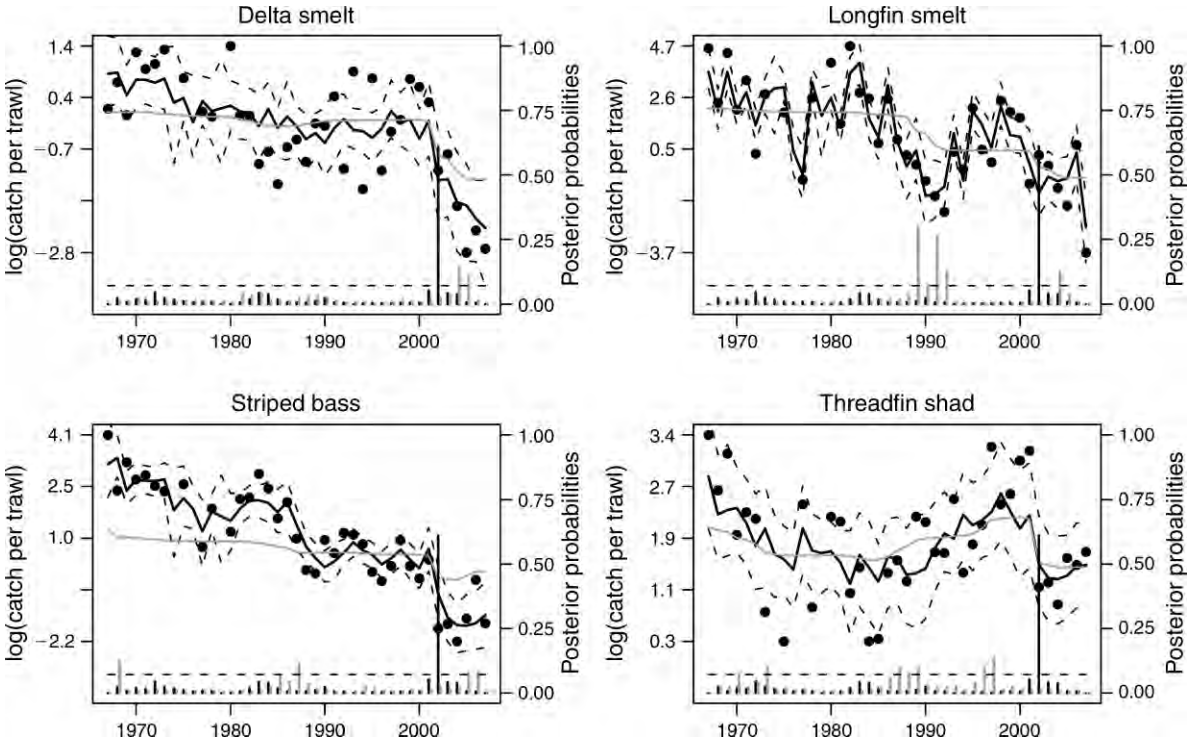

FIG. 7. Abundance [log(catch per trawl)] with fitted values (solid black lines; dashed lines are 95% credible intervals) and intercept parameters (gray solid lines) for delta smelt, longfin smelt, striped bass, and threadfin shad in the multispecies change point model. Intercept parameter = species-specific intercept plus common change point parameter. Bars show posterior probabilities (right axis) of common (black) and species-specific (gray) change points in each year.

were moderately reduced (Table 2). A similar reduction in the estimated effect of winter exports in the multispecies model was observed for threadfin shad. The increased probability of unexplained declines in 2002 and reduced covariate effects in the multispecies model, relative to the single-species models, reflect differences in the amounts of data (evidence) used to fit the different models. Combining data from all species in the multispecies model strengthened the evidence for an unexplained (by the covariates considered) step decline in 2002 for all species and led to a corresponding reduction in the estimated influence of variables that, in single-species models, might have explained 2002 declines for individual species. These results are consistent with a hypothesis that simultaneous, abrupt declines in abundances of multiple species are more likely to have been caused by a common but unknown factor than by different factors for each species (e.g., winter exports for delta smelt and threadfin shad, spring X2 for longfin smelt, another unknown factor for striped bass).

The covariate-conditioned models indicated step declines in abundance of age-0 striped bass in 1987 (evident in a model without autocorrelation) and step declines of longfin smelt in 1989–1991. These declines may be related to the effects of the introduced (ca. 1987) clam *Corbula amurensis*, which caused an ongoing decrease of ~60% in chlorophyll *a* concentration in the estuarine low-salinity zone (Alpine and Cloern 1992). There were concurrent declines in abundance of mysids and some species of copepods upon which striped bass and longfin smelt prey (Kimmerer and Orsi 1996, Orsi and Mecum 1996, Kimmerer 2006). These changes in prey abundance were evident in the diets of striped bass and other fish species (Feyrer et al. 2003). Although variable-selection models did not identify prey variables as strong predictors of fish abundances at the whole-estuary scale of this analysis, summer calanoids and mysid biomass were positively correlated with abundances of striped bass and longfin smelt (calanoids only) in a MAR model of this system (see Mac Nally et al. 2010). When those prey variables were included in covariate-conditioned models for striped bass, evidence for an unexplained step decline in 1987 was reduced greatly (to odds ratio <3), supporting the prey-availability hypothesis. Conversely, the inclusion of prey biomass did not alter substantially evidence for step declines in 1989 and 1991 in longfin smelt abundance.

Covariate relationships and previous analyses

The covariates we identified as strongly associated with pelagic fish abundance, namely X2, water clarity, and export flows, previously have been hypothesized to affect abundance. Jassby et al. (1995) and Kimmerer (2002) identified a relationship between abundances of

TABLE 2. Summary of covariate effects in models of annual abundance of four species of pelagic fishes in the San Francisco Estuary.

Covariate	Pr	Single-species model: Mean slope (SD)	Single-species model: 95% CI	R^2
Delta smelt				0.65
Water clarity	0.81	−0.24 (0.29)	(−0.85, 0.29)	
Winter exports	0.77	−0.25 (0.18)	(−0.60, 0.09)	
Longfin smelt				0.88
Spring X2	1.00	−1.25 (0.18)	(−1.61, −0.88)	
Water clarity	0.96	−0.15 (0.43)	(−1.05, 0.58)	
Striped bass				0.88
Water clarity	0.99	−0.59 (0.24)	(−1.04, −0.06)	
ρ	0.98	0.38 (0.17)	(0.05, 0.69)	
Threadfin shad				0.45
Winter exports	0.51†	−0.14 (0.19)	(−0.52, 0.25)	
Spring exports	0.59†	−0.22 (0.14)	(−0.50, 0.06)	

Notes: We used a variable selection model (Eq. 5) to select covariates and included the covariates in subsequent models if their posterior probability of inclusion (Pr) exceeded 0.75 (see Figs. 3, 4, 5, and 6 for corresponding values for all variables). Mean slope is the posterior mean of the average linear slope over the full range of covariate values in a piecewise linear spline model with up to three knots (changes in slope). All fitted splines were monotonic, and departures from linearity generally were moderate and are described in the "functional response" column. Estimated covariate effects are conditional on the variable being a predictor but incorporate uncertainties about the number and timing of change points. R^2 shows the relative fits of the posterior medians of the fitted values (n_t's in Eq. 6) to the observed log abundance data. Corresponding R^2 values for trend models were: delta smelt, 0.74; longfin smelt, 0.69; striped bass, 0.85; threadfin shad, 0.69. Covariate ρ is the autocorrelation coefficient in Eq. 6.

† Winter and spring exports were included in models for threadfin shad because probabilities of inclusion were sensitive to prior distributions on linear coefficients. Probabilities exceeded 0.75 under certain more restrictive prior distributions (see *Results: Species-specific results* and Appendix).

several species of estuarine-dependent nekton and freshwater flow indexed as spring X2. An association between abundance of striped bass and X2 has been identified before, but the relationship with X2 was weaker than for longfin smelt and the relationship was affected by other factors (Jassby et al. 1995, Kimmerer 2002, Kimmerer et al. 2009). In these previous studies, X2 did not strongly affect the autumn abundance of delta smelt or threadfin shad. These results are consistent with our result that only longfin smelt had a strong (and negative) relationship with spring X2 (Table 2).

The association between water clarity and abundance that we identified also is consistent with previous analyses. Water clarity can affect composition of fish assemblages in large river and estuarine systems (Blaber and Blaber 1980, Quist et al. 2004) and can mediate predator–prey interactions (Abrahams and Kattenfeld 1997, Gregory and Levings 1998). Water clarity (measured by Secchi disc depth) has been related to distributions of several species of fish in the San Francisco Estuary. Delta smelt and striped bass, but not threadfin shad, were most likely to occur where water was turbid during autumn (Feyrer et al. 2007). Secchi depth also explained some of the variation in distribution of delta smelt in summer (Nobriga et al. 2008). Adding Secchi depth to nonlinear models of distribution based on salinity improved fits substantially for delta smelt, striped bass, and longfin smelt (Kimmerer et al. 2009). These effects of water clarity on distributions may translate to effects on abundance to the extent that the fish populations are limited by the availability of habitat. Laboratory experiments and observations suggest that young delta smelt cannot feed effectively unless particles are suspended in the water column (Baskerville-Bridges et al. 2004, Mager et al. 2004).

Export flows in winter and spring were negatively associated with abundance of delta smelt and threadfin shad, respectively, in our models. Previous analyses indicated that export flows can remove a substantial fraction of the delta smelt population in both winter and spring of dry years (Kimmerer 2008). Although previous analyses reported an effect of export flows on the abundance of young striped bass (Stevens et al. 1985), this effect was negligible if egg supply was taken into account (Kimmerer et al. 2001). Threadfin shad has been abundant relative to other species in freshwater zones of the Delta since monitoring began (1967). However, the proportional loss of the threadfin shad population to export operations has not been determined. Of the four species we examined, only threadfin shad occupies the freshwater portion of the Delta for its entire life cycle. The other three species move into brackish water during summer and autumn. Given that water diversions only export freshwater, threadfin shad may have been especially vulnerable to exports throughout the year.

TABLE 2. Extended.

Multispecies model			
Mean slope (SD)	95% CI	R^2	Functional response
		0.63	
−0.24 (0.26)	(−0.74, 0.30)		single-species model: weak at values >2 SD from mean, multispecies model: stronger at values > 1 SD
−0.22 (0.17)	(−0.55, 0.11)		weaker at values < −1 SD
		0.85	
−1.20 (0.18)	(−1.55, −0.83)		stronger at values > mean
−0.27 (0.41)	(−1.14, 0.48)		stronger at values > 1 SD
		0.89	
−0.57 (0.27)	(−1.06, −0.03)		linear
0.40 (0.13)	(0.11, 0.66)		
		0.46	
−0.10 (0.18)	(−0.45, 0.28)		single-species model: weak at values < mean, multispecies model: linear
−0.23 (0.14)	(−0.48, 0.03)		single-species model: weaker at values < −1.5 SD, multispecies model: linear

The variable-selection results suggest that, at the estuary scale, abiotic factors (water clarity, X2, exports) may have more influence on interannual variation in abundances of the four species than do biotic variables. This result is consistent with a MAR analysis of an expert-elicited model of this system that included species interactions among several trophic groups as well as abiotic covariates (Mac Nally et al. 2010). In the MAR analysis, abiotic variables explained 50% more variation than did trophic interactions. Trophic interactions were still important (Mac Nally et al. 2010), but the strongest effects generally were "top-down," with fish apparently having more influence on prey biomass than vice versa. These results suggest that targeted manipulation of abiotic variables such as water clarity, freshwater flow, and water exports could be used to influence fish abundances in this system, but greater understanding of the interactions between abiotic variables and trophic interactions is required before scientifically robust management alternatives can be formulated. Identification of the factor(s) that caused the post-2000 declines remains an important challenge; attempts to reverse declines are unlikely to succeed unless the main drivers of those declines are understood.

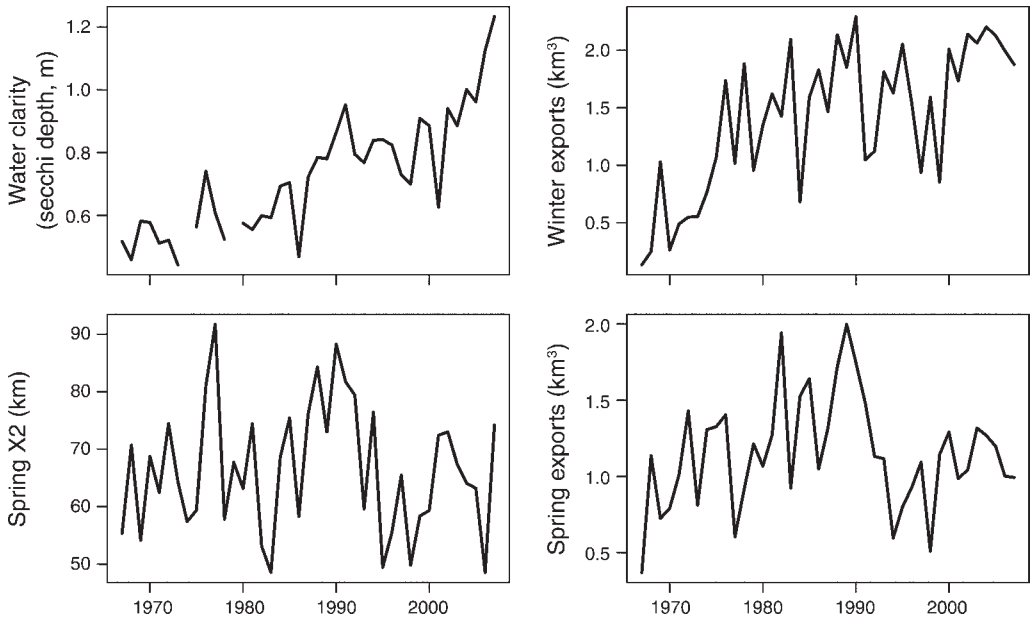

FIG. 8. Trends in covariates used in covariate-conditioned change point models. See Table 1 for explanations of covariates.

Our results confirm that the four species of pelagic fish experienced abrupt declines around 2002 and suggest that all potential drivers not considered in our analyses warrant further investigation.

Strengths of hierarchical Bayesian modeling

The hierarchical Bayesian modeling approach has several advantages over other approaches, such as multiple regression models (Cressie et al. 2009). The hierarchical structure allows sampling or measurement error to be separated from actual variation in underlying abundances, which can improve estimation of the underlying biological processes (Clark 2005). Hierarchical Bayesian models allow considerable flexibility in modeling of biological processes, so a wide variety of process models can be formulated and fitted within a common framework. The availability of public domain software such as WinBUGS, combined with an add-on developed by Lunn et al. (2006) for reversible jump MCMC (Green 1995), makes it increasingly feasible to fit and compare complex hierarchical models within a consistent estimation framework. We examined nonparametric trend models with change points for step and trend changes (Eq. 2), nonlinear variable selection models (Eq. 5), nonlinear covariate models with step changes (Eq. 6), and multiple-response models (Eq. 7), which all included temporal autocorrelation as appropriate. Within each of these general model classes were large sets of special cases that differed with respect to the particular change points and covariate effects included. Many models of a given class were compared or combined for inference on the basis of marginal likelihoods, which inherently penalize model complexity. For example, the capacity to treat the number and location of "knots" (i.e., change points) in linear splines as unknown parameters allowed the relative evidence for change points in specific years to be evaluated by formal comparison of a very large number of possible models (all possible combinations of up to four change points per parameter) while simultaneously estimating other parameters of interest (e.g., covariate effects) and accounting for data uncertainties (e.g., observation errors and missing covariate values).

Future work

Three areas of future research could help reduce uncertainty about drivers of abundance of pelagic fishes in the San Francisco Estuary. One is to pursue, in greater depth, simultaneous modeling of multiple species and interactions among species and covariates. The multiple-species change point models did not consider interactions among the four species of interest (but see Mac Nally et al. 2010), and interactions among covariates were not investigated. Some preliminary work (J. R. Thomson, *unpublished data*) fitting Bayesian additive regression trees (BART; Chipman et al. 2008) included interactions among covariates, but initial results did not yield substantial improvements in fits, and the post-2000 declines were not modeled adequately.

Another area of future work that may clarify mechanisms is to fit process models that include multiple life history stages of the fish species using data available from surveys that complement data from autumn midwater trawl surveys used here. For example, adult delta smelt are sampled from January through April throughout the estuary with a Kodiak trawl (a surface-oriented trawl), and small juveniles are sampled from March through July in the "20-mm survey" (Dege and Brown 2004). In summer, juvenile delta smelt are sampled with tow net surveys. A life history model that linked the abundances of each life stage would provide a more continuous picture of the delta smelt population and would capitalize more fully on available data. The approach to change point identification used here could be applied to any parameter(s) of interest (e.g., population growth parameters) within almost any model structure (Lunn et al. 2006), which may allow identification of important changes in key processes.

A third potential means to elucidate drivers of abundance is to carry out formal statistical comparisons of some of the models formulated by Sommer et al. (2007) and Baxter et al. (2008) to explain declining abundances of pelagic fishes in the San Francisco Estuary. These authors considered many hypotheses for declines in abundance, including changes in stock–recruitment relationships and food webs, mortality from predation and water diversions, contaminants, and changes in the physical environment. Multispecies models with explicit life history submodels could be used to compare the relative likelihood of these alternative hypotheses conditional on the available data. Formal model selection procedures, such as reversible jump MCMC (Green 1995), could be used to estimate posterior probabilities for the models corresponding to different hypotheses.

It is possible, however, that the change points were caused by variables that have not been measured or have not been measured long enough to provide data useful in statistical analyses. For example, of the potentially contributing variables listed by Sommer et al. (2007; Fig. 6), only a few could be included in the models. The effects of toxic algae, for example, have only recently been measured and may have increased. Contaminants are too numerous and dispersed, and effects too sporadic and subtle, for any monitoring program to provide useful information for correlative analyses. Thus, these effects must be investigated through more detailed, mechanistic studies.

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APPENDIX

Details of prior distributions used in change point and associated regression models (*Ecological Archives* A020-051-A1).

SUPPLEMENT

WinBUGS and R code to fit change point and variable selection models (*Ecological Archives* A020-051-S1).

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An Investigation of Factors Affecting the Decline of Delta Smelt (*Hypomesus transpacificus*) in the Sacramento-San Joaquin Estuary

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The delta smelt is an annual fish that is endemic to the Sacramento-San Joaquin Estuary and is protected under federal and California Endangered Species Acts. Record low abundances have occurred since 2004. Three questions are addressed here: What is the relative importance of environmental factors with direct effects on abundance? Do factors that may have indirect effects provide an explanation of abundance changes? Are effects of environmental factors better accounted for individually or as criteria defining the volume of water with suitable abiotic attributes? Strong evidence was found of density-dependent population regulation. The density of prey was the most important environmental factor explaining variations in delta smelt abundance from 1972 to 2006 and over the recent period of decline in the abundance of the fish. Predation and water temperature showed possible effects. Entrainment of delta smelt at south Delta pumping plants showed statistically significant effects on adult-to-juvenile survival but not over the fish's life cycle. Neither the volume of water with suitable abiotic attributes nor other factors with indirect effects, including the location of the 2 ppt isohaline in the Delta in the previous fall ("fall X2"), explained delta smelt population trends beyond those accounted for by prey density.

[Supplementary materials are available for this article. Go to the publisher's online edition of *Reviews in Fisheries Science* for the following free supplemental resources: information on factor selection and specification; and estimating the volume of abiotic habitat.]

Keywords delta smelt, life-cycle model, multiple regression, effects hierarchy, pelagic organism decline

INTRODUCTION

It is a terrible juxtaposition of superlatives for the delta smelt. No other species currently protected under the federal Endangered Species Act has declined so dramatically since its listing. The index of abundance of delta smelt in the Sacramento-San Joaquin Delta has fallen almost three orders of magnitude since the fish was afforded protection in 1993 (California Department of Fish and Game [CDFG], 2010a). The need for immediate conservation responses is acute, but that need confronts another unfortunate delta smelt reality—perhaps less is known about the habitat of delta smelt, resources essential to its persistence, and the environmental stressors causing its low population numbers than is known about any other listed species. The life cycle of the tiny estuarine fish takes place in turbid, open waters, making it impossible to observe its behavior and

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account for many of its vital ecological relationships. Several candidate factors have plausible mechanisms of effect on delta smelt numbers, but previous attempts to relate environmental stressors to the decline of this fish were not able to identify the factors responsible for the recent declines in the abundance index to near-extinction levels. It might be fairly argued that no other federally listed species needs more immediate conservation attention, but a lack of reliable scientific guidance has hampered focused actions in support of delta smelt recovery.

The delta smelt is predominantly an annual species, with few individuals surviving to two years (Bennett, 2005). They are endemic to the San Francisco Bay-Delta Estuary. Delta smelt rear as juveniles and sub-adults upstream and downstream of the confluence of the Sacramento and San Joaquin Rivers for about seven months of the year, from late spring until the following winter (Bennett, 2005). Moyle (2002) described delta smelt as fish that "hang out in the water column and rely on their small size and transparency to hide them from predators in turbid water" (p. 228). Some delta smelt reside upstream in low salinity and fresh waters year around (Sommer et al., 2009). In winter, adults disperse into turbid waters that are necessary for efficient feeding of larvae on zooplankton (Baskerville-Bridges et al., 2004; Mager et al., 2004), with much of the population entering the Sacramento-San Joaquin Delta (Moyle, 2002). Spawning, triggered by increasing water temperature, begins as early as late February and can continue into June (Bennett, 2005). The environmental changes that have accompanied settlement and exploitation of the Delta have forced major adjustments in resources and conditions essential to survival and persistence of delta smelt.

No field data have been derived from experiments that directly relate delta smelt population responses to variation in physical and biotic conditions; however, general agreement exists both on the environmental features that seem to determine the location of delta smelt in the estuary and on stressors that could be contributing to decline of the fish. A conceptual model that describes and relates essential resources and suspected threat factors affecting population dynamics of delta smelt and other declining pelagic organisms in the Delta was developed by a multi-agency working group (Armor et al., 2005; Baxter et al., 2008; Baxter, 2010); however, no quantitative model has been available. Several recent studies have attempted to relate delta smelt population index data to suspected environmental stressors, but those studies had deficiencies that rendered their results uninformative (Feyrer et al., 2007; Mac Nally et al., 2010; Thomson et al., 2010).

Relating delta smelt population trends to changes in environmental factors that affect survival and reproduction of the fish, both directly (for example, predation, food supply, and entrainment) and indirectly (for example, flow and phytoplankton density), risks producing uninformative or confusing results. To maximize the likelihood of identifying actual causative relationships, the analysis presented here is initiated by developing an effects hierarchy that differentiates between those environmental covariates that act directly on the survival, reproduction, or recruitment of the delta smelt and those that act indirectly through one or more factors that act directly. This article focuses primarily on environmental factors with direct effects on survival or reproduction, leaving a rigorous attempt to identify indirect factors with important effects on direct factors for subsequent analyses (see Glibert et al., 2011, for example). This approach has three advantages. First, focusing on the limited number of variables with direct effects on delta smelt reduces the confounding effects of multi-collinearity and differential measurement error. When candidate causation factors are related to or interact with one another, the factor with lower measurement error may displace factors that have greater measurement error, even when those latter factors can be demonstrated to have greater effects signals (Zidek et al., 1996). Second, it reduces the possibility that identification of important environmental factors will be uninformative to decisions about resource management. This problem can arise if a factor with indirect effects is identified as itself important, but that factor acts through other factors that have direct or indirect effects. The best management response may involve controlling, or otherwise mitigating, not the environmental factor with an indirect effect identified as important, but rather, other factors. Third, arrangement of factors according to their hierarchy of effects provides information important in choosing the analytical method. Because pathways of effects can be delineated from knowledge of the mechanisms of ecological effects, a straightforward succession of multiple regression analyses, proceeding down each vertical path of the hierarchy, is suggested as the appropriate analytical approach to identifying the factors that best predict delta smelt population dynamics.

Several analysts have previously used measures of the volume of water with suitable attributes of conductivity, Secchi depth (as a measure of turbidity), and water temperature, which have been termed "abiotic habitat," to account for changes in abundance of delta smelt (e.g., Feyrer et al., 2007). In a subsequent biological opinion on delta smelt developed by the U.S. Fish and Wildlife Service (USFWS), inferences from those analyses were used to assert that a range of suitability in the extent of those abiotic factors limits abundance of delta smelt, and that increasing that extent is important to the recovery of delta smelt (USFWS, 2008). The hypothesis was tested that the volume of water within ranges of conductivity, Secchi depth, and water temperature at which most delta smelt occur explained variations in survival and reproduction. Several measures of that volume were developed and their effects on survival and reproduction were analyzed.

Index values for relative abundance of delta smelt were derived from standard trawler-generated data, specifically, the Fall Midwater Trawl (FMWT; CDFG, 2010a) and the Summer Townet Survey (STN; CDFG, 2010b). From relative abundance estimates, annual estimates of survival from juvenile to sub-adult life stages were developed, as well as survival and reproduction (hereinafter, referred to as "survival") across generations from sub-adult to juvenile life stages. Those estimates

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were used as response variables. Annual values for a variety of environmental variables were then developed, each of which could plausibly affect delta smelt population size and persistence. In doing so, the resource requirements and distribution of delta smelt at different sizes and in different stages in their life cycle were considered. From those candidate factors, a limited number were selected that offer the most plausible mechanism(s) of direct effect on delta smelt survival and abundance. In so doing, well-considered direct factors were differentiated from factors that may indirectly affect the size of and trend in delta smelt numbers through their effects on direct factors. From the abiotic and biotic factors in the Delta that appear to have direct effects on delta smelt, those that may be most important were selected, based on inferences drawn from available data and analyses. Multiple regression was used with three criteria to identify environmental factors that may be most important to survival and to evaluate the relative importance of those factors: goodness of fit of equations measured by the Akaike Information Criterion (AICc), the proportion of variation accounted for, and the significance of the regression coefficients. Using this general method, analyses were conducted to address three fundamental questions with important management implications: What is the relative importance of environmental factors that have direct effects on delta smelt abundance? Do environmental factors with indirect effects further explain abundance changes once effects of factors with direct effect are accounted for? Are the effects of environmental factors best accounted for independently or as criteria by which the volume of water with suitable attributes can be measured?

Based on the availability of data, these questions were directed at three periods in the annual life cycle of delta smelt—sub-adult (fall) to juvenile (summer), juvenile (summer) to sub-adult (fall), and sub-adult (fall) to sub-adult (fall). Because delta smelt has an annual life cycle, the last period is one version of a life-cycle model. Such a model has been identified as critically important in the development of a program to encourage recovery of delta smelt and to prevent jeopardizing its existence (Wanger, 2010). Analysis of the two within-year periods was carried out to better understand the factors that affect delta smelt survival between intermediate life stages during the year.

METHODS

Period of Analysis

The period of analysis covered the years 1972 through 2006. The initial year was selected because it was the first year of comprehensive surveys for zooplankton density throughout regions of the estuary occupied by delta smelt. The year 2006 was chosen because at the time this analysis began, comprehensive environmental data were only available through that year, and the period 2000 to 2006 includes the sharp decline in abundance of delta smelt that has persisted with little change since 2006.

Abundance and Survival

Two trawler-based surveys provide time-series population data from which long-term measures of annual delta smelt abundance can be estimated—the FMWT (1967–present), which samples sub-adult delta smelt, and the STN (1959–present), which samples for juveniles. Those data were used to provide the response variables representing delta smelt population size through time. An index of relative abundance has been calculated from both surveys by the CDFG since before 1970 (http://www.dfg.ca.gov/delta/). The indices are calculated by averaging catch per unit effort (for FMWT) or catch (for STN), assuming that volumes of water passing through the net are approximately the same for all STN tows over each Delta sub-region, then weighting the resulting averages by the estimated volume of water in the respective sub-region and summing sub-region estimates of abundance over all sub-regions. The FMWT index was used as calculated by the CDFG (http://www.dfg.ca.gov/delta/projects.asp?ProjectID=FMWT); this index is generally assumed to be the most accurate long-term index of delta smelt abundance, because it samples larger fish at approximately the same times each year over more stations than the STN. FMWT surveys were not conducted in 1974 and 1979, so those years were eliminated from the analysis.

There were concerns about the STN index. It is based on data from the first two surveys each year, and starting dates for the first survey can vary from year to year by as much as six weeks. Furthermore, more than one tow typically is made at each station, and catch is summed over all tow samples rather than averaged. It could not be confirmed that volumes of water in each sub-region used for the STN index were as accurate as those derived by detailed analysis of NOAA navigation charts. Therefore, despite the decades-long use of the STN index by analysts in this estuary, it was concluded that its flaws were too serious to justify its use as one of the two abundance variables in the present analyses, so an alternative estimate of summer juvenile delta smelt abundance was derived to overcome these problems. This estimate is referred to as "July abundance." It is based only on STN surveys that occur all or in part in July (the only month in which surveys occur each year), uses average rather than summed catch per tow, and uses updated volumes for each sub-region of the Bay Delta system.

Delta smelt survival is the response variable in the statistical analyses in this study. In these analyses, survival, as measured by index values, includes reproduction that occurs during the fall-to-summer period (that is, from pre-spawning adults in the fall to the next generation's juveniles in the July) and the fall-to-fall period (that is, a complete life cycle from pre-spawning adults in the fall to the next generation's pre-spawning adults the following fall). Three measures of delta smelt survival can be derived from the two abundance indices—fall-to-summer

survival, summer-to-fall survival, and fall-to-fall survival. Environmental factors that can reasonably be surmised to affect each of these three measures of survival were analyzed. Analyses of the former two measures provided insight into more important factors affecting fall-to-fall survival.

Environmental Factors and Their Hierarchy of Effects

Drawing on agency reports, several dozen biotic and abiotic factors were specified, that is, identified and quantified, along with variations of those factors, that have plausible mechanisms of effect on the abundance of delta smelt (Armor et al., 2005; Baxter et al., 2008; USFWS, 2009; Baxter, 2010) and for which data were available. Each factor was carefully specified, with consideration of the distribution of delta smelt and ranges of factor variation at different times of the year. Data on delta smelt distribution and environmental factors were segregated into sub-regions of the estuary, shown in Figure 1. Based on their mechanisms of effects, environmental factors were segregated into those with direct effects on delta smelt abundance and those with indirect effects, that is, effects that act through other factors that have direct effects. Factors that have direct effects on survival of delta smelt were grouped into categories (for example, water temperature, prey densities, entrainment at water export pumps); the same was done for factors with indirect effects on the smelt. Descriptions of each factor are in supplemental material to this article, along with the rationale for the selection of each factor and method used for its quantification. Figure 2 illustrates the general categories of factors, arranged as an "effects hierarchy." Apparent in the diagram is that certain factors—such as turbidity, water temperature, and flows through the Delta—appear at several locations in the hierarchy and may act indirectly on delta smelt, often in combination with other indirect factors. Data were available for all direct factors except disease and contaminants; however, effects of disease and contaminants on factors with indirect effect would be manifested as changes in factors with direct effect.

A Sawtooth Pattern in Survival

A pronounced inter-year "sawtooth" pattern in the survival of delta smelt was identified, that is, a persistent pattern of alternating years with higher and lower survival. This pattern was nearly identical in fall-to-summer and fall-to-fall index sequences, as shown in Figure 3. The probability was simulated that alternating peaks and troughs for 13 years would occur, as they did for years 1987 to 2000, if survival were random from year to year. This probability was estimated as 0.025—likely an overestimate because of the actual decreasing trend in delta smelt abundance over that period. Based on this analysis, it was concluded that there was a very low probability that this pattern occurred by chance. Two possible causes of the pattern were considered, one being the effect on delta smelt numbers of an environmental factor or combination of factors that exhibit corresponding, year-to-year sawtooth variation, and the other being an inherent aspect of the physiological ecology and/or

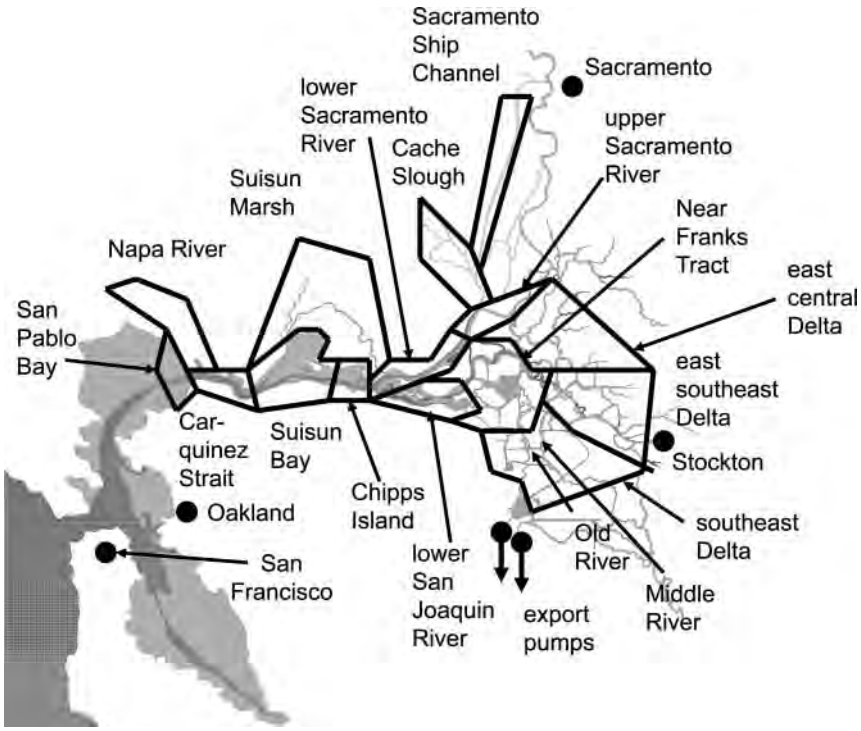

Figure 1 Sub-regions of the Bay-Delta Estuary.

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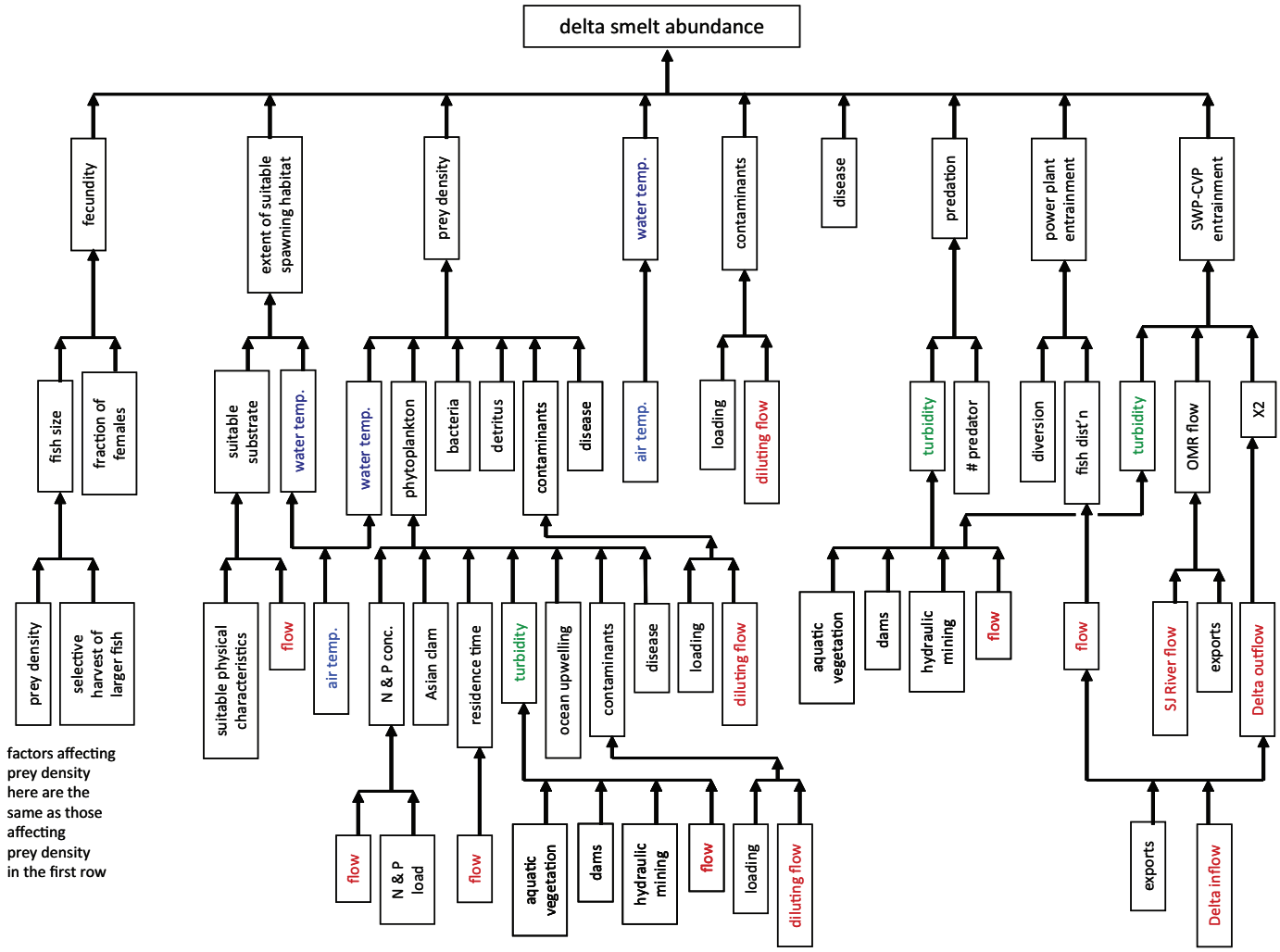

Figure 2 A simplified effects hierarchy of factors affecting delta smelt abundance. Row one, below delta smelt abundance, shows the factor categories that act directly to affect delta smelt. Row two includes factors that act indirectly on the fish. Rows three and four represent second-order and third-order indirect factors. Factors appearing in several locations are colored (color figure available online).

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behavior of delta smelt. Relationships were examined between the sawtooth pattern and environmental factors with both direct and indirect effects on delta smelt. No factor or factors could be identified that explained the sawtooth pattern for more than a few sequential years, so it was concluded that an inherent cause seems more tenable. This effect was captured by including abundance from the year previous to that over which survival was estimated, a term referred to herein as "previous-previous fall abundance."

Identifying Best Regression Equations Using Factors with Direct Effect

General Approach

From each category of environmental factors with direct effects, represented as the factors in the first row in Figure 2, one or two initial factor quantifications were selected that, based on available knowledge of delta smelt biology, were likely to be most important in determining delta smelt survival. Values of those environmental factors are shown in Table 1. The reasons for their selection are presented in supplemental material. Then the effect of each of these factors was analyzed, along with previous delta smelt abundance (to capture effects of density dependence) and previous-previous fall abundance (to capture effects of the sawtooth pattern in survival). Statistical methods for this analysis are described below and are based on two key assumptions: that the FMWT and July abundance indices are approximately proportional to delta smelt abundance, and that the abundance index at one point in time is proportional to the abundance index at a previous time, apart from the effects of measured variables, sampling errors, process error variation, and density-dependent effects.

The analysis was initiated using the Ricker model (Ricker, 1958). This model assumes that the population abundance at

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Table 1 Factors with direct effect on delta smelt selected as most important to fall-to-summer, summer-to-fall, and fall-to-fall survival

	July abundance	FMWT index	Previous FMWT index	Spawning period, days of water temperature 11–20°C	Average water temperature Apr–Jun (°C)	Average water temperature July (°C)	Maximum two-week average water temperature Jul–Sep (°C)	Minimum *Eurytemora* + *Pseudodiaptomus* Apr–Jun (#/m^3)	Average *Eurytemora* + *Pseudodiaptomus* July (#/m^3)	Average *Eurytemora* + *Pseudodiaptomus* Jul–Aug (#/m^3)	Secchi depth Apr–Jun (cm)	Adjusted Kimmerer proportional entrainment	Previous Sep–Dec striped bass adult abundance and Secchi depth	Previous Sep–Dec abundance other predators and Secchi depth	Apr–Jun abundance of other predators and Secchi depth	Sep–Dec striped bass adult abundance and Secchi depth	Sep–Dec abundance other predators and Secchi depth	Average length of delta smelt in December (mm)
Year	*Jab*	*Fab*	*PFAb*	*SpDys*	*TpAJ*	*TpJul*	*TpJS*	*EPAJ*	*EPJul*	*EPJA*	*SecAJ*	*Entrain*	*PStBass*	*PPreds1*	*Preds2*	*StBass*	*Preds1*	*DSLth*
1972	20,005	1,265	1,303	110	17.8	21.3	21.8	1,244	4,725	4,303	30	0.229	24,855	490	354	36,498	586	65.3
1973	11,185	1,145	1,265	104	18.6	21.3	21.9	754	1,547	2,082	32	0.110	36,498	586	793	27,596	1,041	65.3
1974	12,147		1,145	85	17.7	21.0	22.5	614	4,202	3,799	30	0.091	27,596	1,041	446	32,314	850	65.3
1975	8,786	697		92	17.2	20.1	21.5	480	1,520	1,545	26	0.094	32,314	850	280	41,650	735	65.1
1976	24,000	328	697	130	17.6	21.4	21.9	666	4,125	2,895	31	0.262	41,650	735	6,118	65,427	19,410	65.3
1977	25,965	480	328	118	17.0	21.1	21.5	581	4,194	3,972	33	0.256	65,427	19,410	7,095	40,655	22,324	65.6
1978	31,758	572	480	110	17.8	21.1	22.4	1,458	2,082	1,391	30	0.077	40,655	22,324	8,423	28,399	14,726	65.3
1979	5,484		572	90	18.0	21.0	22.1	517	947	722	28	0.160	28,399	14,726	18,631	25,761	37,712	67.8
1980	7,068	1,654	137	137	16.8	20.5	22.5	428	548	647	34	0.038	25,761	37,712	15,120	20,254	20,360	70.3
1981	6,300	374	1,654	108	18.7	21.8	22.8	788	922	724	37	0.199	20,254	20,360	17,070	20,621	22,248	67.2
1982	7,242	333	374	105	17.0	20.6	21.4	19	636	670	37	0.069	20,621	22,248	23,570	21,560	30,605	66.2
1983	1,390	132	333	102	17.3	20.7	22.2	271	530	544	34	0.020	21,560	30,605	13,957	31,059	28,422	62.2
1984	779	182	132	100	18.3	22.4	22.8	251	1,560	1,545	41	0.144	31,059	28,422	20,444	35,459	29,082	69.5
1985	387	110	182	105	18.5	22.0	22.5	135	548	543	43	0.231	35,459	29,082	30,364	46,997	62,483	69.1
1986	3,057	212	110	122	18.1	21.2	21.5	649	626	534	36	0.019	46,997	62,483	22,921	22,752	30,255	68.1
1987	2,743	280	212	102	19.0	20.6	21.3	534	392	519	44	0.199	22,752	30,255	26,771	41,144	42,089	64.8
1988	764	174	280	125	17.8	22.4	23.1	119	364	360	43	0.282	41,144	42,089	26,668	30,207	36,828	69.5
1989	647	366	174	108	17.9	21.1	21.7	384	2,558	3,641	42	0.222	30,207	36,828	24,067	29,441	38,551	67.8
1990	747	364	366	100	18.4	22.0	22.7	200	3,616	3,837	43	0.274	29,441	38,551	26,671	32,336	57,128	63.9
1991	2,486	689	364	108	17.2	21.3	21.8	151	2,542	3,059	38	0.231	32,336	57,128	23,754	39,881	63,209	62.5
1992	471	156	689	99	19.2	21.3	22.5	532	2,733	2,828	44	0.201	39,881	63,209	42,138	44,102	89,736	57.9
1993	5,763	1,078	156	112	17.8	21.5	22.2	603	1,184	1,425	42	0.119	44,102	89,736	25,301	27,938	48,487	54.7
1994	4,156	102	1,078	102	17.8	21.1	21.4	1,112	965	856	56	0.139	27,938	48,487	53,729	32,635	61,942	62.9
1995	2,490	899	102	142	17.0	21.5	22.0	574	2,366	1,431	44	0.064	32,635	61,942	38,412	34,966	59,091	58.5
1996	6,162	127	899	115	18.3	21.4	22.6	381	533	731	49	0.016	34,966	59,091	52,547	44,927	72,056	55.1
1997	2,362	303	127	104	19.3	21.2	21.8	369	590	800	44	0.093	44,927	72,056	33,056	56,551	64,436	57.6
1998	2,209	420	303	117	16.3	21.3	22.6	272	1,002	842	40	0.003	56,551	64,436	21,106	32,979	25,623	59.3
1999	7,478	864	420	112	17.3	21.3	22.0	752	1,308	1,091	41	0.052	32,979	25,623	21,961	42,465	29,853	59.1
2000	4,178	756	864	118	18.9	20.8	22.2	411	825	1,007	44	0.097	42,465	29,853	50,114	60,639	74,907	59.3
2001	2,897	603	756	73	19.5	21.3	22.0	424	758	484	42	0.133	60,639	74,907	50,992	48,811	81,186	63.5
2002	1,115	139	603	108	18.6	21.8	22.2	105	641	462	45	0.206	48,811	81,186	59,540	32,632	75,565	62.2
2003	1,329	210	139	106	18.0	22.2	23.2	136	787	1,525	47	0.175	32,632	75,565	56,424	40,081	86,509	58.6
2004	649	74	210	108	19.1	21.3	22.3	154	354	1,012	44	0.187	40,081	86,509	50,151	82,253	109,036	62
2005	393	27	74	123	18.1	22.0	22.8	57	849	466	51	0.049	82,253	109,036	68,310	58,943	119,419	59.6
2006	352	41	27	95	17.8	22.6	23.7	122	1,321	884	43	0.012	58,943	119,419	53,328	41,977	116,848	58
Fall-to-summer	■		■	■	■	■		■	■		■	■	■	■	■			■
Summer-to-fall	■	■					■			■						■	■	
Fall-to-fall	■		■	■	■		■	■		■	■	■			■			■

The last three rows are shaded to indicate the survival period to which each factor is relevant.

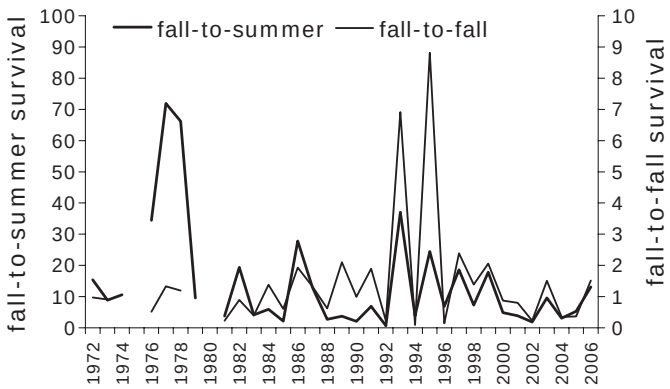

Figure 3 Delta smelt survival values from fall to summer and from fall to fall, which are derived from survey index values.

time $t + 1$ is related to the abundance at time t by an equation of the form

$$N_{t+1} = N_t \mathrm{Exp}\{r(1 - N_t/k)\}, \quad (1)$$

where r is the intrinsic growth rate, and k is the carrying capacity for the population. Taking natural logarithms gives

$$\mathrm{Ln}(N_{t+1}/N_t) = r - (r/k)N_t$$

and a linear relationship of the form

$$\mathrm{Ln}(N_{t+1}/N_t) = A + BN_t \quad (2)$$

relating the change ratio N_{t+1}/N_t to the density-dependent term BN_t. A generalization of this model assumes that the right-hand side of equation 1 also includes multiplicative effects of p variables $X_1, X_2, \ldots, X_p$, so that

$$N_{t+1} = N_t \mathrm{Exp}\{r(1 - N_t/k)\} \times \mathrm{Exp}(\alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p), \quad (3)$$

where α is a constant. Equation 2 then becomes

$$\mathrm{Ln}(N_{t+1}/N_t) = \beta_0 + BN_t + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p, \quad (4)$$

where $\beta_0 = A + \alpha$ is a constant.

A further generalization of the Ricker model includes a term for delta smelt abundance two years before a given population year, allowing characterization of the sawtooth pattern in survival, so that it becomes

$$\mathrm{Ln}(N_{t+1}/N_t) = \beta_0 + BN_t + CN_{t-1} + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p, \quad (5)$$

where C is another regression coefficient. This equation applies when the change in abundance from time t to time $t + 1$ depends to some extent on population abundance both at time t and at time $t - 1$.

Abundance Changes from Fall to Summer

For changes in abundance from fall to summer, the equivalent to equation 5 is

$$\mathrm{Ln}(JAb_{t+1}/FAb_t) = \beta_0 + BFAb_t + CFAb_{t-1} + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p, \quad (6)$$

where JAb_{t+1} is the July abundance in year $t + 1$, and FAb_t is the fall abundance in year t.

In practice, equation 6 will have a process error; the value of the dependent variable will be the value predicted by the right-hand side of the equation plus an error e_t. Also, observed values of $\mathrm{Ln}(JAb_{t+1})$ and $\mathrm{Ln}(PFAb_t)$ and FAb_t and FAb_{t-1} will have sampling errors. This raises the possibility of biases in the estimated values of coefficients on the right-hand side of the equation, if these are estimated by ordinary multiple linear regression.

For this reason, the Solow (1998) method for fitting population models with sampling errors in abundance estimates was initially considered for the estimation of equation 6 and the models below for summer-to-fall and fall-to-fall changes in delta smelt abundance. Essentially, this method uses the principle of simulation and extrapolation (SIMEX) to first simulate an increase in the level of sampling errors in abundance estimates, then it extrapolates to estimate outputs with no sampling errors in the abundance estimates. Use of the Solow method indicated that any biases in the estimated coefficients of X variables are quite small due to sampling errors in the delta smelt abundance indices. Therefore, it was concluded that ordinary multiple regression is appropriate for estimating equation 6 and the equations for summer-to-fall and fall-to-fall changes in the abundance of delta smelt.

Nevertheless, the extent of possible biases was investigated further by simulating data based on fitted versions of equation 6. First, the value of $\mathrm{Ln}(JAb_{t+1}/FAb_t)$ was set equal to the right-hand side of the estimated equation 6 plus a normally distributed process error with a mean of zero. Normally distributed sampling errors were then added to the values of $\mathrm{Ln}(JAb)$ and $\mathrm{Ln}(FAb)$ with means of zero and standard deviations obtained by bootstrap resampling of the FMWT and STN data as described by Manly (2010a, 2010b). The simulated data with process errors and sampling errors were then used to obtain multiple regression estimates of the parameters β_0, B, C, and β_1 to β_p of equation 6. The generation of simulated data was repeated 10,000 times. Mean values of the estimated parameters were compared with the values used to generate the data to establish whether sampling errors in abundance indices introduce important biases in the estimates. Standard deviations in the simulated parameter estimates were also compared with the standard errors obtained from the original regression to estimate equation 6 using the observed data to see if any biases are introduced by sampling errors in the abundance indices. This simulation confirmed that the estimates and standard errors obtained by ordinary regression have negligible biases due to

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sampling errors in the abundance indices, as was expected from the Solow (1998) analysis.

Abundance Changes from Summer to Fall

For summer-to-fall abundance changes, the equivalent to equation 5 becomes

$$\mathrm{Ln}(FAb_t/JAb_t) = \beta_0 + BJAb_t + CJAb_{t-1} + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p.$$

In this case, it is not clear why the abundance of delta smelt in the fall of a given year should depend on the abundance in July in the previous year. There was no evidence of a sawtooth pattern in survival from summer to fall, the effect of which might be captured by this abundance measure, and initial analyses gave no evidence for this type of effect. Therefore, the equation was modified to

$$\mathrm{Ln}(FAb_t/JAb_t) = \beta_0 + BJAb_t + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p. \quad (7)$$

As for abundance changes from fall to summer, there will be process errors in the results from equation 7 and sampling errors in the abundance indices; simulation was used to ensure that these errors do not introduce large biases in the estimated parameters for the equation when they are estimated by ordinary multiple regression. The simulations were carried out in a similar fashion to the simulations used with equation 6. As for the fall-to-summer analysis, this showed negligible bias in estimates and standard errors obtained using ordinary regression due to sampling errors in abundance indices.

Abundance Changes from Fall to Fall

For the fall-to-fall changes in the FMWT abundance index, the equivalent to equation 5 becomes

$$\mathrm{Ln}(FAb_{t+1}/FAb_t) = \beta_0 + BFAb_t + CFAb_{t-1} + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p, \quad (8)$$

where the terms $B\ FAb_t$ and $C\ FAb_{t-1}$ imply that the change in delta smelt abundance from one fall to the next depends on the initial abundance and also the abundance in the fall of the previous year.

As for fall-to-summer and summer-to-fall changes, the use of equation 8 will be affected by process errors and sampling errors in the estimated abundance indices. However, the sampling errors in abundances are particularly likely to introduce biases in estimated parameters for equation 8 when using ordinary multiple regression because of the estimated value of FAb_t residing on both sides of the equation. Simulation was again used to ensure that these biases are relatively small using similar methods to those used with equations 6 and 7. This simulation showed negligible biases in the estimated constant term and in the coefficients of the X variables in equation 8 and negligible biases in the estimated standard errors of these parameters. The simulation indicated that the coefficient of FAb_t has a negligible bias, but the coefficient of FAb_{t-1} has a negative bias of about 10%; at the same time, the standard errors of these estimated density-dependent effects tend to be slightly higher than the estimates from ordinary regression. Using regression to estimate the effects of factors on delta smelt abundance seems to work well, but it should be noted that there may be small bias in estimated density-dependent effects.

This initial analysis used the factors in Table 1 and was carried out as follows. Multiple regression was used to estimate the corrected AICc, to account for the proportion of variation, and to estimate the significance and sign of the regression coefficients for all possible equations using all or some of the initial-analyses factors. From among those equations selected as exhibiting explanatory importance, equations with the lowest AICc and equations with AICc values that were within two units of the lowest AICc were selected (following Burnham and Anderson, 1998). In all cases, equations were restricted to those for which each environmental factor had a level of significance less than 0.10 and coefficients with signs consistent with their hypothesized effect. This analysis identified the abundance and environmental factors that produced the best regression equations for the initial analyses.

Adding Other Factors with Direct Effect to the Best Equations from the Initial Analysis

Using the methods described above, further analyses were carried out to see if the addition of other factors with presumed direct effect, or other ways of quantifying factors from among those not selected for initial analyses, showed important effects. These factors are shown in Table 2. Factors were added sequentially to the best regression equations to assess what portion of the variation in Ln(*Survival*) was explained by each factor. If any of these "secondary" direct factors proved to be important according to the above criteria, it reflected imperfect *a priori* understanding of the relationship between delta smelt and the specific environmental variables. In subsequent analyses, regression equations were used that contained factors with direct effect that can be identified as important from the combined results of these two analyses; these are herein referred to as the best regression equations based on factors that have direct effect.

It should be noted that this method—adding factors to regression equations—cannot completely eliminate problems arising from collinearity among factors; however, because the analysis is restricted to factors that have direct effects on delta smelt, the effects of collinearity are diminished relative to those that would have occurred had all factors that may have indirect effects on delta smelt been included.

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Table 2 Factors with direct effect not selected as most important in initial analyses of fall-to-summer, summer-to-fall, and fall-to-fall survival

Year	July abundance *Jab*	FMWT index *Fab*	Previous FMWT index *PFAb*	Deviation of water temperature from 16°C Mar–May degree-days *TpMM*	Deviation of water temperature from 17°C Apr–July degree-days *TpAJ*	Average *Eurytemora* April 30 (#/m^3) *EuApr*	Average *Eurytemora* + *Pseudodiaptomus* Apr–June (#/m^3) *EPAJ1*	Minimum total calanoid copepod biomass Apr–June (mg C/m^3) *CCAJ*	Average *Limnoithona* April–June (#/m^3) *LimAJ*	Average *Limnoithona* July (#/m^3) *LimJuly*	Average *Limnoithona* July–August (#/m^3) *LimJA*	Average *Eurytemora* + *Pseudodiaptomus* Sep–Dec (#/m^3) *EPSD*	Average *Limnoithona* Sep–Dec (#/m^3) *LimSD*	Average *Eurytemora* + *Pseudodiaptomus* Jan–Mar (#/m^3) *EPJM*	Average *Limnoithona* Jan–Mar (#/m^3) *LimJM*
1972	20,005	1,265	1,303	121	323	2,552	2,298	2,681	0	0	0	2,826	0	346	0
1973	11,185	1,145	1,265	232	354	2,914	1,997	2,220	0	0	0	2,042	0	767	0
1974	12,147		1,145	191	329	1,522	2,606	446	0	0	0	1,659	0	1,586	0
1975	8,786	697		274	376	734	998	711	0	0	0	666	0	184	0
1976	24,000	328	697	238	356	1,144	1,021	876	0	0	0	718	0	570	0
1977	25,965	480	328	201	300	1,071	1,022	872	0	0	0	680	0	1,193	0
1978	31,758	572	480	156	328	1,765	3,341	1,445	0	0	0	1,250	0	465	0
1979	5,484		572	207	369	893	1,140	1,494	0	0	0	907	0	513	0
1980	7,068	1,654		161	218	305	713	4,632	0	0	0	760	353	573	0
1981	6,300	374	1,654	233	415	845	1,006	2,610	5	15	824	588	1,084	516	5
1982	7,242	333	374	266	324	307	1,065	266	5	207	495	246	1,211	530	20
1983	1,390	132	333	232	377	11	594	138	0	184	757	20	2,037	25	0
1984	779	182	132	158	379	248	581	1,823	19	62	636	446	1,762	116	0
1985	387	110	182	192	337	175	327	3,496	106	1,271	2,008	494	1,490	193	0
1986	3,057	212	110	110	315	1,134	1,511	2,404	3	81	157	512	241	0	0
1987	2,743	280	212	264	326	2,015	1,184	2,466	114	633	1,056	228	998	449	0
1988	764	174	280	132	320	2,261	1,068	947	53	266	398	1,045	276	24	0
1989	647	366	174	151	266	632	2,909	1,621	48	192	134	2,255	128	117	0
1990	747	364	366	191	311	574	3,645	1,188	61	17	68	2,019	107	234	0
1991	2,486	689	364	205	315	470	1,513	162	6	27	44	1,480	91	47	0
1992	471	156	689	185	363	1,343	6,219	3,237	5	14	39	1,312	30	63	0
1993	5,763	1,078	156	153	320	776	4,074	1,783	0	218	751	1,047	5,466	125	28
1994	4,156	102	1,078	128	286	5,716	2,888	3,277	913	21,679	25,613	458	11,179	28	202
1995	2,490	899	102	168	309	560	2,046	985	894	9,070	14,901	648	4,344	52	54
1996	6,162	127	899	185	340	470	1,684	1,197	343	10,455	13,451	365	5,331	62	561
1997	2,362	303	127	192	359	650	1,924	1,494	1,917	20,440	21,622	466	17,468	66	185
1998	2,209	420	303	191	301	160	3,971	402	6,788	7,749	9,663	1,155	4,873	82	617
1999	7,478	864	420	246	323	1,740	1,710	987	1,378	17,586	18,700	540	30,340	101	1,231
2000	4,178	756	864	166	311	540	2,842	834	2,850	19,624	12,580	817	24,404	76	2,530
2001	2,897	603	756	240	433	520	1,838	1,045	4,165	37,284	33,272	222	19,672	46	1,765
2002	1,115	139	603	143	326	340	578	845	3,676	37,266	32,897	398	23,642	86	3,617
2003	1,329	210	139	167	404	80	1,411	1,996	2,137	43,190	21,778	363	18,635	94	4,197
2004	649	74	210	162	328	100	824	1,482	4,396	27,296	26,731	266	18,747	59	600
2005	393	27	74	151	361	220	726	1,233	815	19,423	26,595	295	14,849	49	395
2006	352	41	27	292	437	161	3,264	200	1,703	32,331	36,409	356	14,789	153	1,249
Fall-to-summer															
Summer-to-fall															
Fall-to-fall															

The last three rows are shaded to indicate the survival period to which each factor is relevant.

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Comparing the Relative Contribution of Each Factor to the Explained Variation in Ln (Survival)

Using the best equations for fall-to-summer, summer-to-fall, and fall-to-fall survival, based on factors with direct effect, the relative contribution of each factor to the percentage of variation in Ln(*Survival*) was assessed.

Testing of Selected Factors with Potential Indirect Effect on Survival

Although the present approach to identifying the dominant environmental stressors acting on delta smelt is based on the effects hierarchy displayed in Figure 2, the analysis was extended to see if addition of selected indirect factors to equations that are based on factors with direct effects on delta smelt might further contribute to explaining variation in survival. This was done by focusing on the fall-to-fall model, both because that period of analysis represents a complete life cycle and because it limits the number of correlations that can be attempted and, therefore, limits the possibility of spurious correlations arising by chance. The selection criteria, described above for analysis of direct factors were used to test the importance of six indirect factors when added to the best fall-to-fall equation based on the direct factors. The number of indirect factors was restricted to avoid producing uninformative, multiple-factor equations by chance. Six indirect factors were selected from those identified as important to survival in other studies of pelagic fishes in the Delta (Kimmerer, 2002; Feyrer et al., 2007; Grimaldo et al., 2009; Mac Nally et al., 2010; Thomson et al., 2010). The selected factors are presence/absence of the Asian clam (*Corbula amurensis*), the value of X2 (the distance along the main channel from the Golden Gate Bridge to the 2 ppt isohaline, a measure of estuary salinity) averaged over the previous fall ("fall X2"), average Secchi depth in January–March, average ammonium concentration in the Chipps Island and Suisun Bay sub-regions (see Figure 2) in April–June, and Old and Middle Rivers (OMR) flow (that is, flows steered to the south Delta water export pumps) averaged over December–March and April–June. Values of these six indirect factors are shown in Table 3.

Testing Effects of Measures of Abiotic Habitat Volume on the Best Fall-to-Fall Regression Equation

The importance of a combination of conductivity, Secchi depth, and water temperature—deemed abiotic habitat in a previous study (Feyrer et al., 2007)—were analyzed both alone and weighted by prey density. Estimates were made of the volume of water with levels of conductivity, Secchi depth, and water temperature at which virtually all delta smelt occur. These ranges of suitable values were compared with actual values of conductivity, Secchi depth, and water temperature for each month and sub-region (see Figure 1) for the period 1972–2006. Based on estimated volumes of water in each sub-region, the volume of water with suitable abiotic (physical) characteristics available to delta smelt in each month was estimated. These estimated volumes alone were used, and they were weighted with the sum of densities of the prey species *Eurytemora* and *Pseudodiaptomus*. Seasonal average and minimum monthly values of these volumes and prey-weighted volumes were used in the best regression equations based on factors having direct effect on delta smelt abundance to establish whether volume or prey-weighted volume measures met criteria for inclusion in the best regression equation for fall-to-fall survival, either as an addition to or, in the case of prey density, replacement for factors with direct effect.

RESULTS

Statistical Analysis to Identify the Best Regression Equations Using Factors with Direct Effect

Initial analyses were carried out using the factors in Table 1—those environmental factors with direct effect on delta smelt—that were selected as most likely to be important in determining delta smelt abundances based on biological considerations. From among those factors, the most important affecting survival from fall to summer, summer to fall, and fall to fall were identified based on the above-described criteria. Results are shown in Table 4.

From the factors considered in these initial analyses, the most important to fall-to-summer survival (by virtue of their appearance in the best regression equation) are previous-previous fall abundance, previous fall abundance, minimum *Eurytemora* + *Pseudodiaptomus* in April–June, and proportional entrainment of adult and larval-juvenile delta smelt, with some indication that average water temperature in April–June is also important. For survival from summer to fall, the most important factors are July abundance and average *Eurytemora* + *Pseudodiaptomus* density in July–August. For survival from fall to fall, the most important factors are previous-previous fall abundance, previous fall abundance, and minimum *Eurytemora* + *Pseudodiaptomus* in April–June, with some indication that predation in April–June by predators other than striped bass (inland silverside, largemouth bass, crappie, and sunfish) is also important.

Among the factors with direct effects selected for the initial analysis, the number of days of spawning, July water temperature, *Eurytemora* + *Pseudodiaptomus* in July, Secchi depth (turbidity) in April–June, predation by striped bass, and delta smelt fecundity did not appear in the best regression equations for fall-to-summer survival. Maximum two-week average water temperature in July–September and predation did not appear in the best regression equations for summer-to-fall survival. The number of days of spawning, average water temperature in April–June, maximum two-week average water temperature in July-September, average *Eurytemora* + *Pseudodiaptomus* availability in July–August, Secchi depth (turbidity) in April–June, entrainment, predation by striped bass, and delta smelt fecundity did not appear in the best regression equations for fall-to-fall survival.

Table 3 Factors with indirect effect on delta smelt abundance, selected for analysis based on results of other studies

Year	Presence (1) or absence (0) of Asian clam	Previous Oct–Dec avg X2, km of 2 ppt line from Golden Gate	Previous Sept–Dec Secchi depth in sub-regions occupied by delta smelt habitat (cm)	Secchi depth Jan-Mar (cm)	Average ammonium in Chipps Island and Suisun Bay sub-regions, Apr–June (mg/L)	Average December–March flow in Old and Middle Rivers (cfs)	Average April–June flow in Old and Middle Rivers (cfs)
	AsClam	*PODX2*	*PFSec*	*JMSec*	*AJAm1*	*DMOMR*	*AJOMR*
1972	0	71	35	41	0.046	−2,260	−6,606
1973	0	71	38	26	0.034	953	−4,790
1974	0	66	37	35	0.024	−940	−4,955
1975	0	68	41	36	0.045	−2,093	−3,736
1976	0	70	42	51	0.047	−6,033	−5,491
1977	0	89	56	48	0.059	−4,054	−3,037
1978	0	92	58	17	0.027	−4,231	3,827
1979	0	77	40	34	0.027	−686	−5,487
1980	0	79	40	27	0.040	3,887	−1,142
1981	0	79	39	33	0.037	−4,678	−5,342
1982	0	75	42	31	0.035	−3,736	2,769
1983	0	63	42	25	0.040	9,124	14,610
1984	0	58	49	53	0.038	6,026	−5,623
1985	0	70	49	66	0.065	−5,023	−6,424
1986	0	88	61	45	0.039	−732	413
1987	1	78	41	50	0.047	−4,474	−5,471
1988	1	88	55	41	0.073	−8,006	−6,765
1989	1	90	51	44	0.058	−7,645	−7,198
1990	1	88	54	47	0.080	−9,086	−5,858
1991	1	89	62	58	0.083	−5,356	−4,752
1992	1	88	62	60	0.065	−5,561	−3,073
1993	1	87	64	29	0.034	−5,765	−2,304
1994	1	82	58	58	0.093	−4,742	−1,613
1995	1	86	60	31	0.033	−3,145	4,721
1996	1	75	55	37	0.036	−1,281	−2,848
1997	1	78	57	29	0.087	10,376	−3,972
1998	1	81	61	29	0.043	2,103	6,536
1999	1	69	45	51	0.060	−760	−2,155
2000	1	83	47	48	0.065	−5,282	−4,338
2001	1	85	53	45	0.089	−5,681	−2,919
2002	1	82	53	36	0.070	−7,731	−3,857
2003	1	84	50	36	0.055	−8,185	−5,374
2004	1	83	58	34	0.080	−8,080	−4,851
2005	1	82	65	48	0.055	−5,525	−1,055
2006	1	82	68	39	0.040	−3,214	10,026

Additional analyses were carried out using factors with direct effects that were not selected for the initial analyses. These were added to the best equations from the initial analyses to see whether they made a significant improvement. Results of this analysis, shown in Table 5, indicate that average *Eurytemora* + *Pseudodiaptomus* density in January–March should be added as an important factor that explains survival from fall to summer. Average *Eurytemora* + *Pseudodiaptomus* density in September–December should replace average *Eurytemora* + *Pseudodiaptomus* density in July–August as an important factor explaining survival from summer to fall and should be added to the regression equation for fall-to-fall survival.

Of the factors with direct effect on delta smelt population dynamics that was used for the additional analyses, the number of degree-days of deviation of water temperature from optimum in March–May or April–July; average *Eurytemora* density in late April; average *Eurytemora* + *Pseudodiaptomus* density in April–June; and average *Limnoithona* density in April–June, July, or January–March did not appear in the best regression equations for fall-to-summer survival. Average *Limnoithona* density in July–August and September–December did not appear in the best regression equation for summer-to-fall. None of these factors appeared in the best regression equations for fall-to-fall. There was some evidence that minimum calanoid copepod biomass in April–June was important for fall-to-summer survival but not survival from fall-to-fall.

The best regression equations based on factors with direct effects on delta smelt abundance were derived from the best regression equations from the initial analyses, as adjusted by results from the additional analyses using factors with direct effect that were not selected for the initial analyses.

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Table 4 Summary of results of initial analyses of factors with direct effect that were selected as important based on the most reliable knowledge of delta smelt biology

			Initial analyses factors with direct effect on delta smelt survival																	
			Previous previous fall abundance	Previous fall abundance	July abundance	Spawning period, days of water temperature 11–20ºC	Average water temperature Apr–Jun (ºC)	Average water temperature July (ºC)	Maximum two-week average water temperature Jul–Sep (ºC)	Minimum *Eurytemora + Pseudodiaptomus* Apr–Jun (#/m^3)	Average *Eurytemora + Pseudodiaptomus* July (#/m^3)	Average *Eurytemora + Pseudodiaptomus* Jul–Aug (#/m^3)	Secchi depth Apr–Jun (cm)	Adjusted Kimmerer proportional entrainment	Previous Sep–Dec striped bass adult abundance and Secchi depth	Previous Sep–Dec abundance other predators and Secchi depth	Apr–Jun abundance of other predators and Secchi depth	Sep–Dec striped bass adult abundance and Secchi depth	Sep–Dec abundance other predators and Secchi depth	Average length of delta smelt in December (mm)
Period	AICc value	Adjusted R^2	*PFAb* 1	*PFAb*	*Jab*	*SpDys*	*TpAJ*	*TpJul*	*TpJS*	*EPAJ*	*EPJul*	*EPJA*	*SecAJ*	*Entrain*	*PStBass*	*PPreds1*	*Preds2*	*StBass*	*Preds1*	*DSLth*
Fall-to-summer	**36.4**	**59%**	**0.001**	**0.000**	Not relevant to this period	–	–	–	Not relevant to this period	**0.000**	–	Not relevant to this period	–	**0.035**	–	–	–	Not relevant to this period		–
	36.9	**58%**	**0.004**	**0.000**		–	**0.048**	–		**0.000**	–		–	–	–	–	–			–
	37.0	62%	0.002	0.000		–	0.104	–		0.000	–		–	0.077	–	–	–			–
	37.4	61%	0.011	0.000		–	–	–		0.000	–		0.136	0.028	–	–	–			–
	37.7	60%	0.007	0.000		–	–	–		0.001	–		–	0.020	–	–	0.172			–
	38.1	**53%**	**0.002**	**0.000**		–	–	–		**0.000**	–		–	–	–	–	–			–
	38.1	60%	0.002	0.001		–	0.035	–		0.000	–		–	–	0.162	–	–			–
	38.5	59%	Not estimated			–	–	–		0.000	–		–	0.023	–	0.315	–			–
	38.8	58%				–	–	–		0.000	–		–	0.056	0.413	–	–			–
	39.1	54%				–	–	–		0.000	–		0.189	–	–	–	–			–
Summer-to-fall	**38.1**	**60%**	Not relevant to this period		**0.000**	Not relevant to this period			–	Not relevant to this period		**0.002**	Not relevant to this period					–	–	Not relevant to this period
	38.6	61%			0.000				–			0.003						–	0.153	
	39.2	63%			0.000				0.147			0.002						–	0.066	
	39.3	60%			0.000				–			0.002						0.239	–	
	40.0	60%			0.000				0.397			0.002						–	–	
	41.2	60%			Not estimated				0.371			0.002						0.229	–	
	41.2	60%							–			0.003						0.707	0.378	
	42.2	62%							0.169			0.002						0.969	0.172	
	46.9	49%							–			–						–	0.174	
	48.2	49%							0.322			–						–	0.109	
Fall-to-fall	30.8	59%	0.016	0.000	Not relevant to this period	–	–	Not relevant to this period	–	–	Not relevant to this period	–	–	–	Not relevant to this period		0.002	–	–	0.034
	30.9	**53%**	**0.001**	**0.000**		–	–		–	**0.009**		–	–	–			–	–	–	–
	31.7	**52%**	**0.014**	**0.000**		–	–		–	–		–	–	–			**0.015**	–	–	–
	31.8	56%	0.017	0.000		–	–		–	–		–	–	–			–	–	0.003	0.036
	31.9	56%	0.006	0.000		–	–		–	0.073		–	–	–			0.125	–	–	–
	32.1	56%	0.002	0.000		–	–		–	0.016		0.149	–	–			–	–	–	–
	32.3	61%	0.008	0.000		–	–		–	0.133		–	–	–			0.022	–	–	0.061
	32.6	54%	0.005	0.000		–	–		–	0.065		–	–	–			–	–	0.229	–
	32.8	**49%**	**0.014**	**0.000**		–	–		–	–		–	–	–			–	–	**0.029**	–
	32.9	54%	Not estimated			–	–		–	0.034		–	–	–			–	–	–	–

Entries in the last 18 columns are significance levels for regression coefficients from two-sided tests. Gray shading shows instances of AICc greater than two units above the best equation, a level of significance above 0.10, or, in the case of delta smelt length (a measure of fecundity), a negative coefficient in the regression equation, which is contrary to the hypothesized effect. Boldface indicates factors in equations meeting all selection criteria. Tick marks indicate that the factor was not among those used in the equation that was tested.

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Table 5 Results of analyses of factors with direct effect, not selected for the initial analyses, added to the best regression equations for each period, from the initial analyses

			Direct factors not selected for initial analyses											
			Deviation of water temperature from 16° C Mar--May (degree-days)	Deviation of water temperature from 17° C Apr–July (degree-days)	Average *Eurytemora* April 30 (#/m^3)	Average *Eurytemora* + *Pseudodiaptomus* Apr–June (#/m^3)	Minimum total calanoid copepod biomass Apr--June (mg C/m^3)	Average *Limnoithona* April–June (#/m^3)	Average *Limnoithona* July (#/m^3)	Average *Limnoithona* July--August (#/m^3)	Average *Eurytemora* + *Pseudodiaptomus* Sep–Dec (#/m^3)	Average *Limnoithona* Sep–Dec (#/m^3)	Average *Eurytemora* + *Pseudodiaptomus* Jan–Mar (#/m^3)	Average *Limnoithona* Jan–Mar (#/m^3)
Period	AICc value	Adjusted R^2	*TpMM*	*TpAJ*	*EuApr*	*EPAJ1*	*CCAJ*	*LimAJ*	*LimJuly*	*LimJA*	*EPSD*	*LimSD*	*EPJM*	*LimJM*
Fall-to-summer	**38.9**	**70%**	–	–	–	–	–	–	–	Not relevant to this period			**0.003**	–
	39.5	**73%**	–	–	–	–	0.080	–	–				**0.010**	–
	40.1	72%	–	–	–	0.127	–	–	–				0.004	–
	40.8	75%	–	–	–	0.101	0.066	–	–				0.012	–
	41.4	70%	–	–	–	–	–	–	–				0.002	0.331
	42.0	69%	–	–	–	–	–	–	0.578				0.003	–
	42.1	69%	–	0.611	–	–	–	–	–				0.004	–
	42.3	69%	0.835	–	–	–	–	–	–				0.007	–
	42.3	69%	–	–	–	–	–	0.907	–				0.004	–
	42.3	69%	–	–	0.929	–	–	–	–				0.004	–
Summer-to-fall	**39.50**	**67%**	Not relevant to this period							–	**0.012**	–	Not relevant to this period	
	41.55	66%								0.406	0.026	–		
	42.23	66%								–	0.013	0.805		
	42.23	68%								0.095	0.023	0.139		
	44.58	61%								0.169	–	–		
	45.02	62%								0.056	–	0.167		
	46.89	59%								–	–	0.783		
Fall-to-fall	**32.2**	**62%**	–	–	–	–	–	–	Not relevant to this period	–	**0.020**	–	–	–
	33.4	64%	0.120	–	–	–	–	–		–	0.010	–	–	–
	33.8	63%	–	–	–	–	0.160	–		–	0.020	–	–	–
	34.0	63%	–	–	–	–	–	–		–	0.010	0.190	–	–
	34.5	62%	–	–	–	–	–	–		–	0.010	–	–	0.300
	34.6	62%	–	–	–	–	–	0.310		–	0.010	–	–	–
	34.8	61%	–	–	0.370	–	–	–		–	0.020	–	–	–
	35.2	60%	–	–	–	0.580	–	–		–	0.060	–	–	–
	35.3	66%	0.090	–	–	–	–	–		–	0.000	0.150	–	–
	35.3	56%	–	–	–	0.160	–	–		–	---	–	–	–

Entries in the last 12 columns are significance levels for regression coefficients from two-sided tests. Gray shading shows instances of AICc greater than two units above best equation or a level of significance above 0.10. Boldface indicates factors in equations meeting both selection criteria. Tick marks indicate that the factor was not among those used in the equation that was tested.

The best regression equation for the fall-to-summer survival of delta smelt is

$$\mathrm{Ln}(Survival) = 2.003 - 2.197*PFAb + 0.781*PFAb1 + 1.988*EPAJ - 3.826*Entrain + 1.143*EPJM, \quad (9)$$

where survival is the ratio of July abundance, a measure of juvenile abundance in July, to the previous year's FMWT index, a measure of sub-adult abundance; *PFAb* is the FMWT index of the previous year divided by 1,000; *PFAb*1 is the FMWT index of the previous-previous year divided by 1,000; *EPAJ* is the minimum *Eurytemora* + *Pseudodiaptomus* density in April–June divided by 1,000; *Entrain* is the proportional entrainment of delta smelt, as a fraction; and *EPJM* is the average *Eurytemora* + *Pseudodiaptomus* density in January–March divided by 1,000.

The best regression equation found for summer-to-fall survival of delta smelt is

$$\mathrm{Ln}(Survival) = -2.176 - 1.003*JAb + 0.698*EPSD, \quad (10)$$

where *Survival* is the ratio of the FMWT index, a measure of sub-adult abundance, to July abundance, a measure of juvenile abundance in July, in the same year; *JAb* is July abundance, a measure of juvenile abundance in summer divided by 10,000; *PFAb*1 is the FMWT index of the previous-previous year divided by 1,000; and *EPSD* is the average *Eurytemora* + *Pseudodiaptomus* density in September–December divided by 1,000. Note that *EPSD*, the average *Eurytemora* + *Pseudodiaptomus* in September–December, replaced *EPJA*, the average *Eurytemora* + *Pseudodiaptomus* in July–August in the best regression equation from the initial analysis because *EPJA* was no longer significant in the equation for summer-to-fall survival when other factors with direct effects were considered.

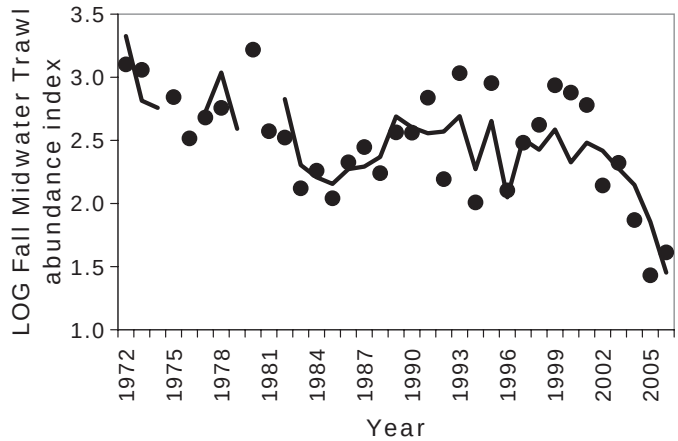

Figure 4 Actual and predicted values of the Fall Midwater Trawl index of abundance of sub-adult delta smelt. Circles are actual values. The line shows predicted values.

The best regression equation found for the fall-to-fall survival of delta smelt is

$$\mathrm{Ln}(Survival) = -0.246 - 2.781*PFAb + 1.048*PFAb1 + 0.997*EPAJ + 0.482*EPSD, \quad (11)$$

where survival is the ratio of the FMWT index, a measure of sub-adult abundance in the fall, to the previous year's FMWT index; *PFAb* is the FMWT index of the previous year divided by 1,000; *PFAb*1 is the FMWT index of the previous-previous year divided by 1,000; *EPAJ* is the minimum *Eurytemora* + *Pseudodiaptomus* density in April–June divided by 1,000; and *EPSD* is average *Eurytemora* + *Pseudodiaptomus* density in September–December divided by 1,000. Figure 4 shows actual abundance of sub-adult delta smelt (the FMWT index) and values predicted by equation 11.

These three equations each reflect a stock-recruitment relationship in which end-of-period abundance is proportional to

Table 6 Percentage of variation in Ln(*Survival*) explained and the contribution of each factor to that percentage

Period	% Ln(*Survival*)[a] variation explained	Important factors	Percent of variation explained[b]	Percent of variation explained[c]
Fall-to-summer	70.2%	*PFAb* = previous fall abundance/1,000	0.0%	38.3%
		*PFAb*1 = previous previous fall abundance/1,000	14.0%	7.7%
		EPAJ = minimum *Eury* + *Pseu*, Apr–Jun/1,000	39.0%	32.8%
		Entrain = proportional entrainment at export pumping plants, %/100	6.0%	9.1%
		EPJM = average *Eury* + *Pseu*, Jan–Mar/1,000	11.2%	11.2%
Summer-to-fall	67.6%	*JAb* = July abundance/10,000	47.0%	64.1%
		EPSD = average *Eury* + *Pseu*, Sep–Dec/1,000	20.6%	20.6%
Fall-to-fall	61.6%	*PFAb* = previous fall abundance/1,000	25.8%	61.6%
		*PFAb*1 = previous-previous fall abundance/1,000	15.2%	18.6%
		EPAJ = minimum *Eury* + *Pseu*, Apr–Jun/1,000	12.5%	8.0%
		EPSD = average *Eury* + *Pseu*, Sep–Dec/1,000	8.1%	8.1%

[a]For fall-to-summer and fall-to-fall analyses, "survival" means survival and reproduction.
[b]Percent of variation explained by the variables when added one at a time in order shown.
[c]Percent of variation explained when variable is added last into the equation.

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beginning-of-period abundance. However, this proportional relationship is adjusted by a density-dependence term that causes abundance to be reduced when beginning-of-period abundance is high and is further adjusted by prey-density terms that cause delta smelt abundance to increase with availability of prey. In addition, summer abundance relative to previous fall abundance is reduced by entrainment. Both summer abundance and fall abundance, relative to previous fall abundance, are higher than expected when the abundance two-years previous is high.

Comparing the Relative Contribution of Each Factor to the Explained Variation in Ln(Survival)

Table 6 shows the percentage of variation in Ln(*Survival*) that is explained by each equation and the contribution of each factor to that percentage. The density-dependence terms, *PFAb* or *JAb*, have relatively important contributions to variation in Ln(*Survival*) for all three periods, and, while *PFAb* is not important as an individual factor for fall-to-summer survival, its inclusion renders important the contribution of other factors once it is added to the equation. Prey-density terms have a relatively important contribution to variation in Ln(*Survival*), as does the previous-previous fall abundance, which accounts for the sawtooth survival pattern. The contribution of entrainment to variation in Ln(*Survival*) is not as important as the contribution of prey densities to fall-to-summer survival. Entrainment was not chosen for inclusion in the fall-to-fall equation because it did not meet the criteria for inclusion.

Testing Selected Factors with Indirect Effects on Survival

There was no evidence that any of six environmental factors with indirect effects, which were identified in previous studies, further explained changes in fall-to-fall delta smelt survival beyond those accounted for by factors with direct effects shown in equations 9, 10, and 11. It is noted that this does not necessarily mean that these or other factors with indirect effects might not have important effects on one or more factors that have direct effects.

Testing Effects of Measures of "Abiotic Habitat" Volume on the Best Fall-to-Fall Regression Equation

This study attempted to add estimates of the volume of water within the suitable range of conductivity, Secchi depth, and water temperature to the best regression equation, as well as suitable volumes weighted with prey density (densities of *Eurytemora* + *Pseudodiaptomus*), the values of which are in the supplemental material to this article. When adding volume weighted by prey density, prey density terms were first removed from the best regression equations. None of those measures met the criteria above for inclusion in the best regression equation for fall-to-fall survival.

DISCUSSION

The analyses presented here focused on environmental factors that have plausible mechanisms for direct effects on the survival of delta smelt, leaving identification of factors having important, indirect effects—that is, the factors that have important effects on important factors with direct effects—for subsequent analyses. Effects on delta smelt survival were analyzed from fall (when delta smelt are sub-adult or pre-spawning adults) to summer (when delta smelt are next-generation juveniles) and from fall to fall (addressing the life cycle across a single generation). The regression equations resulting from this latter analysis serve as a life-cycle model. Effects on survival from summer to fall were also analyzed, thereby allowing insight into sources of mortality during this delta smelt growth stage. Analyses indicate that prey density is the most important environmental factor affecting abundance and population trends in delta smelt over the period 1972 through 2006 and also that changes in prey density appear to best explain the sharp drop in delta smelt abundance in this century. Entrainment of delta smelt at state and federal export pumping plants in the Sacramento-San Joaquin Delta appears to contribute to survival rates from fall to summer and, therefore, to juvenile abundance in summer, but entrainment was not a statistically significant factor in survival from fall to fall—that is, to inter-annual changes in the size of the delta smelt population. Density dependence was an important factor affecting survival from fall to summer, summer to fall, and fall to fall. Its inclusion in the best regression equations was also important in revealing the effects of prey density and entrainment on delta smelt abundance. This finding indicates that density dependence must be accounted for in analyses directed at identifying factors that are important to the abundance of delta smelt. Delta smelt survival from fall to summer and fall to fall showed a persistent sawtooth pattern over much of the period analyzed, and this effect was captured by inclusion of a term for delta smelt abundance in fall of the year prior to beginning-of-period abundance in fall-to-summer and fall-to-fall survival analyses. It is noted that the best regression equations may not apply for values of factors outside the range of values actually observed.

The regression equations can be interpreted as follows, using the fall-to-fall equation as an example. Delta smelt survival is the ratio *FMWT*/*PFAb*, where *PFAb* is the previous year's FMWT index. So, equation 11 can be written as

$$\frac{FAb}{PFAb} = e^{-0.246-(2.781\times10^{-3}PFAb)+(1.048\times10^{-3}PFAb1)+(0.997\times10^{-3}EPAJ)+(0.482\times10^{-3}EPSD)}$$

or

$$FAb = 0.782PFAb\, e^{-(2.781\times10^{-3}PFAb)} e^{(1.048\times10^{-3}PFAb1)} e^{(0.997\times10^{-3}EPAJ)} e^{(0.482\times10^{-3}EPSD)},$$

where *PFAb1* is the previous-previous FMWT index, *EPAJ* is the minimum *Eurytemora* + *Pseudodiaptomus* density in April–June, and *EPSD* is the average *Eurytemora* + *Pseudodiaptomus* density in September–December. Assuming that the

number of delta smelt eggs in spring is proportional to the previous abundance index derived from the FMWT, this equation can be interpreted as follows:

$$
\begin{aligned}
&FMWT = [\text{eggs in spring} = 0.782PFAb] \\
&\times[\text{survival reduction related to density dependence} \\
&\text{from previous FMWT} = e^{-(2.781\times10^{-3}PFAb)}] \\
&\times[\text{survival increase from contribution of previous}- \\
&\text{previous abundance} = e^{(1.048\times10^{-3}PFAb1)}] \\
&\times[\text{survival increase from high minimum food density in} \\
&\text{April} - \text{June} = e^{(0.997\times10^{-3}EPAJ)}] \\
&\times[\text{survival increase from high September}- \\
&\text{December food density} = e^{(0.482\times10^{-3}EPSD)}],
\end{aligned}
$$

with the negative constant term in equation 11 indicating that survival (that is, the combined effects of survival and reproduction) from fall to fall is less than one—typical of a species experiencing an extended decline in abundance.

There was some indication that average water temperature and calanoid copepod biomass (a general measure of prey density) in April–June were important contributors to survival of delta smelt from fall to summer. Furthermore, predation in April–June, representing the combined effects of water clarity and abundance of the predators, inland silversides, largemouth bass, crappie, and sunfish, was important to delta smelt survival from fall to fall. Numerous factors with direct effects on delta smelt survival did not have statistically significant effects on the subsequent abundance of delta smelt, including the length of the spawning period as determined by water temperature; turbidity as an individual factor affecting larval feeding success in spring as measured by Secchi depth; average or maximum water temperature in summer; deviations of water temperature from optimum values in spring; predation in summer and fall by predators other than striped bass and predation in all seasons by striped bass; delta smelt fecundity, as measured by the size (average length) of delta smelt in December; and the average density of *Limnoithona*, an invasive zooplankton that has become the most abundant potential prey species in the estuary.

The effects of factors that might have indirect effects on survival were analyzed using factors that were identified by previous studies as potentially important in determining delta smelt population trends. These factors are the average value of X2 (a measure of western Delta salinity) in the previous fall ("fall X2"), turbidity in winter as measured by Secchi depth, ammonium concentration in spring in downstream sub-regions of the Delta, and flows that feed the Delta's export pumps in winter and spring. None of these factors met the criteria for inclusion in the best regression equations based on factors with direct effects on delta smelt survival. It is noted that these factors and other factors with indirect effects could have important effects on factors that have direct effects on delta smelt, as suggested in Figure 2, but there was no attempt to identify those relationships here, although it is noted that Delta water flows to the export pumps were incorporated in estimates of proportional entrainment.

Results indicate that delta smelt survival was more sensitive to measures of the effects of individually specified factors with direct effects on fish than to measures of the volume of water within suitable ranges of conductivity, Secchi depth, and temperature (abiotic habitat, the term used in Feyrer et al. [2007]). Once the effects of individually specified factors were accounted for, with attention to their co-occurrence with delta smelt, the volume of water with conductivity, Secchi depth, and temperature in the suitable ranges for each of those three variables did not meet the criteria for inclusion in the best regression equation for fall-to-fall survival, nor did such volumes weighted with prey density, even after prey density terms were removed from the best regression equations for fall-to-fall survival based on factors with direct effect.

Some caution should be taken in interpreting results pertaining to entrainment of delta smelt at state and federal Delta export pumping plants. Estimates of delta smelt entrainment are based on those used in a previous modeling exercise (Kimmerer, 2008). Those methods of estimating proportional entrainment provide a more rational conceptual framework than other methods that have been used (see Grimaldo et al. [2009], for example), because Kimmerer estimated entrainment relative to population size, attempted to estimate the standing crop of delta smelt at the time of entrainment (rather than using abundance estimates derived from samples collected several months earlier), and attempted to overcome uncertainties associated with the fact that larval delta smelt are not actually incorporated in fish salvage data from pumping plants. However, Kimmerer's model estimates are based on a number of assumptions. Of 18 assumptions underlying estimates, Miller (2011) concluded that at least 12 of these assumptions introduced bias, and 11 of those 12 introduced an upward bias in the putative effects of export pumps on delta smelt mortality. This study attempted to correct Kimmerer's estimates to account for that bias, but could do so for just three of the 12 assumptions. The corrections reduced Kimmerer's annual estimates of proportional entrainment by about half, and Miller (2011) concluded that further reductions would be appropriate if other assumptions could be quantified. Furthermore, Kimmerer did not estimate proportional entrainment prior to 1995; however, his estimates were extended back to 1972 using correlations with X2, flow, and Secchi depth measures for those years (as described in supplemental material) and Kimmerer's 1995–2006 estimates and those hind-cast estimates were adjusted to account for bias that could be quantified. Therefore, the role of entrainment as a contributing factor to population trends from fall to summer that are largely determined by density-dependence factors and availability of the preferred foods used by delta smelt is uncertain and likely (still) biased upward.

Ascertaining the importance of prey density in determining population trends in delta smelt in part resulted from attentive specification of factor values. The densities of the two prey species, *Eurytemora* and *Pseudodiaptomus*, were used, summed as the measure of prey density, reflecting findings in several

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previous studies that explicitly reference consumption of these zooplankton by delta smelt (see supplemental material). There was also an attempt to account for the location of delta smelt when estimating prey density, because prey densities in subregions that are not occupied by delta smelt cannot be relevant to delta smelt survival. Moreover, there was an attempt to measure the seasonal low point in prey density in the spring of recent years, when the favored prey *Eurytemora* rises from near zero in late winter and then declines to near zero in May or June, at approximately the same time that other suitable prey species *Pseudodiaptomus* increases in numbers from essentially zero and persists at greater numbers until the following winter (see supplemental material).

It is noted that the importance of the factor, minimum *Eurytemora* plus *Pseudodiaptomus* in April–June, which measures the low point in the food availability for young delta smelt, provides a plausible mechanism for Bennett's observation that almost no early-hatch larvae of delta smelt have survived until later life stages in recent years (Bennett, 2005; USFWS 2009). That spring low point appeared in the mid 1980s; since then, if larval delta smelt hatch prior to the occurrence of this low point in densities of the two zooplankton species, larval survival might exhibit a pattern of low returns.

This study's findings are consistent with recent assertions that contaminant-mediated prey availability shows dominant effects on patterns of the abundance of delta smelt and several other fish in the Delta (Glibert, 2010), although the analysis did not attempt to identify the causes of the substantial changes in prey densities in recent years. Furthermore, the analyses address an observation by Feyrer et al. (2007), who concluded that their analyses of just several physical factors as determinants of delta smelt abundance would have been improved by consideration of other factors, particularly prey density. Without carrying out analyses that accounted for density dependence and included such essential variables as prey availability and predation on delta smelt, they concluded that the average value of X2 in the previous fall was the essential causative agent of subsequent summer juvenile abundance (see Feyrer et al., 2007, and USFWS, 2009). The analyses of this study considered the effects of density dependence and prey density, as well as numerous other factors in addition to average X2 position in the previous fall, and once the effects of prey density were accounted for, no evidence was found of effects of average X2 value in the previous fall on delta smelt population dynamics. Thomson et al. (2009) found that water clarity, position of X2 in winter–spring, and the volume of water exports were important to long-term abundance of delta smelt and other fish but could not explain the recent decline in abundance of delta smelt to record low levels. Mac Nally et al. (2010) found that the position of X2 in the spring in the estuary and increased water clarity were important to delta smelt abundance. Differences between the present findings and those of Thomson et al. and Mac Nally et al. are attributed to this study's focus on those factors that specifically should have direct effects on abundance and to a more precise quantification of environmental factors—including explicitly considering spatial and temporal aspects of prey availability, integrating the specific locations of different life stages of delta smelt in average values of variables, and expressing prey availabilities in terms of densities of zooplankton species known to be preferred by delta smelt. Grimaldo et al. (2009) attributed demographic trend effects to entrainment of delta smelt at the export pumping plants (measured as the number of fish salvaged there) and to export volumes by virtue of the relationship of those flows to rates of fish salvage. While some effect of entrainment (which incorporated effects of export flows) was found on delta smelt survival from fall to summer, entrainment of fish at the export pumps did not exhibit a significant relationship with the population dynamics of the fish over its entire life cycle. Assessment of the relative importance of entrainment in determining delta smelt survival, as well as that of several other factors, during various periods in the past and for various future management actions, awaits further analysis.

It is believed that this study's analysis is the first to combine careful quantification of variables, based on publicly available agency data, with wildlife agency-derived conceptual models transformed to represent the hierarchical manner in which environmental factors interact to affect abundance and survival of delta smelt. The benefits of this approach included a reduction in the occurrence of correlations that might arise by chance, due to the inclusion of many variables relative to the number of years of data, and identification of environmental factors on which future studies can focus in order to elucidate the ecological mechanisms as a basis for management actions, thereby providing a sound basis for agency determinations and policy decisions.

Nonetheless, limitations in the presented analyses are acknowledged. Time-series index values of delta smelt abundance are based on data from surveys that were not explicitly designed to sample that fish species, and more recently initiated surveys that are designed to sample delta smelt more efficiently suffer from lack of longer time series and from the challenges of sampling for a species that now is scarce. In addition there are no data on disease, a factor with a potentially important, direct effect on delta smelt abundance and, with the exception of ammonia, almost no data on contaminants that act directly on delta smelt. Some comfort can be taken in findings that 60 to 70% of the variation in delta smelt survival can be explained by factors included in the analyses, but that finding cannot rule out the importance of disease and contaminants. Further limitations to clearer resolution of the causative factors in the decline of delta smelt include the infrequency with which some environmental factors are being measured. For example, zooplankton samples were taken once or twice per month beginning in 1972 and in the separate, 20-mm survey (CDFG, http://www.dfg.ca.gov/delta/projects.asp?ProjectID=20mm), every two weeks in spring beginning in 1995. Hourly water temperature data are not available prior to the mid 1990s, requiring reliance on correlations with air temperature, which, fortunately, is highly related to water temperature. These limitations are offset somewhat by the large variations in delta smelt abundance from year to year, and the 95% decline in

abundance from 1999 to 2006, suggesting that the signals of environmental effects that have been identified are not subtle and that the current lack of desired levels of precision in and frequency of sampling for underlying data for environmental variables can be tolerated.

The present results, indicating that the importance of prey density as measured by the sum of *Eurytemora* + *Pseudodiaptomus* densities, are supported by observed recent sharp declines in the abundance of two other pelagic fish that share at least partial reliance on the same prey—longfin smelt and young striped bass (Armor et al., 2005; Baxter et al., 2008). Slater (2008) concluded from diet studies that young longfin smelt rely heavily on *Eurytemora* in spring, and Moyle (2002) reported that striped bass larvae frequently feed on *Eurytemora*.

The results presented here suggest several areas for further study. Identification of the environmental factors that determine prey density leads the list. There is a need to elucidate and quantify that part of the effects hierarchy related to prey density. Strong inference can be drawn from this study—if the densities of the favored prey species consumed by delta smelt were to increase substantially, delta smelt abundance should increase. Under that circumstance, whatever the effects of entrainment from fall to summer, those effects would become less important because of density dependence. It would appear, therefore, that the key to recovery of delta smelt to levels of abundance that would reduce conservation concern is increased prey density.

Another area for further study relates to the cause of density dependence. Bennett (2005) suggested that density dependence was important based on his observation that, when comparing two poor stock-recruitment relationships—one with and one without density dependence—the one with density dependence appeared to be a better predictor. The present analysis, incorporating effects of many other factors, provides more convincing evidence that density-dependence effects act on delta smelt from fall to summer, summer to fall, and fall to fall, and it has demonstrated effects at low levels of abundance and reveals effects of other factors. Density dependence from summer to fall, as represented by terms for previous abundance in regression equations for survival, is one reason, along with variation in prey density, why entrainment, while contributing to the best regression equation that describes delta smelt survival from fall to summer, did not meet the criteria for inclusion in the best regression equation that explains survival from fall to fall, that is, from one generation to the next. The cause of density dependence in delta smelt deserves further study. This analysis suggests that it arises from some factor that was not considered here, or from a factor that was considered but was not specified adequately, such that its effects would be revealed. Delta smelt spawn most successfully on cobble or clean sand (J. Lindberg, University of California at Davis, personal communication), and meager sediment data (see http://www.water.ca.gov/bdma/meta/benthic.cfm) suggest that few stations in areas occupied by delta smelt show evidence of cobble or clean sand substrate. Nor was the possibility considered that the contemporary relatively small numbers of fish have led to stochastic demographic phenomena, such as difficulty in finding mates or some other manifestation of Allee effects (Allee et al., 1949). Identifying the cause of density dependence on delta smelt could provide a basis for actions to lessen its effects.

Further study is recommended of the inter-year sawtooth pattern in the abundance of delta smelt. This, too, is an important factor in these regression equations. Failure to identify an environmental factor or factors causing this pattern suggests that its cause may be inherent in the reproductive biology of delta smelt. Approximately 5% of delta smelt live for two years and spawn in the second year, producing a large number of eggs because of their larger size (Bennett, 2005). The existence of distinct demographic units of delta smelt that spawn every two years could explain the sawtooth pattern, but the absence of larger fish in the FMWT and STN argues against this possible explanation.

Predation also deserves more study. The identification of predation as a factor of some importance must be confirmed by more careful studies to overcome the general conclusion drawn by Moyle (2002) that there was little evidence of important predation effects, even when delta smelt were abundant relative to other prey fish many years ago. It is possible that the arrival and proliferation of invasive predators alters Moyle's conclusion.

There was some indication that water temperature is important, but water temperature, depending almost entirely on air temperature, cannot be controlled. However, the increasing trend in water temperature could affect various factors that are important to the abundance of delta smelt, including prey density, and such effects deserve study.

Results also indicate that the development of an effects hierarchy can provide an important framework on which to base analyses designed to assess the relative importance of multiple factors affecting the population dynamics of at-risk species. The findings presented here suggest that multiple environmental factors were responsible for the decline in abundance of delta smelt to record low levels, but that multiplicity is vertical with respect to the effects hierarchy, primarily extending down the hierarchy below prey density rather than horizontally across the hierarchy, as others have surmised (Baxter et al., 2010).

Furthermore, in the case of delta smelt, not only does an effects hierarchy suggest the use of simple linear regression models, but the low sampling errors in abundance relative to process errors indicates that this simple and transparent method of analysis is an appropriate method for identifying environmental factors with direct effects. Therefore, at least for delta smelt and perhaps for other fish for which sampling errors in abundance are relatively low, simple linear regression, as an alternative to more complex life-cycle models, can produce informative results.

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An Investigation of Factors Affecting the Decline of Delta Smelt (*Hypomesus transpacificus*) in the Sacramento-San Joaquin Estuary

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The delta smelt is an annual fish that is endemic to the Sacramento-San Joaquin Estuary and is protected under federal and California Endangered Species Acts. Record low abundances have occurred since 2004. Three questions are addressed here: What is the relative importance of environmental factors with direct effects on abundance? Do factors that may have indirect effects provide an explanation of abundance changes? Are effects of environmental factors better accounted for individually or as criteria defining the volume of water with suitable abiotic attributes? Strong evidence was found of density-dependent population regulation. The density of prey was the most important environmental factor explaining variations in delta smelt abundance from 1972 to 2006 and over the recent period of decline in the abundance of the fish. Predation and water temperature showed possible effects. Entrainment of delta smelt at south Delta pumping plants showed statistically significant effects on adult-to-juvenile survival but not over the fish's life cycle. Neither the volume of water with suitable abiotic attributes nor other factors with indirect effects, including the location of the 2 ppt isohaline in the Delta in the previous fall ("fall X2"), explained delta smelt population trends beyond those accounted for by prey density.

[Supplementary materials are available for this article. Go to the publisher's online edition of *Reviews in Fisheries Science* for the following free supplemental resources: information on factor selection and specification; and estimating the volume of abiotic habitat.]

Keywords delta smelt, life-cycle model, multiple regression, effects hierarchy, pelagic organism decline

INTRODUCTION

It is a terrible juxtaposition of superlatives for the delta smelt. No other species currently protected under the federal Endangered Species Act has declined so dramatically since its listing. The index of abundance of delta smelt in the Sacramento-San Joaquin Delta has fallen almost three orders of magnitude since the fish was afforded protection in 1993 (California Department of Fish and Game [CDFG], 2010a). The need for immediate conservation responses is acute, but that need confronts another unfortunate delta smelt reality—perhaps less is known about the habitat of delta smelt, resources essential to its persistence, and the environmental stressors causing its low population numbers than is known about any other listed species. The life cycle of the tiny estuarine fish takes place in turbid, open waters, making it impossible to observe its behavior and

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account for many of its vital ecological relationships. Several candidate factors have plausible mechanisms of effect on delta smelt numbers, but previous attempts to relate environmental stressors to the decline of this fish were not able to identify the factors responsible for the recent declines in the abundance index to near-extinction levels. It might be fairly argued that no other federally listed species needs more immediate conservation attention, but a lack of reliable scientific guidance has hampered focused actions in support of delta smelt recovery.

The delta smelt is predominantly an annual species, with few individuals surviving to two years (Bennett, 2005). They are endemic to the San Francisco Bay-Delta Estuary. Delta smelt rear as juveniles and sub-adults upstream and downstream of the confluence of the Sacramento and San Joaquin Rivers for about seven months of the year, from late spring until the following winter (Bennett, 2005). Moyle (2002) described delta smelt as fish that "hang out in the water column and rely on their small size and transparency to hide them from predators in turbid water" (p. 228). Some delta smelt reside upstream in low salinity and fresh waters year around (Sommer et al., 2009). In winter, adults disperse into turbid waters that are necessary for efficient feeding of larvae on zooplankton (Baskerville-Bridges et al., 2004; Mager et al., 2004), with much of the population entering the Sacramento-San Joaquin Delta (Moyle, 2002). Spawning, triggered by increasing water temperature, begins as early as late February and can continue into June (Bennett, 2005). The environmental changes that have accompanied settlement and exploitation of the Delta have forced major adjustments in resources and conditions essential to survival and persistence of delta smelt.

No field data have been derived from experiments that directly relate delta smelt population responses to variation in physical and biotic conditions; however, general agreement exists both on the environmental features that seem to determine the location of delta smelt in the estuary and on stressors that could be contributing to decline of the fish. A conceptual model that describes and relates essential resources and suspected threat factors affecting population dynamics of delta smelt and other declining pelagic organisms in the Delta was developed by a multi-agency working group (Armor et al., 2005; Baxter et al., 2008; Baxter, 2010); however, no quantitative model has been available. Several recent studies have attempted to relate delta smelt population index data to suspected environmental stressors, but those studies had deficiencies that rendered their results uninformative (Feyrer et al., 2007; Mac Nally et al., 2010; Thomson et al., 2010).

Relating delta smelt population trends to changes in environmental factors that affect survival and reproduction of the fish, both directly (for example, predation, food supply, and entrainment) and indirectly (for example, flow and phytoplankton density), risks producing uninformative or confusing results. To maximize the likelihood of identifying actual causative relationships, the analysis presented here is initiated by developing an effects hierarchy that differentiates between those environmental covariates that act directly on the survival, reproduction, or recruitment of the delta smelt and those that act indirectly through one or more factors that act directly. This article focuses primarily on environmental factors with direct effects on survival or reproduction, leaving a rigorous attempt to identify indirect factors with important effects on direct factors for subsequent analyses (see Glibert et al., 2011, for example). This approach has three advantages. First, focusing on the limited number of variables with direct effects on delta smelt reduces the confounding effects of multi-collinearity and differential measurement error. When candidate causation factors are related to or interact with one another, the factor with lower measurement error may displace factors that have greater measurement error, even when those latter factors can be demonstrated to have greater effects signals (Zidek et al., 1996). Second, it reduces the possibility that identification of important environmental factors will be uninformative to decisions about resource management. This problem can arise if a factor with indirect effects is identified as itself important, but that factor acts through other factors that have direct or indirect effects. The best management response may involve controlling, or otherwise mitigating, not the environmental factor with an indirect effect identified as important, but rather, other factors. Third, arrangement of factors according to their hierarchy of effects provides information important in choosing the analytical method. Because pathways of effects can be delineated from knowledge of the mechanisms of ecological effects, a straightforward succession of multiple regression analyses, proceeding down each vertical path of the hierarchy, is suggested as the appropriate analytical approach to identifying the factors that best predict delta smelt population dynamics.

Several analysts have previously used measures of the volume of water with suitable attributes of conductivity, Secchi depth (as a measure of turbidity), and water temperature, which have been termed "abiotic habitat," to account for changes in abundance of delta smelt (e.g., Feyrer et al., 2007). In a subsequent biological opinion on delta smelt developed by the U.S. Fish and Wildlife Service (USFWS), inferences from those analyses were used to assert that a range of suitability in the extent of those abiotic factors limits abundance of delta smelt, and that increasing that extent is important to the recovery of delta smelt (USFWS, 2008). The hypothesis was tested that the volume of water within ranges of conductivity, Secchi depth, and water temperature at which most delta smelt occur explained variations in survival and reproduction. Several measures of that volume were developed and their effects on survival and reproduction were analyzed.

Index values for relative abundance of delta smelt were derived from standard trawler-generated data, specifically, the Fall Midwater Trawl (FMWT; CDFG, 2010a) and the Summer Townet Survey (STN; CDFG, 2010b). From relative abundance estimates, annual estimates of survival from juvenile to sub-adult life stages were developed, as well as survival and reproduction (hereinafter, referred to as "survival") across generations from sub-adult to juvenile life stages. Those estimates

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were used as response variables. Annual values for a variety of environmental variables were then developed, each of which could plausibly affect delta smelt population size and persistence. In doing so, the resource requirements and distribution of delta smelt at different sizes and in different stages in their life cycle were considered. From those candidate factors, a limited number were selected that offer the most plausible mechanism(s) of direct effect on delta smelt survival and abundance. In so doing, well-considered direct factors were differentiated from factors that may indirectly affect the size of and trend in delta smelt numbers through their effects on direct factors. From the abiotic and biotic factors in the Delta that appear to have direct effects on delta smelt, those that may be most important were selected, based on inferences drawn from available data and analyses. Multiple regression was used with three criteria to identify environmental factors that may be most important to survival and to evaluate the relative importance of those factors: goodness of fit of equations measured by the Akaike Information Criterion (AICc), the proportion of variation accounted for, and the significance of the regression coefficients. Using this general method, analyses were conducted to address three fundamental questions with important management implications: What is the relative importance of environmental factors that have direct effects on delta smelt abundance? Do environmental factors with indirect effects further explain abundance changes once effects of factors with direct effect are accounted for? Are the effects of environmental factors best accounted for independently or as criteria by which the volume of water with suitable attributes can be measured?

Based on the availability of data, these questions were directed at three periods in the annual life cycle of delta smelt—sub-adult (fall) to juvenile (summer), juvenile (summer) to sub-adult (fall), and sub-adult (fall) to sub-adult (fall). Because delta smelt has an annual life cycle, the last period is one version of a life-cycle model. Such a model has been identified as critically important in the development of a program to encourage recovery of delta smelt and to prevent jeopardizing its existence (Wanger, 2010). Analysis of the two within-year periods was carried out to better understand the factors that affect delta smelt survival between intermediate life stages during the year.

METHODS

Period of Analysis

The period of analysis covered the years 1972 through 2006. The initial year was selected because it was the first year of comprehensive surveys for zooplankton density throughout regions of the estuary occupied by delta smelt. The year 2006 was chosen because at the time this analysis began, comprehensive environmental data were only available through that year, and the period 2000 to 2006 includes the sharp decline in abundance of delta smelt that has persisted with little change since 2006.

Abundance and Survival

Two trawler-based surveys provide time-series population data from which long-term measures of annual delta smelt abundance can be estimated—the FMWT (1967–present), which samples sub-adult delta smelt, and the STN (1959–present), which samples for juveniles. Those data were used to provide the response variables representing delta smelt population size through time. An index of relative abundance has been calculated from both surveys by the CDFG since before 1970 (http://www.dfg.ca.gov/delta/). The indices are calculated by averaging catch per unit effort (for FMWT) or catch (for STN), assuming that volumes of water passing through the net are approximately the same for all STN tows over each Delta sub-region, then weighting the resulting averages by the estimated volume of water in the respective sub-region and summing sub-region estimates of abundance over all sub-regions. The FMWT index was used as calculated by the CDFG (http://www.dfg.ca.gov/delta/projects.asp?ProjectID=FMWT); this index is generally assumed to be the most accurate long-term index of delta smelt abundance, because it samples larger fish at approximately the same times each year over more stations than the STN. FMWT surveys were not conducted in 1974 and 1979, so those years were eliminated from the analysis.

There were concerns about the STN index. It is based on data from the first two surveys each year, and starting dates for the first survey can vary from year to year by as much as six weeks. Furthermore, more than one tow typically is made at each station, and catch is summed over all tow samples rather than averaged. It could not be confirmed that volumes of water in each sub-region used for the STN index were as accurate as those derived by detailed analysis of NOAA navigation charts. Therefore, despite the decades-long use of the STN index by analysts in this estuary, it was concluded that its flaws were too serious to justify its use as one of the two abundance variables in the present analyses, so an alternative estimate of summer juvenile delta smelt abundance was derived to overcome these problems. This estimate is referred to as "July abundance." It is based only on STN surveys that occur all or in part in July (the only month in which surveys occur each year), uses average rather than summed catch per tow, and uses updated volumes for each sub-region of the Bay Delta system.

Delta smelt survival is the response variable in the statistical analyses in this study. In these analyses, survival, as measured by index values, includes reproduction that occurs during the fall-to-summer period (that is, from pre-spawning adults in the fall to the next generation's juveniles in the July) and the fall-to-fall period (that is, a complete life cycle from pre-spawning adults in the fall to the next generation's pre-spawning adults the following fall). Three measures of delta smelt survival can be derived from the two abundance indices—fall-to-summer

survival, summer-to-fall survival, and fall-to-fall survival. Environmental factors that can reasonably be surmised to affect each of these three measures of survival were analyzed. Analyses of the former two measures provided insight into more important factors affecting fall-to-fall survival.

Environmental Factors and Their Hierarchy of Effects

Drawing on agency reports, several dozen biotic and abiotic factors were specified, that is, identified and quantified, along with variations of those factors, that have plausible mechanisms of effect on the abundance of delta smelt (Armor et al., 2005; Baxter et al., 2008; USFWS, 2009; Baxter, 2010) and for which data were available. Each factor was carefully specified, with consideration of the distribution of delta smelt and ranges of factor variation at different times of the year. Data on delta smelt distribution and environmental factors were segregated into sub-regions of the estuary, shown in Figure 1. Based on their mechanisms of effects, environmental factors were segregated into those with direct effects on delta smelt abundance and those with indirect effects, that is, effects that act through other factors that have direct effects. Factors that have direct effects on survival of delta smelt were grouped into categories (for example, water temperature, prey densities, entrainment at water export pumps); the same was done for factors with indirect effects on the smelt. Descriptions of each factor are in supplemental material to this article, along with the rationale for the selection of each factor and method used for its quantification. Figure 2 illustrates the general categories of factors, arranged as an "effects hierarchy." Apparent in the diagram is that certain factors—such as turbidity, water temperature, and flows through the Delta—appear at several locations in the hierarchy and may act indirectly on delta smelt, often in combination with other indirect factors. Data were available for all direct factors except disease and contaminants; however, effects of disease and contaminants on factors with indirect effect would be manifested as changes in factors with direct effect.

A Sawtooth Pattern in Survival

A pronounced inter-year "sawtooth" pattern in the survival of delta smelt was identified, that is, a persistent pattern of alternating years with higher and lower survival. This pattern was nearly identical in fall-to-summer and fall-to-fall index sequences, as shown in Figure 3. The probability was simulated that alternating peaks and troughs for 13 years would occur, as they did for years 1987 to 2000, if survival were random from year to year. This probability was estimated as 0.025—likely an overestimate because of the actual decreasing trend in delta smelt abundance over that period. Based on this analysis, it was concluded that there was a very low probability that this pattern occurred by chance. Two possible causes of the pattern were considered, one being the effect on delta smelt numbers of an environmental factor or combination of factors that exhibit corresponding, year-to-year sawtooth variation, and the other being an inherent aspect of the physiological ecology and/or

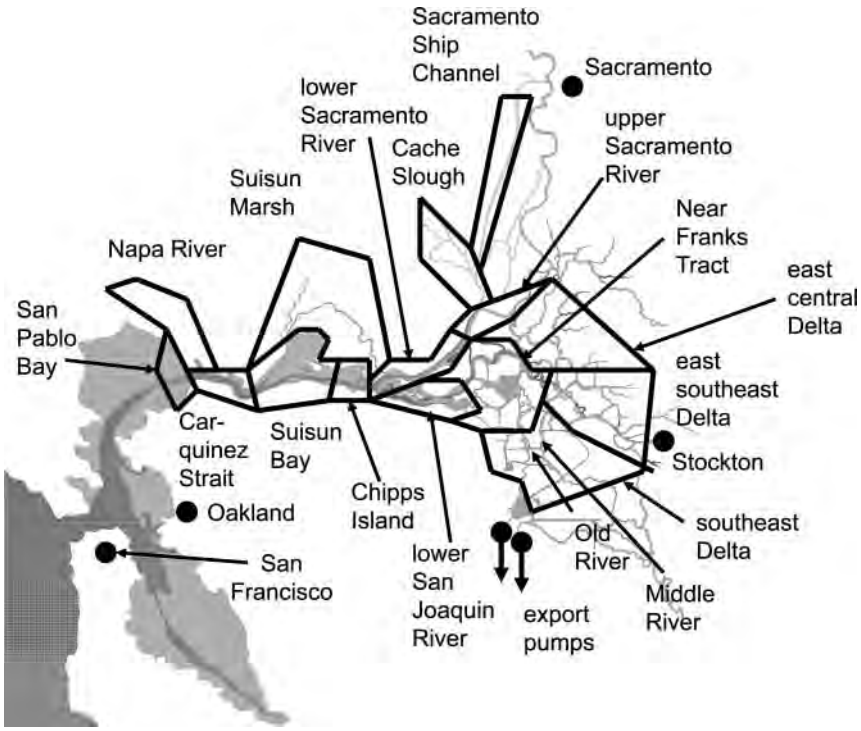

Figure 1 Sub-regions of the Bay-Delta Estuary.

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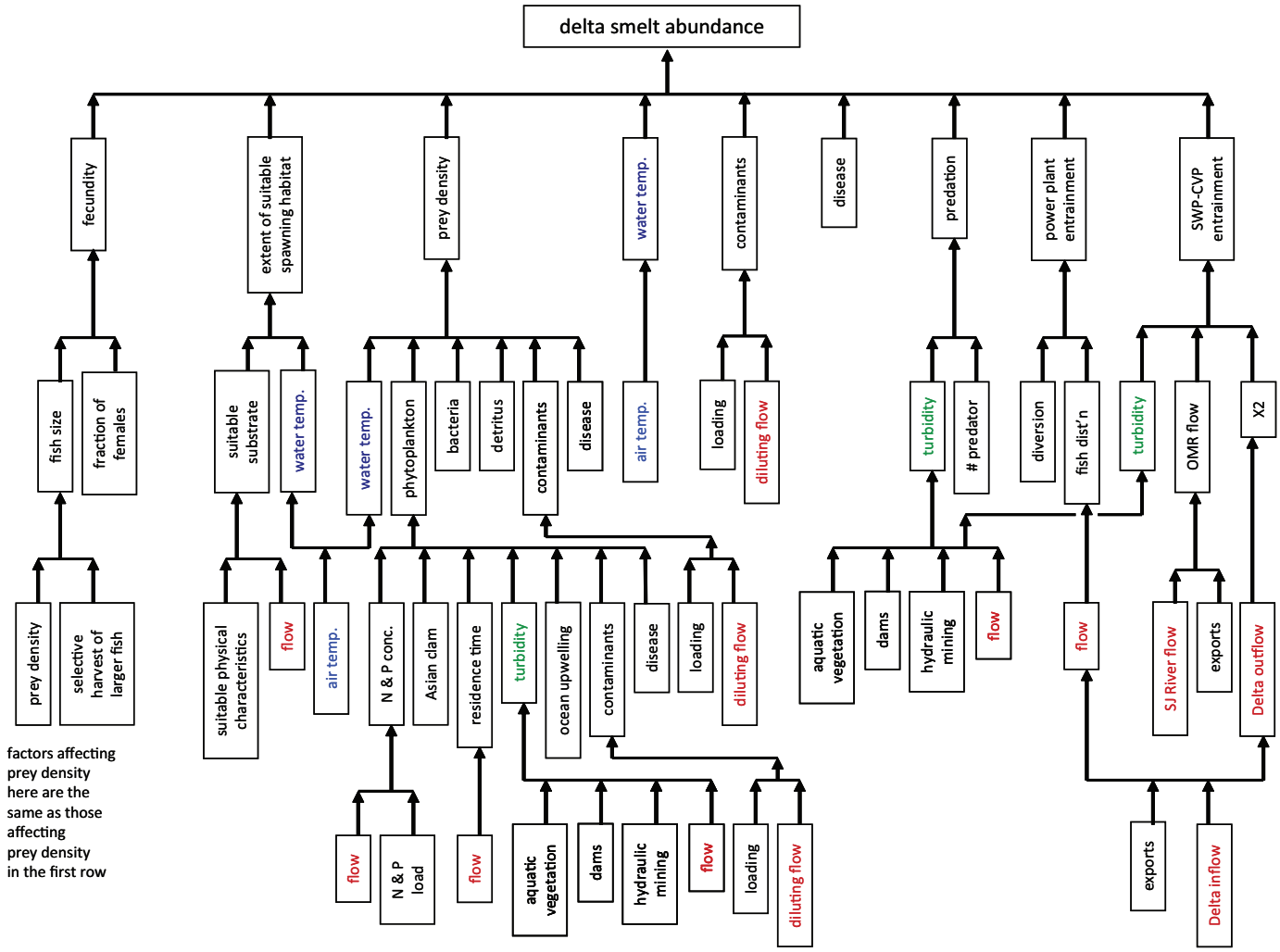

Figure 2 A simplified effects hierarchy of factors affecting delta smelt abundance. Row one, below delta smelt abundance, shows the factor categories that act directly to affect delta smelt. Row two includes factors that act indirectly on the fish. Rows three and four represent second-order and third-order indirect factors. Factors appearing in several locations are colored (color figure available online).

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behavior of delta smelt. Relationships were examined between the sawtooth pattern and environmental factors with both direct and indirect effects on delta smelt. No factor or factors could be identified that explained the sawtooth pattern for more than a few sequential years, so it was concluded that an inherent cause seems more tenable. This effect was captured by including abundance from the year previous to that over which survival was estimated, a term referred to herein as "previous-previous fall abundance."

Identifying Best Regression Equations Using Factors with Direct Effect

General Approach

From each category of environmental factors with direct effects, represented as the factors in the first row in Figure 2, one or two initial factor quantifications were selected that, based on available knowledge of delta smelt biology, were likely to be most important in determining delta smelt survival. Values of those environmental factors are shown in Table 1. The reasons for their selection are presented in supplemental material. Then the effect of each of these factors was analyzed, along with previous delta smelt abundance (to capture effects of density dependence) and previous-previous fall abundance (to capture effects of the sawtooth pattern in survival). Statistical methods for this analysis are described below and are based on two key assumptions: that the FMWT and July abundance indices are approximately proportional to delta smelt abundance, and that the abundance index at one point in time is proportional to the abundance index at a previous time, apart from the effects of measured variables, sampling errors, process error variation, and density-dependent effects.

The analysis was initiated using the Ricker model (Ricker, 1958). This model assumes that the population abundance at

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Table 1 Factors with direct effect on delta smelt selected as most important to fall-to-summer, summer-to-fall, and fall-to-fall survival

	July abundance	FMWT index	Previous FMWT index	Spawning period, days of water temperature 11–20°C	Average water temperature Apr–Jun (°C)	Average water temperature July (°C)	Maximum two-week average water temperature Jul–Sep (°C)	Minimum *Eurytemora* + *Pseudodiaptomus* Apr–Jun (#/m^3)	Average *Eurytemora* + *Pseudodiaptomus* July (#/m^3)	Average *Eurytemora* + *Pseudodiaptomus* Jul–Aug (#/m^3)	Secchi depth Apr–Jun (cm)	Adjusted Kimmerer proportional entrainment	Previous Sep–Dec striped bass adult abundance and Secchi depth	Previous Sep–Dec abundance other predators and Secchi depth	Apr–Jun abundance of other predators and Secchi depth	Sep–Dec striped bass adult abundance and Secchi depth	Sep–Dec abundance other predators and Secchi depth	Average length of delta smelt in December (mm)
Year	*Jab*	*Fab*	*PFAb*	*SpDys*	*TpAJ*	*TpJul*	*TpJS*	*EPAJ*	*EPJul*	*EPJA*	*SecAJ*	*Entrain*	*PStBass*	*PPreds1*	*Preds2*	*StBass*	*Preds1*	*DSLth*
1972	20,005	1,265	1,303	110	17.8	21.3	21.8	1,244	4,725	4,303	30	0.229	24,855	490	354	36,498	586	65.3
1973	11,185	1,145	1,265	104	18.6	21.3	21.9	754	1,547	2,082	32	0.110	36,498	586	793	27,596	1,041	65.3
1974	12,147		1,145	85	17.7	21.0	22.5	614	4,202	3,799	30	0.091	27,596	1,041	446	32,314	850	65.3
1975	8,786	697		92	17.2	20.1	21.5	480	1,520	1,545	26	0.094	32,314	850	280	41,650	735	65.1
1976	24,000	328	697	130	17.6	21.4	21.9	666	4,125	2,895	31	0.262	41,650	735	6,118	65,427	19,410	65.3
1977	25,965	480	328	118	17.0	21.1	21.5	581	4,194	3,972	33	0.256	65,427	19,410	7,095	40,655	22,324	65.6
1978	31,758	572	480	110	17.8	21.1	22.4	1,458	2,082	1,391	30	0.077	40,655	22,324	8,423	28,399	14,726	65.3
1979	5,484		572	90	18.0	21.0	22.1	517	947	722	28	0.160	28,399	14,726	18,631	25,761	37,712	67.8
1980	7,068	1,654	137	137	16.8	20.5	22.5	428	548	647	34	0.038	25,761	37,712	15,120	20,254	20,360	70.3
1981	6,300	374	1,654	108	18.7	21.8	22.8	788	922	724	37	0.199	20,254	20,360	17,070	20,621	22,248	67.2
1982	7,242	333	374	105	17.0	20.6	21.4	19	636	670	37	0.069	20,621	22,248	23,570	21,560	30,605	66.2
1983	1,390	132	333	102	17.3	20.7	22.2	271	530	544	34	0.020	21,560	30,605	13,957	31,059	28,422	62.2
1984	779	182	132	100	18.3	22.4	22.8	251	1,560	1,545	41	0.144	31,059	28,422	20,444	35,459	29,082	69.5
1985	387	110	182	105	18.5	22.0	22.5	135	548	543	43	0.231	35,459	29,082	30,364	46,997	62,483	69.1
1986	3,057	212	110	122	18.1	21.2	21.5	649	626	534	36	0.019	46,997	62,483	22,921	22,752	30,255	68.1
1987	2,743	280	212	102	19.0	20.6	21.3	534	392	519	44	0.199	22,752	30,255	26,771	41,144	42,089	64.8
1988	764	174	280	125	17.8	22.4	23.1	119	364	360	43	0.282	41,144	42,089	26,668	30,207	36,828	69.5
1989	647	366	174	108	17.9	21.1	21.7	384	2,558	3,641	42	0.222	30,207	36,828	24,067	29,441	38,551	67.8
1990	747	364	366	100	18.4	22.0	22.7	200	3,616	3,837	43	0.274	29,441	38,551	26,671	32,336	57,128	63.9
1991	2,486	689	364	108	17.2	21.3	21.8	151	2,542	3,059	38	0.231	32,336	57,128	23,754	39,881	63,209	62.5
1992	471	156	689	99	19.2	21.3	22.5	532	2,733	2,828	44	0.201	39,881	63,209	42,138	44,102	89,736	57.9
1993	5,763	1,078	156	112	17.8	21.5	22.2	603	1,184	1,425	42	0.119	44,102	89,736	25,301	27,938	48,487	54.7
1994	4,156	102	1,078	102	17.8	21.1	21.4	1,112	965	856	56	0.139	27,938	48,487	53,729	32,635	61,942	62.9
1995	2,490	899	102	142	17.0	21.5	22.0	574	2,366	1,431	44	0.064	32,635	61,942	38,412	34,966	59,091	58.5
1996	6,162	127	899	115	18.3	21.4	22.6	381	533	731	49	0.016	34,966	59,091	52,547	44,927	72,056	55.1
1997	2,362	303	127	104	19.3	21.2	21.8	369	590	800	44	0.093	44,927	72,056	33,056	56,551	64,436	57.6
1998	2,209	420	303	117	16.3	21.3	22.6	272	1,002	842	40	0.003	56,551	64,436	21,106	32,979	25,623	59.3
1999	7,478	864	420	112	17.3	21.3	22.0	752	1,308	1,091	41	0.052	32,979	25,623	21,961	42,465	29,853	59.1
2000	4,178	756	864	118	18.9	20.8	22.2	411	825	1,007	44	0.097	42,465	29,853	50,114	60,639	74,907	59.3
2001	2,897	603	756	73	19.5	21.3	22.0	424	758	484	42	0.133	60,639	74,907	50,992	48,811	81,186	63.5
2002	1,115	139	603	108	18.6	21.8	22.2	105	641	462	45	0.206	48,811	81,186	59,540	32,632	75,565	62.2
2003	1,329	210	139	106	18.0	22.2	23.2	136	787	1,525	47	0.175	32,632	75,565	56,424	40,081	86,509	58.6
2004	649	74	210	108	19.1	21.3	22.3	154	354	1,012	44	0.187	40,081	86,509	50,151	82,253	109,036	62
2005	393	27	74	123	18.1	22.0	22.8	57	849	466	51	0.049	82,253	109,036	68,310	58,943	119,419	59.6
2006	352	41	27	95	17.8	22.6	23.7	122	1,321	884	43	0.012	58,943	119,419	53,328	41,977	116,848	58
Fall-to-summer	■		■	■	■	■		■	■		■	■	■	■	■			■
Summer-to-fall	■	■					■			■						■	■	
Fall-to-fall	■		■	■	■		■	■		■	■	■			■			■

The last three rows are shaded to indicate the survival period to which each factor is relevant.

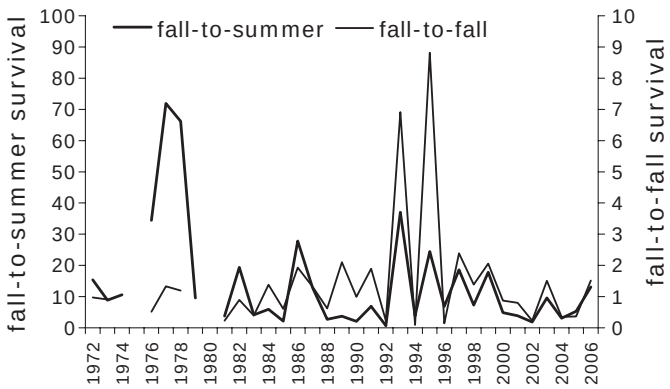

Figure 3 Delta smelt survival values from fall to summer and from fall to fall, which are derived from survey index values.

time $t + 1$ is related to the abundance at time t by an equation of the form

$$N_{t+1} = N_t \mathrm{Exp}\{r(1 - N_t/k)\}, \quad (1)$$

where r is the intrinsic growth rate, and k is the carrying capacity for the population. Taking natural logarithms gives

$$\mathrm{Ln}(N_{t+1}/N_t) = r - (r/k)N_t$$

and a linear relationship of the form

$$\mathrm{Ln}(N_{t+1}/N_t) = A + BN_t \quad (2)$$

relating the change ratio N_{t+1}/N_t to the density-dependent term BN_t. A generalization of this model assumes that the right-hand side of equation 1 also includes multiplicative effects of p variables $X_1, X_2, \ldots, X_p$, so that

$$N_{t+1} = N_t \mathrm{Exp}\{r(1 - N_t/k)\} \times \mathrm{Exp}(\alpha + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p), \quad (3)$$

where α is a constant. Equation 2 then becomes

$$\mathrm{Ln}(N_{t+1}/N_t) = \beta_0 + BN_t + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p, \quad (4)$$

where $\beta_0 = A + \alpha$ is a constant.

A further generalization of the Ricker model includes a term for delta smelt abundance two years before a given population year, allowing characterization of the sawtooth pattern in survival, so that it becomes

$$\mathrm{Ln}(N_{t+1}/N_t) = \beta_0 + BN_t + CN_{t-1} + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p, \quad (5)$$

where C is another regression coefficient. This equation applies when the change in abundance from time t to time $t + 1$ depends to some extent on population abundance both at time t and at time $t - 1$.

Abundance Changes from Fall to Summer

For changes in abundance from fall to summer, the equivalent to equation 5 is

$$\mathrm{Ln}(JAb_{t+1}/FAb_t) = \beta_0 + BFAb_t + CFAb_{t-1} + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p, \quad (6)$$

where JAb_{t+1} is the July abundance in year $t + 1$, and FAb_t is the fall abundance in year t.

In practice, equation 6 will have a process error; the value of the dependent variable will be the value predicted by the right-hand side of the equation plus an error e_t. Also, observed values of $\mathrm{Ln}(JAb_{t+1})$ and $\mathrm{Ln}(PFAb_t)$ and FAb_t and FAb_{t-1} will have sampling errors. This raises the possibility of biases in the estimated values of coefficients on the right-hand side of the equation, if these are estimated by ordinary multiple linear regression.

For this reason, the Solow (1998) method for fitting population models with sampling errors in abundance estimates was initially considered for the estimation of equation 6 and the models below for summer-to-fall and fall-to-fall changes in delta smelt abundance. Essentially, this method uses the principle of simulation and extrapolation (SIMEX) to first simulate an increase in the level of sampling errors in abundance estimates, then it extrapolates to estimate outputs with no sampling errors in the abundance estimates. Use of the Solow method indicated that any biases in the estimated coefficients of X variables are quite small due to sampling errors in the delta smelt abundance indices. Therefore, it was concluded that ordinary multiple regression is appropriate for estimating equation 6 and the equations for summer-to-fall and fall-to-fall changes in the abundance of delta smelt.

Nevertheless, the extent of possible biases was investigated further by simulating data based on fitted versions of equation 6. First, the value of $\mathrm{Ln}(JAb_{t+1}/FAb_t)$ was set equal to the right-hand side of the estimated equation 6 plus a normally distributed process error with a mean of zero. Normally distributed sampling errors were then added to the values of $\mathrm{Ln}(JAb)$ and $\mathrm{Ln}(FAb)$ with means of zero and standard deviations obtained by bootstrap resampling of the FMWT and STN data as described by Manly (2010a, 2010b). The simulated data with process errors and sampling errors were then used to obtain multiple regression estimates of the parameters β_0, B, C, and β_1 to β_p of equation 6. The generation of simulated data was repeated 10,000 times. Mean values of the estimated parameters were compared with the values used to generate the data to establish whether sampling errors in abundance indices introduce important biases in the estimates. Standard deviations in the simulated parameter estimates were also compared with the standard errors obtained from the original regression to estimate equation 6 using the observed data to see if any biases are introduced by sampling errors in the abundance indices. This simulation confirmed that the estimates and standard errors obtained by ordinary regression have negligible biases due to

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sampling errors in the abundance indices, as was expected from the Solow (1998) analysis.

Abundance Changes from Summer to Fall

For summer-to-fall abundance changes, the equivalent to equation 5 becomes

$$\mathrm{Ln}(FAb_t/JAb_t) = \beta_0 + BJAb_t + CJAb_{t-1} + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p.$$

In this case, it is not clear why the abundance of delta smelt in the fall of a given year should depend on the abundance in July in the previous year. There was no evidence of a sawtooth pattern in survival from summer to fall, the effect of which might be captured by this abundance measure, and initial analyses gave no evidence for this type of effect. Therefore, the equation was modified to

$$\mathrm{Ln}(FAb_t/JAb_t) = \beta_0 + BJAb_t + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p. \quad (7)$$

As for abundance changes from fall to summer, there will be process errors in the results from equation 7 and sampling errors in the abundance indices; simulation was used to ensure that these errors do not introduce large biases in the estimated parameters for the equation when they are estimated by ordinary multiple regression. The simulations were carried out in a similar fashion to the simulations used with equation 6. As for the fall-to-summer analysis, this showed negligible bias in estimates and standard errors obtained using ordinary regression due to sampling errors in abundance indices.

Abundance Changes from Fall to Fall

For the fall-to-fall changes in the FMWT abundance index, the equivalent to equation 5 becomes

$$\mathrm{Ln}(FAb_{t+1}/FAb_t) = \beta_0 + BFAb_t + CFAb_{t-1} + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p, \quad (8)$$

where the terms $B\ FAb_t$ and $C\ FAb_{t-1}$ imply that the change in delta smelt abundance from one fall to the next depends on the initial abundance and also the abundance in the fall of the previous year.

As for fall-to-summer and summer-to-fall changes, the use of equation 8 will be affected by process errors and sampling errors in the estimated abundance indices. However, the sampling errors in abundances are particularly likely to introduce biases in estimated parameters for equation 8 when using ordinary multiple regression because of the estimated value of FAb_t residing on both sides of the equation. Simulation was again used to ensure that these biases are relatively small using similar methods to those used with equations 6 and 7. This simulation showed negligible biases in the estimated constant term and in the coefficients of the X variables in equation 8 and negligible biases in the estimated standard errors of these parameters. The simulation indicated that the coefficient of FAb_t has a negligible bias, but the coefficient of FAb_{t-1} has a negative bias of about 10%; at the same time, the standard errors of these estimated density-dependent effects tend to be slightly higher than the estimates from ordinary regression. Using regression to estimate the effects of factors on delta smelt abundance seems to work well, but it should be noted that there may be small bias in estimated density-dependent effects.

This initial analysis used the factors in Table 1 and was carried out as follows. Multiple regression was used to estimate the corrected AICc, to account for the proportion of variation, and to estimate the significance and sign of the regression coefficients for all possible equations using all or some of the initial-analyses factors. From among those equations selected as exhibiting explanatory importance, equations with the lowest AICc and equations with AICc values that were within two units of the lowest AICc were selected (following Burnham and Anderson, 1998). In all cases, equations were restricted to those for which each environmental factor had a level of significance less than 0.10 and coefficients with signs consistent with their hypothesized effect. This analysis identified the abundance and environmental factors that produced the best regression equations for the initial analyses.

Adding Other Factors with Direct Effect to the Best Equations from the Initial Analysis

Using the methods described above, further analyses were carried out to see if the addition of other factors with presumed direct effect, or other ways of quantifying factors from among those not selected for initial analyses, showed important effects. These factors are shown in Table 2. Factors were added sequentially to the best regression equations to assess what portion of the variation in Ln(*Survival*) was explained by each factor. If any of these "secondary" direct factors proved to be important according to the above criteria, it reflected imperfect *a priori* understanding of the relationship between delta smelt and the specific environmental variables. In subsequent analyses, regression equations were used that contained factors with direct effect that can be identified as important from the combined results of these two analyses; these are herein referred to as the best regression equations based on factors that have direct effect.

It should be noted that this method—adding factors to regression equations—cannot completely eliminate problems arising from collinearity among factors; however, because the analysis is restricted to factors that have direct effects on delta smelt, the effects of collinearity are diminished relative to those that would have occurred had all factors that may have indirect effects on delta smelt been included.

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Table 2 Factors with direct effect not selected as most important in initial analyses of fall-to-summer, summer-to-fall, and fall-to-fall survival

Year	July abundance *Jab*	FMWT index *Fab*	Previous FMWT index *PFAb*	Deviation of water temperature from 16°C Mar–May degree-days *TpMM*	Deviation of water temperature from 17°C Apr–July degree-days *TpAJ*	Average *Eurytemora* April 30 (#/m^3) *EuApr*	Average *Eurytemora* + *Pseudodiaptomus* Apr–June (#/m^3) *EPAJ1*	Minimum total calanoid copepod biomass Apr–June (mg C/m^3) *CCAJ*	Average *Limnoithona* April–June (#/m^3) *LimAJ*	Average *Limnoithona* July (#/m^3) *LimJuly*	Average *Limnoithona* July–August (#/m^3) *LimJA*	Average *Eurytemora* + *Pseudodiaptomus* Sep–Dec (#/m^3) *EPSD*	Average *Limnoithona* Sep–Dec (#/m^3) *LimSD*	Average *Eurytemora* + *Pseudodiaptomus* Jan–Mar (#/m^3) *EPJM*	Average *Limnoithona* Jan–Mar (#/m^3) *LimJM*
1972	20,005	1,265	1,303	121	323	2,552	2,298	2,681	0	0	0	2,826	0	346	0
1973	11,185	1,145	1,265	232	354	2,914	1,997	2,220	0	0	0	2,042	0	767	0
1974	12,147		1,145	191	329	1,522	2,606	446	0	0	0	1,659	0	1,586	0
1975	8,786	697		274	376	734	998	711	0	0	0	666	0	184	0
1976	24,000	328	697	238	356	1,144	1,021	876	0	0	0	718	0	570	0
1977	25,965	480	328	201	300	1,071	1,022	872	0	0	0	680	0	1,193	0
1978	31,758	572	480	156	328	1,765	3,341	1,445	0	0	0	1,250	0	465	0
1979	5,484		572	207	369	893	1,140	1,494	0	0	0	907	0	513	0
1980	7,068	1,654		161	218	305	713	4,632	0	0	0	760	353	573	0
1981	6,300	374	1,654	233	415	845	1,006	2,610	5	15	824	588	1,084	516	5
1982	7,242	333	374	266	324	307	1,065	266	5	207	495	246	1,211	530	20
1983	1,390	132	333	232	377	11	594	138	0	184	757	20	2,037	25	0
1984	779	182	132	158	379	248	581	1,823	19	62	636	446	1,762	116	0
1985	387	110	182	192	337	175	327	3,496	106	1,271	2,008	494	1,490	193	0
1986	3,057	212	110	110	315	1,134	1,511	2,404	3	81	157	512	241	0	0
1987	2,743	280	212	264	326	2,015	1,184	2,466	114	633	1,056	228	998	449	0
1988	764	174	280	132	320	2,261	1,068	947	53	266	398	1,045	276	24	0
1989	647	366	174	151	266	632	2,909	1,621	48	192	134	2,255	128	117	0
1990	747	364	366	191	311	574	3,645	1,188	61	17	68	2,019	107	234	0
1991	2,486	689	364	205	315	470	1,513	162	6	27	44	1,480	91	47	0
1992	471	156	689	185	363	1,343	6,219	3,237	5	14	39	1,312	30	63	0
1993	5,763	1,078	156	153	320	776	4,074	1,783	0	218	751	1,047	5,466	125	28
1994	4,156	102	1,078	128	286	5,716	2,888	3,277	913	21,679	25,613	458	11,179	28	202
1995	2,490	899	102	168	309	560	2,046	985	894	9,070	14,901	648	4,344	52	54
1996	6,162	127	899	185	340	470	1,684	1,197	343	10,455	13,451	365	5,331	62	561
1997	2,362	303	127	192	359	650	1,924	1,494	1,917	20,440	21,622	466	17,468	66	185
1998	2,209	420	303	191	301	160	3,971	402	6,788	7,749	9,663	1,155	4,873	82	617
1999	7,478	864	420	246	323	1,740	1,710	987	1,378	17,586	18,700	540	30,340	101	1,231
2000	4,178	756	864	166	311	540	2,842	834	2,850	19,624	12,580	817	24,404	76	2,530
2001	2,897	603	756	240	433	520	1,838	1,045	4,165	37,284	33,272	222	19,672	46	1,765
2002	1,115	139	603	143	326	340	578	845	3,676	37,266	32,897	398	23,642	86	3,617
2003	1,329	210	139	167	404	80	1,411	1,996	2,137	43,190	21,778	363	18,635	94	4,197
2004	649	74	210	162	328	100	824	1,482	4,396	27,296	26,731	266	18,747	59	600
2005	393	27	74	151	361	220	726	1,233	815	19,423	26,595	295	14,849	49	395
2006	352	41	27	292	437	161	3,264	200	1,703	32,331	36,409	356	14,789	153	1,249
Fall-to-summer															
Summer-to-fall															
Fall-to-fall															

The last three rows are shaded to indicate the survival period to which each factor is relevant.

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Comparing the Relative Contribution of Each Factor to the Explained Variation in Ln (Survival)

Using the best equations for fall-to-summer, summer-to-fall, and fall-to-fall survival, based on factors with direct effect, the relative contribution of each factor to the percentage of variation in Ln(*Survival*) was assessed.

Testing of Selected Factors with Potential Indirect Effect on Survival

Although the present approach to identifying the dominant environmental stressors acting on delta smelt is based on the effects hierarchy displayed in Figure 2, the analysis was extended to see if addition of selected indirect factors to equations that are based on factors with direct effects on delta smelt might further contribute to explaining variation in survival. This was done by focusing on the fall-to-fall model, both because that period of analysis represents a complete life cycle and because it limits the number of correlations that can be attempted and, therefore, limits the possibility of spurious correlations arising by chance. The selection criteria, described above for analysis of direct factors were used to test the importance of six indirect factors when added to the best fall-to-fall equation based on the direct factors. The number of indirect factors was restricted to avoid producing uninformative, multiple-factor equations by chance. Six indirect factors were selected from those identified as important to survival in other studies of pelagic fishes in the Delta (Kimmerer, 2002; Feyrer et al., 2007; Grimaldo et al., 2009; Mac Nally et al., 2010; Thomson et al., 2010). The selected factors are presence/absence of the Asian clam (*Corbula amurensis*), the value of X2 (the distance along the main channel from the Golden Gate Bridge to the 2 ppt isohaline, a measure of estuary salinity) averaged over the previous fall ("fall X2"), average Secchi depth in January–March, average ammonium concentration in the Chipps Island and Suisun Bay sub-regions (see Figure 2) in April–June, and Old and Middle Rivers (OMR) flow (that is, flows steered to the south Delta water export pumps) averaged over December–March and April–June. Values of these six indirect factors are shown in Table 3.

Testing Effects of Measures of Abiotic Habitat Volume on the Best Fall-to-Fall Regression Equation

The importance of a combination of conductivity, Secchi depth, and water temperature—deemed abiotic habitat in a previous study (Feyrer et al., 2007)—were analyzed both alone and weighted by prey density. Estimates were made of the volume of water with levels of conductivity, Secchi depth, and water temperature at which virtually all delta smelt occur. These ranges of suitable values were compared with actual values of conductivity, Secchi depth, and water temperature for each month and sub-region (see Figure 1) for the period 1972–2006. Based on estimated volumes of water in each sub-region, the volume of water with suitable abiotic (physical) characteristics available to delta smelt in each month was estimated. These estimated volumes alone were used, and they were weighted with the sum of densities of the prey species *Eurytemora* and *Pseudodiaptomus*. Seasonal average and minimum monthly values of these volumes and prey-weighted volumes were used in the best regression equations based on factors having direct effect on delta smelt abundance to establish whether volume or prey-weighted volume measures met criteria for inclusion in the best regression equation for fall-to-fall survival, either as an addition to or, in the case of prey density, replacement for factors with direct effect.

RESULTS

Statistical Analysis to Identify the Best Regression Equations Using Factors with Direct Effect

Initial analyses were carried out using the factors in Table 1—those environmental factors with direct effect on delta smelt—that were selected as most likely to be important in determining delta smelt abundances based on biological considerations. From among those factors, the most important affecting survival from fall to summer, summer to fall, and fall to fall were identified based on the above-described criteria. Results are shown in Table 4.

From the factors considered in these initial analyses, the most important to fall-to-summer survival (by virtue of their appearance in the best regression equation) are previous-previous fall abundance, previous fall abundance, minimum *Eurytemora* + *Pseudodiaptomus* in April–June, and proportional entrainment of adult and larval-juvenile delta smelt, with some indication that average water temperature in April–June is also important. For survival from summer to fall, the most important factors are July abundance and average *Eurytemora* + *Pseudodiaptomus* density in July–August. For survival from fall to fall, the most important factors are previous-previous fall abundance, previous fall abundance, and minimum *Eurytemora* + *Pseudodiaptomus* in April–June, with some indication that predation in April–June by predators other than striped bass (inland silverside, largemouth bass, crappie, and sunfish) is also important.

Among the factors with direct effects selected for the initial analysis, the number of days of spawning, July water temperature, *Eurytemora* + *Pseudodiaptomus* in July, Secchi depth (turbidity) in April–June, predation by striped bass, and delta smelt fecundity did not appear in the best regression equations for fall-to-summer survival. Maximum two-week average water temperature in July–September and predation did not appear in the best regression equations for summer-to-fall survival. The number of days of spawning, average water temperature in April–June, maximum two-week average water temperature in July-September, average *Eurytemora* + *Pseudodiaptomus* availability in July–August, Secchi depth (turbidity) in April–June, entrainment, predation by striped bass, and delta smelt fecundity did not appear in the best regression equations for fall-to-fall survival.

Table 3 Factors with indirect effect on delta smelt abundance, selected for analysis based on results of other studies

Year	Presence (1) or absence (0) of Asian clam	Previous Oct–Dec avg X2, km of 2 ppt line from Golden Gate	Previous Sept–Dec Secchi depth in sub-regions occupied by delta smelt habitat (cm)	Secchi depth Jan-Mar (cm)	Average ammonium in Chipps Island and Suisun Bay sub-regions, Apr–June (mg/L)	Average December–March flow in Old and Middle Rivers (cfs)	Average April–June flow in Old and Middle Rivers (cfs)
	AsClam	*PODX2*	*PFSec*	*JMSec*	*AJAm1*	*DMOMR*	*AJOMR*
1972	0	71	35	41	0.046	−2,260	−6,606
1973	0	71	38	26	0.034	953	−4,790
1974	0	66	37	35	0.024	−940	−4,955
1975	0	68	41	36	0.045	−2,093	−3,736
1976	0	70	42	51	0.047	−6,033	−5,491
1977	0	89	56	48	0.059	−4,054	−3,037
1978	0	92	58	17	0.027	−4,231	3,827
1979	0	77	40	34	0.027	−686	−5,487
1980	0	79	40	27	0.040	3,887	−1,142
1981	0	79	39	33	0.037	−4,678	−5,342
1982	0	75	42	31	0.035	−3,736	2,769
1983	0	63	42	25	0.040	9,124	14,610
1984	0	58	49	53	0.038	6,026	−5,623
1985	0	70	49	66	0.065	−5,023	−6,424
1986	0	88	61	45	0.039	−732	413
1987	1	78	41	50	0.047	−4,474	−5,471
1988	1	88	55	41	0.073	−8,006	−6,765
1989	1	90	51	44	0.058	−7,645	−7,198
1990	1	88	54	47	0.080	−9,086	−5,858
1991	1	89	62	58	0.083	−5,356	−4,752
1992	1	88	62	60	0.065	−5,561	−3,073
1993	1	87	64	29	0.034	−5,765	−2,304
1994	1	82	58	58	0.093	−4,742	−1,613
1995	1	86	60	31	0.033	−3,145	4,721
1996	1	75	55	37	0.036	−1,281	−2,848
1997	1	78	57	29	0.087	10,376	−3,972
1998	1	81	61	29	0.043	2,103	6,536
1999	1	69	45	51	0.060	−760	−2,155
2000	1	83	47	48	0.065	−5,282	−4,338
2001	1	85	53	45	0.089	−5,681	−2,919
2002	1	82	53	36	0.070	−7,731	−3,857
2003	1	84	50	36	0.055	−8,185	−5,374
2004	1	83	58	34	0.080	−8,080	−4,851
2005	1	82	65	48	0.055	−5,525	−1,055
2006	1	82	68	39	0.040	−3,214	10,026

Additional analyses were carried out using factors with direct effects that were not selected for the initial analyses. These were added to the best equations from the initial analyses to see whether they made a significant improvement. Results of this analysis, shown in Table 5, indicate that average *Eurytemora* + *Pseudodiaptomus* density in January–March should be added as an important factor that explains survival from fall to summer. Average *Eurytemora* + *Pseudodiaptomus* density in September–December should replace average *Eurytemora* + *Pseudodiaptomus* density in July–August as an important factor explaining survival from summer to fall and should be added to the regression equation for fall-to-fall survival.

Of the factors with direct effect on delta smelt population dynamics that was used for the additional analyses, the number of degree-days of deviation of water temperature from optimum in March–May or April–July; average *Eurytemora* density in late April; average *Eurytemora* + *Pseudodiaptomus* density in April–June; and average *Limnoithona* density in April–June, July, or January–March did not appear in the best regression equations for fall-to-summer survival. Average *Limnoithona* density in July–August and September–December did not appear in the best regression equation for summer-to-fall. None of these factors appeared in the best regression equations for fall-to-fall. There was some evidence that minimum calanoid copepod biomass in April–June was important for fall-to-summer survival but not survival from fall-to-fall.

The best regression equations based on factors with direct effects on delta smelt abundance were derived from the best regression equations from the initial analyses, as adjusted by results from the additional analyses using factors with direct effect that were not selected for the initial analyses.

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Table 4 Summary of results of initial analyses of factors with direct effect that were selected as important based on the most reliable knowledge of delta smelt biology

			Initial analyses factors with direct effect on delta smelt survival																	
			Previous previous fall abundance	Previous fall abundance	July abundance	Spawning period, days of water temperature 11–20ºC	Average water temperature Apr–Jun (ºC)	Average water temperature July (ºC)	Maximum two-week average water temperature Jul–Sep (ºC)	Minimum *Eurytemora + Pseudodiaptomus* Apr–Jun (#/m^3)	Average *Eurytemora + Pseudodiaptomus* July (#/m^3)	Average *Eurytemora + Pseudodiaptomus* Jul–Aug (#/m^3)	Secchi depth Apr–Jun (cm)	Adjusted Kimmerer proportional entrainment	Previous Sep–Dec striped bass adult abundance and Secchi depth	Previous Sep–Dec abundance other predators and Secchi depth	Apr–Jun abundance of other predators and Secchi depth	Sep–Dec striped bass adult abundance and Secchi depth	Sep–Dec abundance other predators and Secchi depth	Average length of delta smelt in December (mm)
Period	AICc value	Adjusted R^2	*PFAb* 1	*PFAb*	*Jab*	*SpDys*	*TpAJ*	*TpJul*	*TpJS*	*EPAJ*	*EPJul*	*EPJA*	*SecAJ*	*Entrain*	*PStBass*	*PPreds1*	*Preds2*	*StBass*	*Preds1*	*DSLth*
Fall-to-summer	**36.4**	**59%**	**0.001**	**0.000**	Not relevant to this period	–	–	–	Not relevant to this period	**0.000**	–	Not relevant to this period	–	**0.035**	–	–	–	Not relevant to this period		–
	36.9	**58%**	**0.004**	**0.000**		–	**0.048**	–		**0.000**	–		–	–	–	–	–			–
	37.0	62%	0.002	0.000		–	0.104	–		0.000	–		–	0.077	–	–	–			–
	37.4	61%	0.011	0.000		–	–	–		0.000	–		0.136	0.028	–	–	–			–
	37.7	60%	0.007	0.000		–	–	–		0.001	–		–	0.020	–	–	0.172			–
	38.1	**53%**	**0.002**	**0.000**		–	–	–		**0.000**	–		–	–	–	–	–			–
	38.1	60%	0.002	0.001		–	0.035	–		0.000	–		–	–	0.162	–	–			–
	38.5	59%	Not estimated			–	–	–		0.000	–		–	0.023	–	0.315	–			–
	38.8	58%				–	–	–		0.000	–		–	0.056	0.413	–	–			–
	39.1	54%				–	–	–		0.000	–		0.189	–	–	–	–			–
Summer-to-fall	**38.1**	**60%**	Not relevant to this period		**0.000**	Not relevant to this period			–	Not relevant to this period		**0.002**	Not relevant to this period					–	–	Not relevant to this period
	38.6	61%			0.000				–			0.003						–	0.153	
	39.2	63%			0.000				0.147			0.002						–	0.066	
	39.3	60%			0.000				–			0.002						0.239	–	
	40.0	60%			0.000				0.397			0.002						–	–	
	41.2	60%			Not estimated				0.371			0.002						0.229	–	
	41.2	60%							–			0.003						0.707	0.378	
	42.2	62%							0.169			0.002						0.969	0.172	
	46.9	49%							–			–						–	0.174	
	48.2	49%							0.322			–						–	0.109	
Fall-to-fall	30.8	59%	0.016	0.000	Not relevant to this period	–	–	Not relevant to this period	–	–	Not relevant to this period	–	–	–	Not relevant to this period		0.002	–	–	0.034
	30.9	**53%**	**0.001**	**0.000**		–	–		–	**0.009**		–	–	–			–	–	–	–
	31.7	**52%**	**0.014**	**0.000**		–	–		–	–		–	–	–			**0.015**	–	–	–
	31.8	56%	0.017	0.000		–	–		–	–		–	–	–			–	–	0.003	0.036
	31.9	56%	0.006	0.000		–	–		–	0.073		–	–	–			0.125	–	–	–
	32.1	56%	0.002	0.000		–	–		–	0.016		0.149	–	–			–	–	–	–
	32.3	61%	0.008	0.000		–	–		–	0.133		–	–	–			0.022	–	–	0.061
	32.6	54%	0.005	0.000		–	–		–	0.065		–	–	–			–	–	0.229	–
	32.8	**49%**	**0.014**	**0.000**		–	–		–	–		–	–	–			–	–	**0.029**	–
	32.9	54%	Not estimated			–	–		–	0.034		–	–	–			–	–	–	–

Entries in the last 18 columns are significance levels for regression coefficients from two-sided tests. Gray shading shows instances of AICc greater than two units above the best equation, a level of significance above 0.10, or, in the case of delta smelt length (a measure of fecundity), a negative coefficient in the regression equation, which is contrary to the hypothesized effect. Boldface indicates factors in equations meeting all selection criteria. Tick marks indicate that the factor was not among those used in the equation that was tested.

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Table 5 Results of analyses of factors with direct effect, not selected for the initial analyses, added to the best regression equations for each period, from the initial analyses

			Direct factors not selected for initial analyses											
			Deviation of water temperature from 16° C Mar--May (degree-days)	Deviation of water temperature from 17° C Apr–July (degree-days)	Average *Eurytemora* April 30 (#/m^3)	Average *Eurytemora* + *Pseudodiaptomus* Apr–June (#/m^3)	Minimum total calanoid copepod biomass Apr--June (mg C/m^3)	Average *Limnoithona* April–June (#/m^3)	Average *Limnoithona* July (#/m^3)	Average *Limnoithona* July--August (#/m^3)	Average *Eurytemora* + *Pseudodiaptomus* Sep–Dec (#/m^3)	Average *Limnoithona* Sep–Dec (#/m^3)	Average *Eurytemora* + *Pseudodiaptomus* Jan–Mar (#/m^3)	Average *Limnoithona* Jan–Mar (#/m^3)
Period	AICc value	Adjusted R^2	*TpMM*	*TpAJ*	*EuApr*	*EPAJ1*	*CCAJ*	*LimAJ*	*LimJuly*	*LimJA*	*EPSD*	*LimSD*	*EPJM*	*LimJM*
Fall-to-summer	**38.9**	**70%**	–	–	–	–	–	–	–	Not relevant to this period			**0.003**	–
	39.5	**73%**	–	–	–	–	0.080	–	–				**0.010**	–
	40.1	72%	–	–	–	0.127	–	–	–				0.004	–
	40.8	75%	–	–	–	0.101	0.066	–	–				0.012	–
	41.4	70%	–	–	–	–	–	–	–				0.002	0.331
	42.0	69%	–	–	–	–	–	–	0.578				0.003	–
	42.1	69%	–	0.611	–	–	–	–	–				0.004	–
	42.3	69%	0.835	–	–	–	–	–	–				0.007	–
	42.3	69%	–	–	–	–	–	0.907	–				0.004	–
	42.3	69%	–	–	0.929	–	–	–	–				0.004	–
Summer-to-fall	**39.50**	**67%**	Not relevant to this period							–	**0.012**	–	Not relevant to this period	
	41.55	66%								0.406	0.026	–		
	42.23	66%								–	0.013	0.805		
	42.23	68%								0.095	0.023	0.139		
	44.58	61%								0.169	–	–		
	45.02	62%								0.056	–	0.167		
	46.89	59%								–	–	0.783		
Fall-to-fall	**32.2**	**62%**	–	–	–	–	–	–	Not relevant to this period	–	**0.020**	–	–	–
	33.4	64%	0.120	–	–	–	–	–		–	0.010	–	–	–
	33.8	63%	–	–	–	–	0.160	–		–	0.020	–	–	–
	34.0	63%	–	–	–	–	–	–		–	0.010	0.190	–	–
	34.5	62%	–	–	–	–	–	–		–	0.010	–	–	0.300
	34.6	62%	–	–	–	–	–	0.310		–	0.010	–	–	–
	34.8	61%	–	–	0.370	–	–	–		–	0.020	–	–	–
	35.2	60%	–	–	–	0.580	–	–		–	0.060	–	–	–
	35.3	66%	0.090	–	–	–	–	–		–	0.000	0.150	–	–
	35.3	56%	–	–	–	0.160	–	–		–	---	–	–	–

Entries in the last 12 columns are significance levels for regression coefficients from two-sided tests. Gray shading shows instances of AICc greater than two units above best equation or a level of significance above 0.10. Boldface indicates factors in equations meeting both selection criteria. Tick marks indicate that the factor was not among those used in the equation that was tested.

The best regression equation for the fall-to-summer survival of delta smelt is

$$\mathrm{Ln}(Survival) = 2.003 - 2.197*PFAb + 0.781*PFAb1 + 1.988*EPAJ - 3.826*Entrain + 1.143*EPJM, \quad (9)$$

where survival is the ratio of July abundance, a measure of juvenile abundance in July, to the previous year's FMWT index, a measure of sub-adult abundance; *PFAb* is the FMWT index of the previous year divided by 1,000; *PFAb*1 is the FMWT index of the previous-previous year divided by 1,000; *EPAJ* is the minimum *Eurytemora* + *Pseudodiaptomus* density in April–June divided by 1,000; *Entrain* is the proportional entrainment of delta smelt, as a fraction; and *EPJM* is the average *Eurytemora* + *Pseudodiaptomus* density in January–March divided by 1,000.

The best regression equation found for summer-to-fall survival of delta smelt is

$$\mathrm{Ln}(Survival) = -2.176 - 1.003*JAb + 0.698*EPSD, \quad (10)$$

where *Survival* is the ratio of the FMWT index, a measure of sub-adult abundance, to July abundance, a measure of juvenile abundance in July, in the same year; *JAb* is July abundance, a measure of juvenile abundance in summer divided by 10,000; *PFAb*1 is the FMWT index of the previous-previous year divided by 1,000; and *EPSD* is the average *Eurytemora* + *Pseudodiaptomus* density in September–December divided by 1,000. Note that *EPSD*, the average *Eurytemora* + *Pseudodiaptomus* in September–December, replaced *EPJA*, the average *Eurytemora* + *Pseudodiaptomus* in July–August in the best regression equation from the initial analysis because *EPJA* was no longer significant in the equation for summer-to-fall survival when other factors with direct effects were considered.

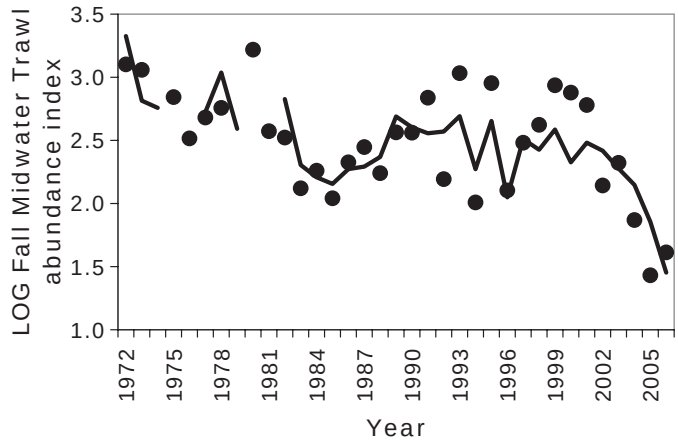

Figure 4 Actual and predicted values of the Fall Midwater Trawl index of abundance of sub-adult delta smelt. Circles are actual values. The line shows predicted values.

The best regression equation found for the fall-to-fall survival of delta smelt is

$$\mathrm{Ln}(Survival) = -0.246 - 2.781*PFAb + 1.048*PFAb1 + 0.997*EPAJ + 0.482*EPSD, \quad (11)$$

where survival is the ratio of the FMWT index, a measure of sub-adult abundance in the fall, to the previous year's FMWT index; *PFAb* is the FMWT index of the previous year divided by 1,000; *PFAb*1 is the FMWT index of the previous-previous year divided by 1,000; *EPAJ* is the minimum *Eurytemora* + *Pseudodiaptomus* density in April–June divided by 1,000; and *EPSD* is average *Eurytemora* + *Pseudodiaptomus* density in September–December divided by 1,000. Figure 4 shows actual abundance of sub-adult delta smelt (the FMWT index) and values predicted by equation 11.

These three equations each reflect a stock-recruitment relationship in which end-of-period abundance is proportional to

Table 6 Percentage of variation in Ln(*Survival*) explained and the contribution of each factor to that percentage

Period	% Ln(*Survival*)[a] variation explained	Important factors	Percent of variation explained[b]	Percent of variation explained[c]
Fall-to-summer	70.2%	*PFAb* = previous fall abundance/1,000	0.0%	38.3%
		*PFAb*1 = previous previous fall abundance/1,000	14.0%	7.7%
		EPAJ = minimum *Eury* + *Pseu*, Apr–Jun/1,000	39.0%	32.8%
		Entrain = proportional entrainment at export pumping plants, %/100	6.0%	9.1%
		EPJM = average *Eury* + *Pseu*, Jan–Mar/1,000	11.2%	11.2%
Summer-to-fall	67.6%	*JAb* = July abundance/10,000	47.0%	64.1%
		EPSD = average *Eury* + *Pseu*, Sep–Dec/1,000	20.6%	20.6%
Fall-to-fall	61.6%	*PFAb* = previous fall abundance/1,000	25.8%	61.6%
		*PFAb*1 = previous-previous fall abundance/1,000	15.2%	18.6%
		EPAJ = minimum *Eury* + *Pseu*, Apr–Jun/1,000	12.5%	8.0%
		EPSD = average *Eury* + *Pseu*, Sep–Dec/1,000	8.1%	8.1%

[a]For fall-to-summer and fall-to-fall analyses, "survival" means survival and reproduction.
[b]Percent of variation explained by the variables when added one at a time in order shown.
[c]Percent of variation explained when variable is added last into the equation.

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beginning-of-period abundance. However, this proportional relationship is adjusted by a density-dependence term that causes abundance to be reduced when beginning-of-period abundance is high and is further adjusted by prey-density terms that cause delta smelt abundance to increase with availability of prey. In addition, summer abundance relative to previous fall abundance is reduced by entrainment. Both summer abundance and fall abundance, relative to previous fall abundance, are higher than expected when the abundance two-years previous is high.

Comparing the Relative Contribution of Each Factor to the Explained Variation in Ln(Survival)

Table 6 shows the percentage of variation in Ln(*Survival*) that is explained by each equation and the contribution of each factor to that percentage. The density-dependence terms, *PFAb* or *JAb*, have relatively important contributions to variation in Ln(*Survival*) for all three periods, and, while *PFAb* is not important as an individual factor for fall-to-summer survival, its inclusion renders important the contribution of other factors once it is added to the equation. Prey-density terms have a relatively important contribution to variation in Ln(*Survival*), as does the previous-previous fall abundance, which accounts for the sawtooth survival pattern. The contribution of entrainment to variation in Ln(*Survival*) is not as important as the contribution of prey densities to fall-to-summer survival. Entrainment was not chosen for inclusion in the fall-to-fall equation because it did not meet the criteria for inclusion.

Testing Selected Factors with Indirect Effects on Survival

There was no evidence that any of six environmental factors with indirect effects, which were identified in previous studies, further explained changes in fall-to-fall delta smelt survival beyond those accounted for by factors with direct effects shown in equations 9, 10, and 11. It is noted that this does not necessarily mean that these or other factors with indirect effects might not have important effects on one or more factors that have direct effects.

Testing Effects of Measures of "Abiotic Habitat" Volume on the Best Fall-to-Fall Regression Equation

This study attempted to add estimates of the volume of water within the suitable range of conductivity, Secchi depth, and water temperature to the best regression equation, as well as suitable volumes weighted with prey density (densities of *Eurytemora* + *Pseudodiaptomus*), the values of which are in the supplemental material to this article. When adding volume weighted by prey density, prey density terms were first removed from the best regression equations. None of those measures met the criteria above for inclusion in the best regression equation for fall-to-fall survival.

DISCUSSION

The analyses presented here focused on environmental factors that have plausible mechanisms for direct effects on the survival of delta smelt, leaving identification of factors having important, indirect effects—that is, the factors that have important effects on important factors with direct effects—for subsequent analyses. Effects on delta smelt survival were analyzed from fall (when delta smelt are sub-adult or pre-spawning adults) to summer (when delta smelt are next-generation juveniles) and from fall to fall (addressing the life cycle across a single generation). The regression equations resulting from this latter analysis serve as a life-cycle model. Effects on survival from summer to fall were also analyzed, thereby allowing insight into sources of mortality during this delta smelt growth stage. Analyses indicate that prey density is the most important environmental factor affecting abundance and population trends in delta smelt over the period 1972 through 2006 and also that changes in prey density appear to best explain the sharp drop in delta smelt abundance in this century. Entrainment of delta smelt at state and federal export pumping plants in the Sacramento-San Joaquin Delta appears to contribute to survival rates from fall to summer and, therefore, to juvenile abundance in summer, but entrainment was not a statistically significant factor in survival from fall to fall—that is, to inter-annual changes in the size of the delta smelt population. Density dependence was an important factor affecting survival from fall to summer, summer to fall, and fall to fall. Its inclusion in the best regression equations was also important in revealing the effects of prey density and entrainment on delta smelt abundance. This finding indicates that density dependence must be accounted for in analyses directed at identifying factors that are important to the abundance of delta smelt. Delta smelt survival from fall to summer and fall to fall showed a persistent sawtooth pattern over much of the period analyzed, and this effect was captured by inclusion of a term for delta smelt abundance in fall of the year prior to beginning-of-period abundance in fall-to-summer and fall-to-fall survival analyses. It is noted that the best regression equations may not apply for values of factors outside the range of values actually observed.

The regression equations can be interpreted as follows, using the fall-to-fall equation as an example. Delta smelt survival is the ratio *FMWT*/*PFAb*, where *PFAb* is the previous year's FMWT index. So, equation 11 can be written as

$$\frac{FAb}{PFAb} = e^{-0.246-(2.781\times10^{-3}PFAb)+(1.048\times10^{-3}PFAb1)+(0.997\times10^{-3}EPAJ)+(0.482\times10^{-3}EPSD)}$$

or

$$FAb = 0.782PFAb\, e^{-(2.781\times10^{-3}PFAb)} e^{(1.048\times10^{-3}PFAb1)} e^{(0.997\times10^{-3}EPAJ)} e^{(0.482\times10^{-3}EPSD)},$$

where *PFAb1* is the previous-previous FMWT index, *EPAJ* is the minimum *Eurytemora* + *Pseudodiaptomus* density in April–June, and *EPSD* is the average *Eurytemora* + *Pseudodiaptomus* density in September–December. Assuming that the

number of delta smelt eggs in spring is proportional to the previous abundance index derived from the FMWT, this equation can be interpreted as follows:

$$
\begin{aligned}
&FMWT = [\text{eggs in spring} = 0.782PFAb] \\
&\times[\text{survival reduction related to density dependence} \\
&\text{from previous FMWT} = e^{-(2.781\times10^{-3}PFAb)}] \\
&\times[\text{survival increase from contribution of previous}- \\
&\text{previous abundance} = e^{(1.048\times10^{-3}PFAb1)}] \\
&\times[\text{survival increase from high minimum food density in} \\
&\text{April} - \text{June} = e^{(0.997\times10^{-3}EPAJ)}] \\
&\times[\text{survival increase from high September}- \\
&\text{December food density} = e^{(0.482\times10^{-3}EPSD)}],
\end{aligned}
$$

with the negative constant term in equation 11 indicating that survival (that is, the combined effects of survival and reproduction) from fall to fall is less than one—typical of a species experiencing an extended decline in abundance.

There was some indication that average water temperature and calanoid copepod biomass (a general measure of prey density) in April–June were important contributors to survival of delta smelt from fall to summer. Furthermore, predation in April–June, representing the combined effects of water clarity and abundance of the predators, inland silversides, largemouth bass, crappie, and sunfish, was important to delta smelt survival from fall to fall. Numerous factors with direct effects on delta smelt survival did not have statistically significant effects on the subsequent abundance of delta smelt, including the length of the spawning period as determined by water temperature; turbidity as an individual factor affecting larval feeding success in spring as measured by Secchi depth; average or maximum water temperature in summer; deviations of water temperature from optimum values in spring; predation in summer and fall by predators other than striped bass and predation in all seasons by striped bass; delta smelt fecundity, as measured by the size (average length) of delta smelt in December; and the average density of *Limnoithona*, an invasive zooplankton that has become the most abundant potential prey species in the estuary.

The effects of factors that might have indirect effects on survival were analyzed using factors that were identified by previous studies as potentially important in determining delta smelt population trends. These factors are the average value of X2 (a measure of western Delta salinity) in the previous fall ("fall X2"), turbidity in winter as measured by Secchi depth, ammonium concentration in spring in downstream sub-regions of the Delta, and flows that feed the Delta's export pumps in winter and spring. None of these factors met the criteria for inclusion in the best regression equations based on factors with direct effects on delta smelt survival. It is noted that these factors and other factors with indirect effects could have important effects on factors that have direct effects on delta smelt, as suggested in Figure 2, but there was no attempt to identify those relationships here, although it is noted that Delta water flows to the export pumps were incorporated in estimates of proportional entrainment.

Results indicate that delta smelt survival was more sensitive to measures of the effects of individually specified factors with direct effects on fish than to measures of the volume of water within suitable ranges of conductivity, Secchi depth, and temperature (abiotic habitat, the term used in Feyrer et al. [2007]). Once the effects of individually specified factors were accounted for, with attention to their co-occurrence with delta smelt, the volume of water with conductivity, Secchi depth, and temperature in the suitable ranges for each of those three variables did not meet the criteria for inclusion in the best regression equation for fall-to-fall survival, nor did such volumes weighted with prey density, even after prey density terms were removed from the best regression equations for fall-to-fall survival based on factors with direct effect.

Some caution should be taken in interpreting results pertaining to entrainment of delta smelt at state and federal Delta export pumping plants. Estimates of delta smelt entrainment are based on those used in a previous modeling exercise (Kimmerer, 2008). Those methods of estimating proportional entrainment provide a more rational conceptual framework than other methods that have been used (see Grimaldo et al. [2009], for example), because Kimmerer estimated entrainment relative to population size, attempted to estimate the standing crop of delta smelt at the time of entrainment (rather than using abundance estimates derived from samples collected several months earlier), and attempted to overcome uncertainties associated with the fact that larval delta smelt are not actually incorporated in fish salvage data from pumping plants. However, Kimmerer's model estimates are based on a number of assumptions. Of 18 assumptions underlying estimates, Miller (2011) concluded that at least 12 of these assumptions introduced bias, and 11 of those 12 introduced an upward bias in the putative effects of export pumps on delta smelt mortality. This study attempted to correct Kimmerer's estimates to account for that bias, but could do so for just three of the 12 assumptions. The corrections reduced Kimmerer's annual estimates of proportional entrainment by about half, and Miller (2011) concluded that further reductions would be appropriate if other assumptions could be quantified. Furthermore, Kimmerer did not estimate proportional entrainment prior to 1995; however, his estimates were extended back to 1972 using correlations with X2, flow, and Secchi depth measures for those years (as described in supplemental material) and Kimmerer's 1995–2006 estimates and those hind-cast estimates were adjusted to account for bias that could be quantified. Therefore, the role of entrainment as a contributing factor to population trends from fall to summer that are largely determined by density-dependence factors and availability of the preferred foods used by delta smelt is uncertain and likely (still) biased upward.

Ascertaining the importance of prey density in determining population trends in delta smelt in part resulted from attentive specification of factor values. The densities of the two prey species, *Eurytemora* and *Pseudodiaptomus*, were used, summed as the measure of prey density, reflecting findings in several

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previous studies that explicitly reference consumption of these zooplankton by delta smelt (see supplemental material). There was also an attempt to account for the location of delta smelt when estimating prey density, because prey densities in subregions that are not occupied by delta smelt cannot be relevant to delta smelt survival. Moreover, there was an attempt to measure the seasonal low point in prey density in the spring of recent years, when the favored prey *Eurytemora* rises from near zero in late winter and then declines to near zero in May or June, at approximately the same time that other suitable prey species *Pseudodiaptomus* increases in numbers from essentially zero and persists at greater numbers until the following winter (see supplemental material).

It is noted that the importance of the factor, minimum *Eurytemora* plus *Pseudodiaptomus* in April–June, which measures the low point in the food availability for young delta smelt, provides a plausible mechanism for Bennett's observation that almost no early-hatch larvae of delta smelt have survived until later life stages in recent years (Bennett, 2005; USFWS 2009). That spring low point appeared in the mid 1980s; since then, if larval delta smelt hatch prior to the occurrence of this low point in densities of the two zooplankton species, larval survival might exhibit a pattern of low returns.

This study's findings are consistent with recent assertions that contaminant-mediated prey availability shows dominant effects on patterns of the abundance of delta smelt and several other fish in the Delta (Glibert, 2010), although the analysis did not attempt to identify the causes of the substantial changes in prey densities in recent years. Furthermore, the analyses address an observation by Feyrer et al. (2007), who concluded that their analyses of just several physical factors as determinants of delta smelt abundance would have been improved by consideration of other factors, particularly prey density. Without carrying out analyses that accounted for density dependence and included such essential variables as prey availability and predation on delta smelt, they concluded that the average value of X2 in the previous fall was the essential causative agent of subsequent summer juvenile abundance (see Feyrer et al., 2007, and USFWS, 2009). The analyses of this study considered the effects of density dependence and prey density, as well as numerous other factors in addition to average X2 position in the previous fall, and once the effects of prey density were accounted for, no evidence was found of effects of average X2 value in the previous fall on delta smelt population dynamics. Thomson et al. (2009) found that water clarity, position of X2 in winter–spring, and the volume of water exports were important to long-term abundance of delta smelt and other fish but could not explain the recent decline in abundance of delta smelt to record low levels. Mac Nally et al. (2010) found that the position of X2 in the spring in the estuary and increased water clarity were important to delta smelt abundance. Differences between the present findings and those of Thomson et al. and Mac Nally et al. are attributed to this study's focus on those factors that specifically should have direct effects on abundance and to a more precise quantification of environmental factors—including explicitly considering spatial and temporal aspects of prey availability, integrating the specific locations of different life stages of delta smelt in average values of variables, and expressing prey availabilities in terms of densities of zooplankton species known to be preferred by delta smelt. Grimaldo et al. (2009) attributed demographic trend effects to entrainment of delta smelt at the export pumping plants (measured as the number of fish salvaged there) and to export volumes by virtue of the relationship of those flows to rates of fish salvage. While some effect of entrainment (which incorporated effects of export flows) was found on delta smelt survival from fall to summer, entrainment of fish at the export pumps did not exhibit a significant relationship with the population dynamics of the fish over its entire life cycle. Assessment of the relative importance of entrainment in determining delta smelt survival, as well as that of several other factors, during various periods in the past and for various future management actions, awaits further analysis.

It is believed that this study's analysis is the first to combine careful quantification of variables, based on publicly available agency data, with wildlife agency-derived conceptual models transformed to represent the hierarchical manner in which environmental factors interact to affect abundance and survival of delta smelt. The benefits of this approach included a reduction in the occurrence of correlations that might arise by chance, due to the inclusion of many variables relative to the number of years of data, and identification of environmental factors on which future studies can focus in order to elucidate the ecological mechanisms as a basis for management actions, thereby providing a sound basis for agency determinations and policy decisions.

Nonetheless, limitations in the presented analyses are acknowledged. Time-series index values of delta smelt abundance are based on data from surveys that were not explicitly designed to sample that fish species, and more recently initiated surveys that are designed to sample delta smelt more efficiently suffer from lack of longer time series and from the challenges of sampling for a species that now is scarce. In addition there are no data on disease, a factor with a potentially important, direct effect on delta smelt abundance and, with the exception of ammonia, almost no data on contaminants that act directly on delta smelt. Some comfort can be taken in findings that 60 to 70% of the variation in delta smelt survival can be explained by factors included in the analyses, but that finding cannot rule out the importance of disease and contaminants. Further limitations to clearer resolution of the causative factors in the decline of delta smelt include the infrequency with which some environmental factors are being measured. For example, zooplankton samples were taken once or twice per month beginning in 1972 and in the separate, 20-mm survey (CDFG, http://www.dfg.ca.gov/delta/projects.asp?ProjectID=20mm), every two weeks in spring beginning in 1995. Hourly water temperature data are not available prior to the mid 1990s, requiring reliance on correlations with air temperature, which, fortunately, is highly related to water temperature. These limitations are offset somewhat by the large variations in delta smelt abundance from year to year, and the 95% decline in

abundance from 1999 to 2006, suggesting that the signals of environmental effects that have been identified are not subtle and that the current lack of desired levels of precision in and frequency of sampling for underlying data for environmental variables can be tolerated.

The present results, indicating that the importance of prey density as measured by the sum of *Eurytemora* + *Pseudodiaptomus* densities, are supported by observed recent sharp declines in the abundance of two other pelagic fish that share at least partial reliance on the same prey—longfin smelt and young striped bass (Armor et al., 2005; Baxter et al., 2008). Slater (2008) concluded from diet studies that young longfin smelt rely heavily on *Eurytemora* in spring, and Moyle (2002) reported that striped bass larvae frequently feed on *Eurytemora*.

The results presented here suggest several areas for further study. Identification of the environmental factors that determine prey density leads the list. There is a need to elucidate and quantify that part of the effects hierarchy related to prey density. Strong inference can be drawn from this study—if the densities of the favored prey species consumed by delta smelt were to increase substantially, delta smelt abundance should increase. Under that circumstance, whatever the effects of entrainment from fall to summer, those effects would become less important because of density dependence. It would appear, therefore, that the key to recovery of delta smelt to levels of abundance that would reduce conservation concern is increased prey density.

Another area for further study relates to the cause of density dependence. Bennett (2005) suggested that density dependence was important based on his observation that, when comparing two poor stock-recruitment relationships—one with and one without density dependence—the one with density dependence appeared to be a better predictor. The present analysis, incorporating effects of many other factors, provides more convincing evidence that density-dependence effects act on delta smelt from fall to summer, summer to fall, and fall to fall, and it has demonstrated effects at low levels of abundance and reveals effects of other factors. Density dependence from summer to fall, as represented by terms for previous abundance in regression equations for survival, is one reason, along with variation in prey density, why entrainment, while contributing to the best regression equation that describes delta smelt survival from fall to summer, did not meet the criteria for inclusion in the best regression equation that explains survival from fall to fall, that is, from one generation to the next. The cause of density dependence in delta smelt deserves further study. This analysis suggests that it arises from some factor that was not considered here, or from a factor that was considered but was not specified adequately, such that its effects would be revealed. Delta smelt spawn most successfully on cobble or clean sand (J. Lindberg, University of California at Davis, personal communication), and meager sediment data (see http://www.water.ca.gov/bdma/meta/benthic.cfm) suggest that few stations in areas occupied by delta smelt show evidence of cobble or clean sand substrate. Nor was the possibility considered that the contemporary relatively small numbers of fish have led to stochastic demographic phenomena, such as difficulty in finding mates or some other manifestation of Allee effects (Allee et al., 1949). Identifying the cause of density dependence on delta smelt could provide a basis for actions to lessen its effects.

Further study is recommended of the inter-year sawtooth pattern in the abundance of delta smelt. This, too, is an important factor in these regression equations. Failure to identify an environmental factor or factors causing this pattern suggests that its cause may be inherent in the reproductive biology of delta smelt. Approximately 5% of delta smelt live for two years and spawn in the second year, producing a large number of eggs because of their larger size (Bennett, 2005). The existence of distinct demographic units of delta smelt that spawn every two years could explain the sawtooth pattern, but the absence of larger fish in the FMWT and STN argues against this possible explanation.

Predation also deserves more study. The identification of predation as a factor of some importance must be confirmed by more careful studies to overcome the general conclusion drawn by Moyle (2002) that there was little evidence of important predation effects, even when delta smelt were abundant relative to other prey fish many years ago. It is possible that the arrival and proliferation of invasive predators alters Moyle's conclusion.

There was some indication that water temperature is important, but water temperature, depending almost entirely on air temperature, cannot be controlled. However, the increasing trend in water temperature could affect various factors that are important to the abundance of delta smelt, including prey density, and such effects deserve study.

Results also indicate that the development of an effects hierarchy can provide an important framework on which to base analyses designed to assess the relative importance of multiple factors affecting the population dynamics of at-risk species. The findings presented here suggest that multiple environmental factors were responsible for the decline in abundance of delta smelt to record low levels, but that multiplicity is vertical with respect to the effects hierarchy, primarily extending down the hierarchy below prey density rather than horizontally across the hierarchy, as others have surmised (Baxter et al., 2010).

Furthermore, in the case of delta smelt, not only does an effects hierarchy suggest the use of simple linear regression models, but the low sampling errors in abundance relative to process errors indicates that this simple and transparent method of analysis is an appropriate method for identifying environmental factors with direct effects. Therefore, at least for delta smelt and perhaps for other fish for which sampling errors in abundance are relatively low, simple linear regression, as an alternative to more complex life-cycle models, can produce informative results.

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Analysis of pelagic species decline in the upper San Francisco Estuary using multivariate autoregressive modeling (MAR)

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Abstract. Four species of pelagic fish of particular management concern in the upper San Francisco Estuary, California, USA, have declined precipitously since ca. 2002: delta smelt (*Hypomesus transpacificus*), longfin smelt (*Spirinchus thaleichthys*), striped bass (*Morone saxatilis*), and threadfin shad (*Dorosoma petenense*). The estuary has been monitored since the late 1960s with extensive collection of data on the fishes, their pelagic prey, phytoplankton biomass, invasive species, and physical factors. We used multivariate autoregressive (MAR) modeling to discern the main factors responsible for the declines. An expert-elicited model was built to describe the system. Fifty-four relationships were built into the model, only one of which was of uncertain direction a priori. Twenty-eight of the proposed relationships were strongly supported by or consistent with the data, while 26 were close to zero (not supported by the data but not contrary to expectations). The position of the 2‰ isohaline (a measure of the physical response of the estuary to freshwater flow) and increased water clarity over the period of analyses were two factors affecting multiple declining taxa (including fishes and the fishes' main zooplankton prey). Our results were relatively robust with respect to the form of stock–recruitment model used and to inclusion of subsidiary covariates but may be enhanced by using detailed state–space models that describe more fully the life-history dynamics of the declining species.

Key words: Bayesian analysis; delta smelt; expert models; longfin smelt; Sacramento River, California, USA; San Joaquin River, California, USA; striped bass; threadfin shad; threatened species; water management.

Introduction

Estuaries, especially those associated with large rivers near major cities, are among the ecosystems most adversely affected by land use change (Nichols et al. 1986). Impacts of human actions in all upstream watersheds (catchments) are concentrated in the estuaries (Kennish 2002, Townend 2004). Diversion of water affects the location of boundaries between fresh, brackish, and saline water (Drinkwater and Frank 1994, Gillanders and Kingsford 2002, Gleick 2003). Large settlements often are located along shorelines, which convey contaminants and effects of boating and fishing to estuarine systems (Dauer et al. 2000). Shipping has led to introductions of many aquatic invasive species (Bollens et al. 2002, Williams and Grosholz 2008). Climate change will affect interactions between oceans and estuaries and will reduce catchment inflows in many regions (Scavia et al. 2002, Vicuna and Dracup 2007, Cai and Cowan 2008, Schindler et al. 2008).

The San Francisco Estuary is an archetype of a stressed estuarine system (Kimmerer et al. 2005*a*). The social, economic, and ecological effects of freshwater flows and diversions throughout the San Francisco Estuary have received much attention. Some 25 million Californians and 12 000 km^2 of agricultural land rely on water diversions from the delta created by the Sacramento and San Joaquin rivers. Annual agricultural

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revenue from California's Central Valley, which accounts for about half of the production of fruits and vegetables in the United States, frequently approaches US$15 billion.

Populations of many aquatic species in the estuary have declined since extensive human activities began in the mid-1800s (Bennett and Moyle 1996, Brown and Moyle 2005). However, conflicts over water management recently have intensified because of the apparently precipitous decline in four species of pelagic fish (delta smelt [*Hypomesus transpacificus*], longfin smelt [*Spirinchus thaleichthys*], striped bass [*Morone saxatilis*], and threadfin shad [*Dorosoma petenense*]) since ca. 2002 (Thomson et al. 2010). Delta smelt was listed as threatened under the U.S. and California Endangered Species Acts in 1993. Recent litigation to protect the species resulted in court orders to halt water diversions temporarily (Wanger 2007*a*, *b*). Longfin smelt was listed as threatened under the California Endangered Species Act in 2009, although a petition for federal listing was declined. Striped bass was deliberately introduced to the Sacramento–San Joaquin Delta from the east coast of the United States in 1879 and supports a sport fishery (Moyle 2002). Threadfin shad was introduced into California reservoirs as a forage fish in 1954 and spread to the Delta (Moyle 2002, Feyrer et al. 2009).

To date, models and statistical analyses to identify mechanisms causing fish declines in the San Francisco Estuary generally have been on a species-by-species basis (Jassby et al. 1995, Kimmerer et al. 2001, Bennett 2005). These efforts suggest that several abiotic factors (e.g., water flows, salinity, turbidity), bottom-up biotic effects (e.g., zooplankton abundances, invasion of a filter-feeding, non-native clam [*Corbula amurensis*]), and top-down factors (e.g., incidental mortality associated with water diversions to pumping facilities) may play important roles. However, the relative importance of these factors remains unclear (Sommer et al. 2007). Identification of processes causing declines is critical because possible solutions include major investments in infrastructure, changes in water management, and rehabilitation of species' habitats, which would cost billions of dollars.

Although detailed analyses of the population dynamics of any one declining species are valid, it is plausible that more insight might be gained through multivariate analyses that consider community dynamics, including direct and indirect effects of interacting species and abiotic factors. These analyses might yield inferences on the biotic and abiotic factors that best explain patterns of abundance for multiple species in the community and on the relative influences of density dependence, among-species interactions, and abiotic factors on species abundances.

We used a multivariate statistical technique called multivariate autoregressive modeling (MAR) (Ives et al. 2003) with 40 years of data for pelagic fishes and their principal prey within the upper San Francisco Estuary. In a manner similar to path analysis (Shipley 1997), MAR uses time series data for multiple taxa to estimate the degree of association between the different taxa as well as between covariates and each taxon. Multivariate autoregressive modeling includes autoregressive terms for each species' abundance. Ives et al. (2003) provided a detailed introduction to the underlying theory and assumptions of MAR along with methods for estimating model parameters. Multivariate autoregressive modeling has been used in analyses of community dynamics in lakes in Wisconsin (Ives et al. 2003), Lake Washington (Hampton and Schindler 2006), and Lake Baikal (Hampton et al. 2008).

We developed a Bayesian implementation of MAR. Bayesian methods allow propagation of and account for multiple sources of uncertainty in complex models (Punt and Hilborn 1997) and allow great flexibility in model structure (Cressie et al. 2009). The Bayesian MAR modeling is a complementary approach to methods we used in a companion paper, which presented a Bayesian change point analysis (Thomson et al. 2010). The two methods were developed in tandem to evaluate whether the different strengths of the MAR and change point analyses provided similar inferences about factors potentially underlying causes of declines in the fish species. Multivariate autoregressive modeling is based on a food web structure, which allows both direct and indirect influences on the focal species (fish) to be represented. Moreover, MAR models the dynamics of all species (including prey) simultaneously. It is based on linear relationships (on a log-abundance scale), both within the food web and with covariates, over the entire time period.

Our implementation of MAR is underlain by an expert-elicited model, which draws on expert knowledge to specify whether particular trophic or covariate effects may be influential. The change point analysis is not embedded in a food web context, although availabilities of prey taxa can be used as covariates, but it does explicitly employ time dependence and nonlinearity in covariate relationships between log-abundances of the focal species and covariates. The change point method uses Bayesian variable selection (Green 1995) so that relationships do not need to be specified a priori. Both individual-species (species-specific model parameters) and multiple-species (common hyper-parameter distributions) versions of the change point analyses were implemented (Thomson et al. 2010), with the latter having some overlap, therefore, with the MAR analyses.

Here, we describe the upper San Francisco Estuary, the four species of fish on which we focused and their principal prey, and the set of covariates included in the MAR model. Multivariate autoregressive models are heavily parameterized because they describe many among-taxa interactions and relationships to covariates. Therefore, we developed an expert-elicited, circumscribed model that reduced the number of parameters to be estimated. We review the relative importance of

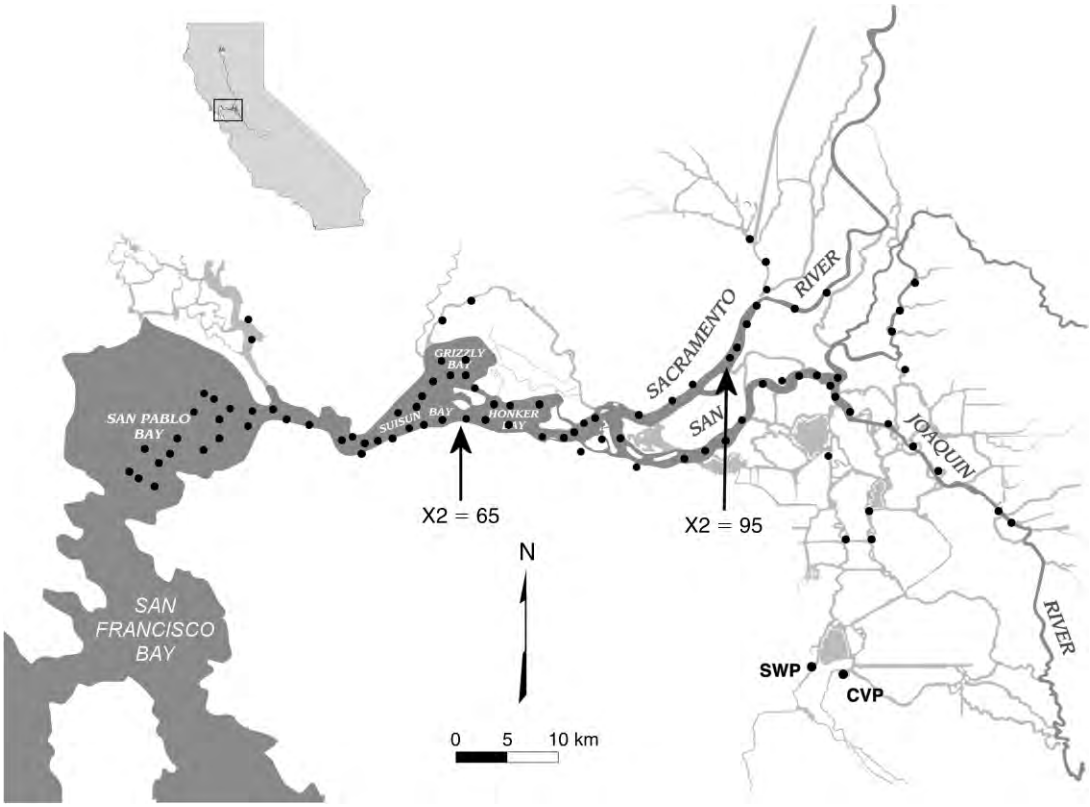

FIG. 1. Location and physiography of the upper San Francisco Estuary, California, USA. The solid circles denote sampling locations of the autumn midwater trawl surveys; arrows indicate two representative positions of the 2‰ isohaline (X2); SWP (State Water Project) and CVP (Central Valley Project) are locations of water exports from the estuary.

different factors in driving the temporal dynamics of our four declining fish species and comment on the usefulness and limitations of MAR models. Last, we comment on the agreement or otherwise between the MAR and change point approaches.

METHODS

The San Francisco Estuary

The San Francisco Estuary consists of three major regions: San Francisco Bay, the most seaward region; Suisun Bay, an intermediate brackish region; and the generally freshwater Sacramento–San Joaquin Delta (Fig. 1). The watershed has wet winters and dry summers. The Delta is the core of a massive system of dams and canals that store and divert water from the estuary for agricultural, industrial, and domestic use throughout California (Nichols et al. 1986). The water diversion facilities export ~30% of the annual freshwater flow into the Delta, although that percentage has exceeded 60% during many recent summers. Regulations, including standards for the position of the 2‰ isohaline (a measure of the physical response of the estuary to freshwater flow; Jassby et al. 1995), locally termed "X2," have become increasingly stringent.

Response variables: declining fish and their principal prey

Delta smelt is endemic to the San Francisco Estuary and reaches 60–70 mm standard length (SL) (Bennett 2005), feeding on zooplankton, mainly calanoid copepods, throughout life. The delta smelt is weakly anadromous, migrating between the brackish waters of Suisun Bay and the freshwaters of the Delta. Upstream migration begins in the late autumn or early winter and spawning occurs from March through May in freshwater. Most delta smelt spawn ~12 months after hatching, with a small percentage surviving for another year to spawn. Young delta smelt move downstream in early summer and remain in the low-salinity zone (0.5–10‰) until they migrate for spawning.

Longfin smelt is native to the San Francisco Estuary. The species usually reaches 90–110 mm SL (Moyle 2002, Rosenfield and Baxter 2007) and is anadromous. It spawns at age 2 yr in freshwater in the Delta from December to April. Young longfin smelt occur from the low-salinity zone seaward throughout the estuary and into the coastal ocean. Longfin smelt feed on copepods as larvae and mysids and amphipods as young and adults.

Striped bass is a potentially large (>1 m), potentially long-lived (>10 yr) anadromous species. Females begin

TABLE 1. Definitions of variables used in the multivariate autoregressive modeling, years for which data were available, and ranges of values for variables.

Variable	Years (missing)	Range	Definition
Response variables			
Delta smelt (*Hypomesus transpacificus*)	1967–2007 (3)	0.06–4.02	autumn (Sep–Dec) midwater trawl, mean total catch per trawl
Longfin smelt (*Spirinchus thaleichthys*)	1967–2007 (3)	0.03–113.16	autumn (Sep–Dec) midwater trawl, mean total catch per trawl
Striped bass (*Morone saxatilis*)	1967–2007 (3)	0.12–59.38	autumn (Sep–Dec) midwater trawl, mean age-0 catch per trawl
Threadfin shad (*Dorosoma petenense*)	1967–2007 (3)	1.36–31.21	autumn (Sep–Dec) midwater trawl, mean total catch per trawl
Calanoid copepods, spring	1972–2007 (1)	0.98–43.87	mean biomass of calanoid copepodites and adults during spring (Mar–May) in low-salinity zone
Calanoid copepods, summer	1972–2007 (1)	2.93–27.62	mean biomass of calanoid copepodites and adults during summer (Jun–Sep) in low-salinity zone
Mysids	1972–2007 (0)	0.42–35.05	mean biomass of mysid shrimp during Jun–Sep in low-salinity zone
Covariates			
Northern anchovy (*Engraulis mordax*)	1980–2006 (1)	0.22–490.42	mean catch per trawl of northern anchovy in the Bay Study midwater trawl (Jun–Sep) in the low-salinity zone
"Other zooplankton" in spring	1972–2006 (0)	3.79–56.86	mean biomass of other zooplankton (not including crab and barnacle larvae, cumaceans) during spring (Mar–May) in the freshwater zone
Spring chlorophyll *a* (freshwater zone)	1972–2006 (0)	2.35–43.54	mean chl *a* (mg/m^3) during spring (Mar–May) in freshwater zone
Spring chlorophyll *a* (low-salinity zone)	1975–2006 (0)	1.12–21.32	mean chl *a* (mg/m^3) during spring (Mar–May) in low-salinity zone
Summer chlorophyll *a*	1975–2006 (0)	1.23–20.15	mean chl *a* (mg/m^3) during summer (Jun–Sep) in low-salinity zone
Cyclopoid copepod *Limnoithona tetraspina*	1972–2006 (0)	0–7.78	mean biomass of *Limnoithona* copepodites and adults during summer (Jun–Sep) in low-salinity zone
Inland silverside (*Menidia beryllina*)	1994–2006 (0)	19.88–116.54	mean catch per seine haul of inland silverside in the USFWS survey during Jul–Sep (for stations within the delta)
Largemouth bass (*Micropterus salmoides*)	1994–2006 (0)	0.02–8.00	mean catch per seine haul of largemouth bass in the USFWS survey during Jul–Sep (for stations within the delta)
Spring X2 (isohaline)	1967–2006 (0)	48.53–91.74	mean Mar–May position of the 2‰ isohaline (X2)
Autumn X2 (isohaline)	1967–2006 (0)	60.24–93.18	mean Sep–Dec position of the 2‰ isohaline (X2)
Water clarity	1967–2006 (0)	0.44–11.00	mean Secchi depth (m) for the autumn midwater trawl survey
Winter exports	1967–2006 (0)	0.13–12.00	total volume of water (km^3) exported by the California State Water Project and Central Valley Project during Dec–Feb
Spring exports	1967–2006 (0)	0.37–13.00	total volume of water (km^3) exported by the California State Water Project and Central Valley Project during Mar–May
Invasive clam *Corbula amurensis*	1967–2006 (0)	0–1	binary variable for presence (1987–2006, 1) or absence (1967–1986, 0)
Duration of spawning window for delta smelt	1975–2007 (0)	24–85	no. days for which mean temperature was between 15° and 20°C,† mean of five continuous monitoring stations throughout Suisun Bay and the Sacramento–San Joaquin Delta
Mean summer water temperature	1967–2006 (0)	20.45–23.65	mean water temperature (°C), mean of five continuous monitoring stations throughout Suisun Bay and the Sacramento–San Joaquin Delta during Jun–Sep

Notes: Mean catch per trawl was measured in terms of individuals. Biomass was measured as mg C/m^3. The freshwater zone was determined to be <0.5‰. The low-salinity zone was determined to be at 0.5–10‰. The X2 position was measured in km upstream from the Golden Gate Bridge.

† Range of water temperatures that best induce spawning by delta smelt (15°C) and limit larval survivorship (20°C).

to spawn at age 4 yr in the Sacramento River and, to a lesser extent, in the San Joaquin River, from April through June. Eggs drift with the current as they develop and hatch. Larvae drift into the low-salinity zone where they grow, later dispersing throughout the estuary. Adults occur primarily in saline waters of the estuary and the coastal ocean, except during spawning migrations. Age-0 striped bass feed mainly on copepods, later switching to macroinvertebrates and then to fish.

Threadfin shad typically is <100 mm total length and primarily inhabits freshwater. It switches between filter- and particle-feeding, consuming phytoplankton, zoo-

plankton, and detritus. Most threadfin shad spawn in their second summer, although some may spawn at the end of their first year. Spawning occurs mainly in June and July. Threadfin shad is the most abundant pelagic fish in the upper San Francisco Estuary.

While other fish and plankton groups might be included in our model as response variables, we chose to limit our analysis to species of zooplankton that are especially important for delta smelt, longfin smelt, age-0 striped bass, and threadfin shad. Adult and juvenile (copepodites) calanoid copepods have different relationships with the fish in spring and summer, so we considered the two life stages as different "taxa" in our models. Mysid shrimps were regarded as most important to the fishes in the mid to late summer (Table 1).

Covariates

The covariates used in the MAR (Table 1) relate to factors thought to be important for one or more of the response variables (Table 2). Covariates included fish species that are potential competitors or predators of the four declining fish species (possibly at only certain life-history stages), food for the latter fishes or their crustacean prey (including phytoplankton), competitors (*Limnoithona*) or predators (*Corbula*) of the crustaceans, the primary surrogate of the fishes' habitat (X2) in spring and autumn, amounts of water extracted from the Delta in winter and spring, water clarity (measured using Secchi discs), and two water temperature variables (duration of the delta smelt spawning window, mean summer water temperature).

The expert model (Table 2) was based on extensive, long-term knowledge and experience of several of the authors (W. J. Kimmerer, F. Feyrer, W. A. Bennett, L. Brown, S. D. Culberson, G. Castillo), and justifications for expected relationships were drawn from the literature. Although Bayesian model selection (Green 1995) might have been incorporated into the MAR model, as was done for the complementary change point analyses (Thomson et al. 2010), we believe that there is didactic value in concentrating on the evidential support for the expert-elicited model.

Statistical Estimation

MAR: Gompertz dynamics

We used a variant of a MAR model (Ives et al. 2003) to represent dynamics of the response variables. We represented population dynamics with the Gompertz model (Dennis et al. 2006). We began with a deterministic version of the Gompertz model (Reddingius 1971):

$$n_{i,t} = n_{i,t-1} \exp(\gamma_i + \delta_i \ln n_{i,t-1}) \tag{1}$$

in which $n_{i,t}$ is abundance of species i at time t, $n_{i,t-1}$ is abundance of species i at time $t-1$, γ_i is the intrinsic rate of population growth for species i, and δ_i, which has been interpreted as the degree of density dependence.

We extended Eq. 1 first by allowing propagation for longer lags (up to L years prior to the current year), that is, an Lth-order Gompertz model (Zeng et al. 1998):

$$n_{i,t} = n_{i,t-1} \exp(\gamma_i + \sum_{l=1}^{L} \delta_{il} \ln n_{i,t-l}). \tag{2}$$

It is possible that the γ_i may vary, so we allowed linear time dependence: $\gamma_i(t) = \gamma_{i,0} + \gamma_{i,1}t$. We expected the $\gamma_{i,1}$ parameters to be <0 given the declines in the abundances of the fishes. Taking logarithms, setting $x_{i,t} = \ln n_{i,t}$, and allowing species-specific lags (L_i), we have

$$x_{i,t} = x_{i,t-1} + \gamma_i(t) + \sum_{l=1}^{L_i} \delta_{il} x_{i,t-l}. \tag{3}$$

Interspecific interactions among the seven taxa included as response variables were incorporated by appending terms relating to the previous year $\beta_{ij}x_{j,t-1}$, excluding self-terms:

$$x_{i,t} = x_{i,t-1} + \gamma_i(t) + \sum_{l=1}^{L_i} \delta_{il} x_{i,t-l} + \sum_{j=1, j\neq i}^{J} \beta_{ij} x_{j,t-1}. \tag{4}$$

We included effects of covariates u_k through α coefficients for the current year t:

$$x_{i,t} = x_{i,t-1} + \gamma_i(t) + \sum_{l=1}^{L_i} \delta_{il} x_{i,t-l} + \sum_{j=1, j\neq i}^{J} \beta_{ij} x_{j,t-1} + \sum_{k=1}^{K} \alpha_{ik} u_{k,t}. \tag{5}$$

MAR implementation

We used a Bayesian framework for implementing the model. There are many advantages to so doing. First, propagation of measurement uncertainties is straightforward using hierarchical models. Second, missing data are easily accommodated and estimated within the same process by which the parameters estimated are made, rather than a clumsier two-stage imputation–estimation approach. Third, we believe that the prior expectations, which also are easily implemented in a Bayesian framework, are critical encapsulations of the state of knowledge before the modeling was undertaken and need to be made explicit, as we have done.

We implemented Eq. 5 using the following model in WinBUGS, version 1.4 (Spiegelhalter et al. 2003):

$$z_{i,t} \sim \mathcal{N}(x_{i,t}, \omega_{i,t}^2) \qquad x_{i,t} \sim \mathcal{N}(\mu_{i,t}, \sigma_i^2) \qquad c'_{k,t} \sim \mathcal{N}(u_{k,t}, \zeta_k^2)$$

$$\mu_{i,t} = x_{i,t-1} + \gamma_i(t) + \sum_{l=1}^{L_i} \delta_{il} x_{i,t-l} + \sum_{j=1, j\neq i}^{J} \beta_{ij} x_{j,t-1} + \sum_{k=1}^{K} \alpha_{ik} u_{k,t} \tag{6}$$

($\mathcal{N}$ denotes the normal distribution). The model states

TABLE 2. Matrix of effects included in the model with explanations.

Response variable or covariate	Response variable							Explanation
	DS	LFS	SB	TFS	CA-SP	CA-SU	MYS	
Delta smelt (DS)					–	–		Calanoid copepods are consumed by delta smelt (Hobbs et al. 2006).
Longfin smelt (LFS)					–	–	–	Calanoid copepods and mysids are consumed by longfin smelt (Feyrer et al. 2003).
Striped bass (SB)					–	–	–	Calanoid copepods and mysids are eaten by young striped bass (Feyrer et al. 2003, Bryant and Arnold 2007).
Threadfin shad (TFS)								Threadfin shad consume phytoplankton and copepods but are most abundant in freshwater (Turner and Kelley 1966, Feyrer et al. 2007).
Calanoids, spring (CA-SP)	+	+	+					Key food for young fish in spring.
Calanoids, summer (CA-SU)	+	+	+				+	Key food for young fish in summer; mysids consume calanoids (Siegfried et al. 1979, Siegfried and Kopache 1980).
Mysids (MYS)		+	+			–		Key food for young longfin smelt and striped bass in summer.
Anchovy					–	–	–	Biomass dominant, consumes all plankton (Kimmerer 2006).
Other zooplankton				+				Threadfin shad consume zooplankton in freshwater (Turner and Kelley 1966).
Chlorophyll *a*, spring, freshwater					+			
Chlorophyll *a*, spring, low-salinity zone					+		+	Calanoids eat microplankton, including phytoplankton (Gifford et al. 2007) and respond positively to phytoplankton blooms (Kimmerer et al. 2005*b*).
Chlorophyll *a*, summer, low-salinity zone						+	+	Mysids eat phytoplankton and small zooplankton (Siegfried and Kopache 1908).
Limnoithona tetraspina						–		Indirect effect through depression of food resource (ciliates; not measured) (Bouley and Kimmerer 2006, Gifford et al. 2007).
Inland silverside	–				–	–		Silversides consume copepods and potentially delta smelt eggs and larvae (Bennett and Moyle 1996).
Largemouth bass	–		–	–				Potentially important predator on small fish in freshwater (Nobriga and Feyrer 2008).
X2, spring		–	–		+/–		–	Effects of spring X2 on subsequent abundance in the following autumn (Jassby et al. 1995, Kimmerer et al. 2009).
X2, autumn	–	–	–					X2 affects surface area available for fish through salinity distribution (Feyrer et al. 2007).
Water clarity	–	–	–	–				Turbidity favors all fish at various life-history stages by offering increased protection from predators (Feyrer et al. 2007, Nobriga and Feyrer 2008, Kimmerer et al. 2009).
Export flow, winter	–	–						Adult smelt are entrained by pumping facilities during winter (Baxter et al. 2008, Kimmerer 2008).
Export flow, spring	–	–	–	–				Juvenile and adult smelt and shad and juvenile striped bass are entrained by pumping facilities during spring (Baxter et al. 2008).
Corbula amurensis					–	–		Nauplius larvae of copepods are consumed by *Corbula* (Kimmerer et al. 1994).
Spawning window	+							Spawning window for delta smelt is constrained by temperature (Bennett 2005).
Mean summer water temperature	–							Delta smelt are negatively influenced by high water temperatures, reducing time spent in the freshwater Delta (Swanson et al. 2000).

Notes: A "+" denotes that the covariate was expected to exert a positive influence on the response variable (e.g., food source). A "–" indicates that the covariate was expected to have a negative influence on the response variable (e.g., by consumption). All null entries were deemed likely to be unimportant by expert knowledge. The abbreviations "X2" refers to the position of the 2‰ isohaline (a measure of the physical response of the estuary to freshwater flow).

that the (ln-transformed) observed values ($z_{i,t}$) represent the true values ($x_{i,t}$). The former have observation errors, which are included by use of (ln-transformed) unobserved values ($x_{i,t}$) and observation errors, $\omega^2_{i,t}$. The observation errors were estimated from SEs of mean values for the response variables for each time period. Given that the $z_{i,t}$ were ln-transformed, we used a Taylor functional expansion to approximate the ln-transformed SEs [$\mathrm{SE}(\ln(\bar{n})) \approx \mathrm{SE}(\bar{n})/\bar{n}$] (Seber 1973, Stuart and Ord 1987). Process variances (σ^2_i) were allowed to be species-specific and were implemented with priors on σ_i of U(0.01, 10) (Gelman 2005) (U = Uniform). The true,

unobserved values ($\mu_{i,t}$) are driven by the population dynamic parameters, trophic interactions, and covariates as described by the MAR model (Eq. 5).

Observed covariates $c_{k,t}$ were standardized for all available years of data (subtract mean $\bar{c}_k$, divide by standard deviations SD_k over all years, $c'_{k,t} = (c_{k,t} - \bar{c}_k)/SD_k$). Standardizing is helpful for model convergence and for equalizing numerical ranges among different scales of measurement. Uncertainties in covariate measurements (within-year SEs) correspondingly were scaled by the interannual standard deviations (i.e., $SE_{k,t}/SD_k$). The model specifies that the true (standardized) covariate values ($u_{k,t}$) are related to the observed standardized values ($c'_{k,t}$) but include the covariate-specific uncertainties [$\zeta_k^2 = (SE_{k,t}/SD_k)^2$]. Uncertainties for most covariates were included in the models (a few variables, such as presence of *Corbula*, were regarded as fixed). There were sporadic missing data for some covariates, which we allowed to be interpolated within the Markov chain Monte Carlo (MCMC) modeling. These missing covariate values need to be segregated from the main estimation of effects by using the "cut()" function in WinBUGS. If the uncertainties are not so isolated, the model will "sacrifice" fitting precision for the parameters describing dynamics of the response variables to better "fit" missing covariate values, which is not intended (Carrigan et al. 2007).

Priors

Relatively uninformative priors were assigned for these model parameters:

$$\gamma_{i,0} \sim \mathcal{N}(0,1) \qquad \eta_\gamma \sim \mathcal{N}(0,10^3) \qquad \sigma_\gamma \sim \mathrm{U}(0.01,10)$$
$$\sigma_i \sim \mathrm{U}(0.01,10) \qquad \delta_{il} \sim \mathcal{N}(0,1). \tag{7}$$

Use of standard Normal priors for the γ_0 and δ parameters is consistent with the expected values being within approximately ± 1 (i.e., constrained to reasonable values) given the ln-transforms for the response variables and the standardized covariates. From expert elicitation, species-specific lags were 2 (delta smelt), 3 (longfin smelt), 5 (striped bass), 2 (threadfin shad), and 1 (calanoids and mysids).

For the key α, β, and γ_1 parameters, we used a Weibull distribution to represent the prior beliefs of the expert-elicited model (Table 2). Use of the Weibull allows long tails in the expected direction if these are supported by the data. We used the construction ψ_0Weibull(2, 1) + ψ_1, where $\psi_0 = 1$ for expected influences in a positive direction and is -1 for negative expected influences, while ψ_1 is -0.55 for expected influences in a positive direction and 0.55 for negative ones. These configurations invest ~3:1 prior probability mass in favor of the expected influence. Only one α parameter had a neutral expected influence (Table 2), so this was assigned a $\mathcal{N}(0, 10^3)$ prior (i.e., low precision). Many of the potential relationships were specifically excluded from the model (i.e., deemed unlikely to be important). For such relationships, coefficients were assigned $\mathcal{N}(0, 10^{-6})$ priors (i.e., 0 with high certainty).

Parameter inference

We inferred importance of model parameters from the probability distributions of the parameters. We computed the proportion of the posterior probability distribution for each parameter exceeding 0 (designated as PPM), which is computed in WinBUGS with the "step()" function. The posterior odds are PPM/(1 − PPM) for a positive parameter and (1 − PPM)/PPM for a negative parameter. The ratio of these posterior odds to the prior odds is termed the odds ratio (OR). Common decision criteria for ORs are 3.2–10 (substantial evidence) and 10–100 (strong evidence) (Jeffreys 1961). For an uninformative prior, in which the ratio of prior probabilities for the parameter is unity, the OR is PPM/(1 − PPM) (or (1 − PPM)/PPM for negative parameters). We used a decision criterion of $\geq$10 for such parameters.

For informative priors, the prior odds were 3 (positive or negative). If the OR $\geq$ 3.2, we concluded that there was substantial support in the data for the expected relationship. If $1 \leq \mathrm{OR} < 3.2$, the data did not invalidate the expectation but there was less support (Jeffreys 1961). If $1 \geq \mathrm{OR} > 1/3.2$, then the data weakly contradicted the expectation. If OR $\leq$ 1/3.2, then the prior ratio of 3:1 had been shifted to 1:1 (or more extreme), suggesting that the expected relationship was inconsistent with the data but likely to be null. We interpreted OR $<$ 1/10 (viz. from 3:1 prior expectation to 1:3.2 posterior odds) as clear refutation of the expected relationship.

Modeling details and model fit

Parameters were estimated from three MCMC chains of 20 000 iterations after 10 000 iterations of burn-in ("model settling"). We checked MCMC mixing and convergence using the "boa" package (Smith 2006) in *R* (R Development Core Team 2006).

We determined relative importance of the autoregressive (A), among-response variables (R), and covariate (C) factors of the best model. To do so, we calculated the r^2 for eight models: null (fitting constant-only averages for the seven response variables), A, R, C, A + R, A + C, R + C, A + R + C (full model). These models were effected by deleting terms from Eq. 6 as appropriate. The γ_i terms were retained for all models. The r^2 are the squared Pearson correlation coefficients between the z and μ values from the seven response variables and all years. To decompose variance we used hierarchical partitioning (Chevan and Sutherland 1991, Mac Nally 2000), which identifies independent contributions from individual terms (viz. A, R, and C) and joint variance explanation. We used the R package "hier.part" (Walsh and Mac Nally 2003) to perform the decomposition.

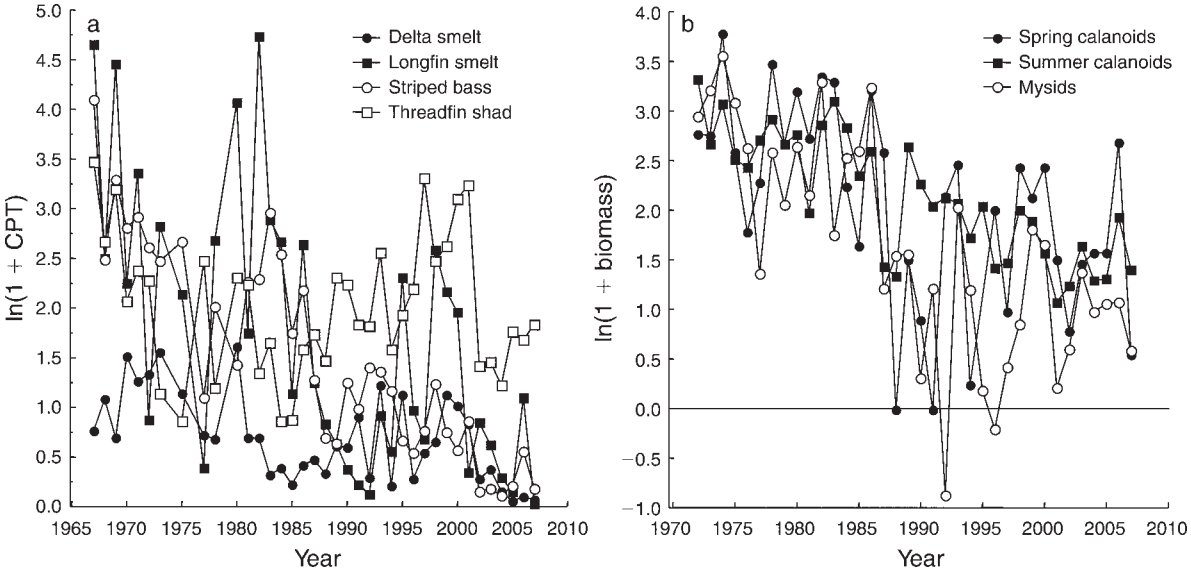

FIG. 2. Population trends (log-transformed) of (a) four fish species (mean catch per trawl [CPT]) and (b) zooplankton taxa (biomass, originally measured in mg C/m^3).

RESULTS

Abundance trajectories

Abundances of all four species of fish declined over the period of data collection, especially since about 2002 (Fig. 2a). Biomasses of the three crustacean groups have been declining consistently since the 1970s, with less evidence of a sudden decline in the 2000s (Fig. 2b).

Overall model characteristics

We used the r^2 (squared Pearson correlation coefficient) between the observed values and the posteriors of the fitted means as our measure of model fit. The full model (autoregressive components, among-response variables interactions, covariates) had an $r^2 = 0.69$. This explained variance was decomposed into independent explanatory amounts of (a) 0.13 for the autoregressive components (A), (b) 0.21 for among-response variable components (R), and (c) 0.35 for covariate relationships (C) (hence 1:1.62:2.69). Thus, the covariates were roughly 66% more important in explaining variation than the response variables, which in turn were ~62% more important than autoregressive elements.

Specific relationships

Parameter estimates and related details are provided in Appendix A. Some covariates appeared to affect more than one response variable (Fig. 3a, b). For expectations that seemed strongly supported by the data, the large values of spring X2 (upstream location) were negatively related to abundances of longfin smelt, biomass of calanoids in spring, and biomass of mysids (Fig. 3a). High water clarity was associated negatively with abundances of striped bass and threadfin shad, while high mean summer water temperatures had an inverse relationship with delta smelt abundance (Fig. 3a).

Several expectations were more weakly supported by the data, but were not refuted. Spring exports were negatively associated with abundances of delta smelt and threadfin shad (Fig. 3b). Many of the trophic interactions among response variables were supported to some extent, including negative relationships between the abundance of longfin smelt and delta smelt and biomass of calanoids in summer, negative correlations between abundance of striped bass and calanoid biomass in spring, and a positive relationship between concentration of chlorophyll *a* in spring and biomass of mysids and calanoids. Calanoid biomass in spring and summer was negatively associated with presence of the nonnative clam *Corbula amurensis*, while abundance of largemouth bass and volume of winter exports were negatively associated with abundance of delta smelt (Fig. 3b).

For all four declining fish species, the parameters indicating density dependence (δ) from the previous year were strongly negative, ranging from -0.79 ± 0.26 (mean $\pm$ SD) for threadfin shad to -1.03 ± 0.18 for longfin smelt (Appendix A). Current abundances were positively related to those for two years previous for longfin smelt (0.30 ± 0.16). Other lag effects were deemed unimportant, although a four-year lag (positive) for striped bass had OR = 9.2.

For the γ parameters, only one result seemed unexpected. The anticipated negative slope for threadfin shad was positive, with high certainty (OR $< 1/57.8$; Appendix A). This suggested, counterintuitively, that the intrinsic population growth parameter had increased over the duration of study.

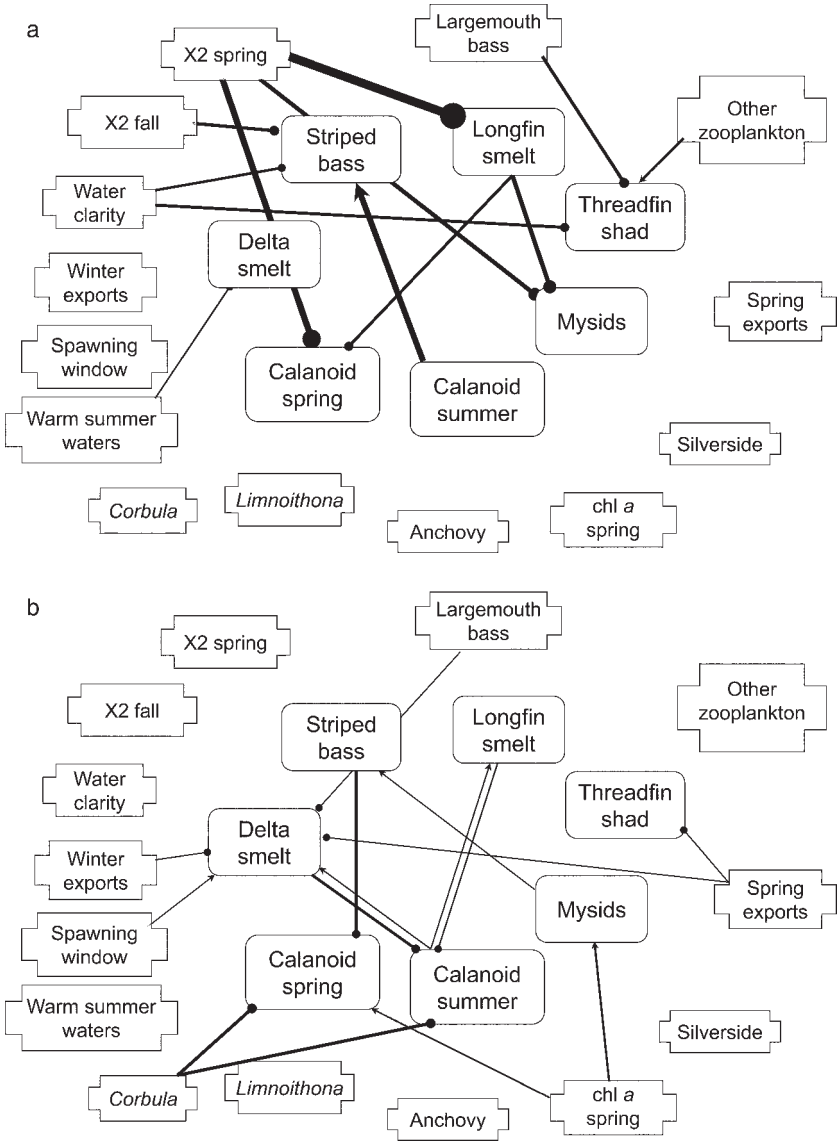

FIG. 3. Relationships supported by the Bayesian multivariate autoregressive analysis of the expert-elicited model, with width of lines proportional to the regression coefficient divided by its standard error. Response variables (focal taxa) are enclosed in rounded boxes while covariates are in boxes with side tabs. Arrows toward a focal taxon indicate a positive effect related to the focal taxon or covariate of line origin, while solid circles indicate negative relationships. (a) Relationships for which the odds ratio ≥ 3.2. (b) Relationships for which the odds ratio falls between 1 and 3.2. The abbreviation "X2" refers to the 2‰ isohaline.

DISCUSSION

Overview of the MAR results

The importance of covariates (51% of explained variation) suggests that some aspects of the environment that can be managed are associated with the declining fish species (e.g., X2 and exports). However, other potential remedial actions would be difficult or impossible to enact (e.g., total removal of *Corbula amurensis*). The relatively large proportion of variance explained by interactions among the declining fishes and their prey suggests that trophic interactions also are important, but it is less clear how management actions could modify such relationships.

The MAR analysis largely supported the expert model, suggesting that existing knowledge is sufficient to identify important interactions and processes, although not all relationships were supported. The expert model included 54 relationships, all but one of which was assigned an expected direction (Table 2). The latter was an "uninformed" expectation that calanoids in spring would be affected by spring X2. The direction was found to be strongly negative (Fig. 3a), suggesting that spring calanoid abundance is greater when X2 is

more seaward. Of the 53 relationships with expected directions, 13 were strongly supported on the basis of odds ratios (OR) of $\geq$3.2 (Fig. 3a) and 15 were not inconsistent with the expected direction ($3.2 > \text{OR} \geq 1$) (Fig. 3b). The other 25 coefficients had posterior means close to zero, indicating that the data did not support the expected directions.

One advantage of using the MAR approach is that results can be represented easily in a form with which most ecologists are familiar, a (partial) food web (Fig. 3). The predator–prey relationships involving the calanoids and mysids support existing reports of direct and indirect effects on the four declining fish species. For example, abundance of striped bass was positively related to availability of calanoid copepods in summer (Fig. 3a). This was negatively associated with the occurrence of the introduced clam *Corbula amurensis* (Fig. 3b), which has induced an ongoing decrease of ~60% in chlorophyll *a* concentration in the low-salinity zone (Alpine and Cloern 1992). Other indirect food limitation relationships may be the chlorophyll *a* (spring) → mysids → striped bass and chlorophyll *a* (spring) → calanoids (spring) → striped bass pathways (Fig. 3b). Longfin smelt abundances had strong negative correlations with calanoids in spring and summer and mysids in spring (Fig. 3a, b). Abundance of delta smelt was related to calanoid biomass in summer (Fig. 3b). These results and relationships of copepods and mysids to chlorophyll *a* concentrations (Fig. 3b) suggest that food web dynamics are important for both smelt species. The isohaline position (X2) in spring had strong negative relationships with spring calanoids and mysids, which also would propagate back through those food pathways (Fig. 3a).

Few covariate relationships were expressed clearly for more than one of the four declining fish species (Fig. 3a, b). Increased water clarity appeared to be related negatively to both striped bass and to threadfin shad (Fig. 3a). Increased water clarity has been attributed to reduction of sediment supply in the rivers (Wright and Schoellhamer 2004) and to sediment capture by submerged aquatic vegetation. Water clarity affects fish feeding (Hecht and Vanderlingen 1992) and vulnerability to predation (Gregory and Levings 1998). Abundance of largemouth bass, a potential predator of the declining fish species (Nobriga and Feyrer 2008), was negatively related to abundance of threadfin shad and, more weakly, to abundance of delta smelt (Fig. 3). Abundance of largemouth bass has increased in the Delta concurrently with expansion of submerged aquatic vegetation (Brown and Michniuk 2007), which provides high-quality habitat for the species. Greater cover of submerged aquatic vegetation also reduces turbidity. Reduced water clarity has been identified as a key component of habitat for delta smelt, at least in autumn (Feyrer et al. 2007). The absence of a discernible relationship between water clarity and abundance of delta smelt may be due to an indirect expression through trophic relationships. Young delta smelt require suspended particles in the water column to feed properly (Baskerville-Bridges et al. 2002, Mager et al. 2002), so reduced prey availability (e.g., summer calanoids) may mask the direct water clarity effect. The multiple effects of temperature, feeding, exports, and introduced species are more consistent with understanding of delta smelt biology (Bennett 2005, Baxter et al. 2008) than are effects of individual covariates per se.

There were clear relationships between warmer summer waters (negative) and duration of water temperatures suitable for spawning (positive) (Fig. 3) and delta smelt, which were consistent with known effects of high temperatures on delta smelt survival (Swanson et al. 2000) and spawning requirements (Bennett 2005).

Increases in water exports in both winter and spring were negatively associated with abundance of delta smelt and increases in spring exports with abundance of threadfin shad. Losses of delta smelt previously have been related to exports through entrainment and mortality at pumping facilities and may be important to population dynamics under some circumstances, particularly during dry years (Kimmerer 2008). Effects of spring exports on threadfin shad have not been measured but possibly are important given that this is the only species of the four to occupy freshwater throughout its life cycle and whose main distribution is near the export facilities (Feyrer et al. 2009).

Modeling formulation: data and limitations

Using MAR, we identified plausible results, notwithstanding a number of important caveats within the model framework, which relate to the nature of the underlying data and to the structure of the analytical model.

Data limitations.—Three major forms of data limitation inherent in MAR are relevant to our study: (1) characterization of all variables and covariates by using a single value per year; (2) lack of spatially and temporally explicit data; and (3) selection of covariates and their measurement. For the declining fish species, we used an estimate of abundance based on average catch per sampling trawl over ~100 sampling stations over each of the four autumn months (September to December). Fish have been collected by other sampling methods (e.g., beach seine nets), but either not consistently over the duration of the data collection or only recently. We included observation error as the standard error from the ~400 trawls per year, but whether this is the most appropriate measure is arguable (Newman 2008).

Apart from allowing γ_i to be time-dependent (albeit linearly), the MAR model assumed process stationarity over the entire duration, which means that the structure of the model and distributions of model parameters are regarded as being the same over the 40+ years. It is possible that population dynamics of the declining taxa

changed greatly as a function of population size. It is plausible that per capita reproductive rates, age structures, social (e.g., schooling) behaviors, Allee effects (Stephens and Sutherland 1999), and vulnerability to predation may differ when there are many individuals compared to when there are few. This is a common tenet in conservation biology (Caughley 1994).

Given the high certainty that all four species declined in concert in 2002 (Thomson et al. 2010), we modified Eq. 6 to allow all parameters to have a two-phase structure. The first phase was the 1967–2001 period and the second phase was 2002–2007. Each parameter was represented by a term of the form $\varpi + \delta\varpi$, where $\delta\varpi$ was the deviation in the second phase from values in the first phase. There were no parameters in which $\delta\varpi$ differed substantially from zero using our OR criteria. This suggests that the stationarity assumption of the MAR model is reasonable, although the small number of years in phase two may make changes difficult to detect.

Stakeholders have commissioned extensive correlative analyses (D. Fullerton, W. J. Miller, and B. F. J. Manly, *unpublished data*), which suggest a wide range of possibilities for potential covariates that might have sparked the precipitous declines. We included eight commonly mentioned covariates in additional runs of the MAR model (Appendix B). Our inferences were little changed, which suggests that our expert model was resilient to inclusion of additional variables and that the latter were largely uninformative.

Model form and structure.—The MAR model is underlain by the Gompertz population dynamic model (Eq. 1). Inference on stock recruitment is contingent on the form of the model (Maunder 2003). We explored whether our inferences were highly dependent on the use of the Gompertz by replacing it with another widely used formulation, the Ricker model (Appendix C; Zeng et al. 1998). The Ricker model emphasized more strongly several relationships: for example, the negative relationships between striped bass and X2 (autumn) and between spring calanoids and X2 (spring) (Appendix C). The Ricker and Gompertz versions of the MAR model generally provided similar inferences but the Gompertz appeared to resolve with greater precision a larger number of relationships given our criteria for their identification (i.e., using ORs).

The values for the δ_{i1} coefficients for the four declining fish species suggested strong negative density dependence (values between −0.79 and −1.03 for one-year lag; Appendix A). Such results seem difficult to reconcile biologically given that the fish sampled each year are young-of-the-year and it is difficult to conceive of a mechanism producing such density dependence. It is possible that this apparent contradiction may be a statistical artifact of the parameterization of the usual Gompertz model. Estimates of γ and δ can be highly correlated and identifiability depends upon length of time series (J. Ponciano, *personal communication*). Even if there were estimation problems for γ and δ, these probably do not affect our estimates of trophic interactions and covariate relationships. From simulations of a Gompertz model with one covariate, we found that the estimate for the covariate coefficient was unbiased even though the estimates of γ and δ were biased (results not shown).

The MAR formulation assumed linear relationships (on the log-abundance scale) and no interactions among covariates, although many interactions are plausible. Interactions would add substantially to the complexity and difficulty of interpretation of an already highly parameterized model. Inclusion of nonlinear functions and interactions among covariates may reduce capacity to resolve drivers of responses if used injudiciously.

A comparison of major outcomes of the MAR analysis with those of the change point analyses, which did allow nonlinear functions of covariates, showed some commonalities, but also several differences. Relationships with water clarity were important in the change point analyses for delta smelt, striped bass, and longfin smelt, although the relationship for the latter was rather stronger in a multispecies model (Thomson et al. 2010). A correlation of water clarity with abundances of threadfin shad, but not with delta smelt, was identified in MAR. A pervasive relationship of spring X2 with abundances of longfin smelt was clear in both analyses. A correlation of winter exports with delta smelt was evident in the change point, but was weaker in the MAR (Fig. 3b). The MAR analysis, but not the change point analysis, identified a correlation between autumn X2 and striped bass. Spring exports appeared to be related to abundances of threadfin shad in both analyses, although the magnitude of the correlation was less in the MAR. Unlike the change-point analysis, the MAR analysis did not identify a relationship between winter exports and threadfin shad. However, in the change-point analysis the magnitude of the average regression coefficient for winter exports and threadfin shad was substantially less than that for spring exports (Thomson et al. 2010). The trophic interactions evident in the MAR, of which many were pronounced (Fig. 3), were less evident in the model selection procedures used in the change point analysis.

A broader life-history model with a more general state–space approach to modeling the pelagic species decline should be more informative (M. N. Maunder and K. B. Newman, *personal communication*). Such a model would incorporate multiple sources of survey data, including data pertinent to egg, larval, juvenile, and adult phases and covariates appropriate for each stage (Maunder 2004).

Estuarine management

Our application of the MAR model provides evidence from a multivariate analysis of how abiotic habitat factors directly relate to declining fish abundance in the upper San Francisco Estuary and indirectly to these fish

populations through the food web. Synthesis of previous univariate analyses have come to similar conclusions, albeit indirectly (Bennett 2005, Baxter et al. 2008). Before the fish species declined precipitously, the abiotic component of their habitat in the estuary was represented mainly as X2 because position of the salinity field was correlated with the abundances of many organisms (Jassby et al. 1995). Recent results have highlighted the importance of other abiotic variables, including water clarity and water temperatures, in the estuary (Feyrer et al. 2007, Nobriga and Feyrer 2008). Our results, which identify trophic relationships, suggest the need to better understand the processes underlying the influence of abiotic conditions on the food web of the estuary. The upper San Francisco Estuary is an exemplar, perhaps an extreme one, of severe, adverse ecological response to many of the stressors to which such systems increasingly are exposed (Fig. 3). Some of the key issues relate to how the isohaline position (X2), which seems to have a profound effect on the declining fish and on their prey, might be managed. While evidence that water exports directly affect striped bass or longfin smelt in a consistent linear manner is weak, there is evidence of potential effects of water exports on delta smelt and threadfin shad. Successfully managing the estuary, at least for the declining fish species, requires a more complete understanding of how the direct effects of water exports interact with the indirect effect of controlling abiotic conditions and the food web.

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APPENDIX A

Details of parameter estimates for the multivariate autoregressive (MAR) model including credible intervals of odds ratios (all model parameters are listed) (*Ecological Archives* A020-050-A1).

APPENDIX B

Details of parameter estimates for multivariate autoregressive (MAR) model with and without distinct variables suggested by other analyses (only parameters with large odds ratios are listed) (*Ecological Archives* A020-050-A2).

APPENDIX C

Details of parameter estimates for multivariate autoregressive (MAR) models underlain by Ricker and Gompertz population-dynamic formulations (only parameters with large odds ratios are listed) (*Ecological Archives* A020-050-A3).

UNITED STATES DISTRICT COURT

FOR THE EASTERN DISTRICT OF CALIFORNIA

DELTA SMELT CONSOLIDATED CASES	1:09-cv-00407 OWW DLB 1:09-cv-00480-OWW-GSA 1:09-cv-00422-OWW-GSA 1:09-cv-00631-OWW-DLB 1:09-cv-00892-OWW-DLB
SAN LUIS & DELTA-MENDOTA WATER AUTHORITY, *et al.* v. SALAZAR, *et al.* (1:09-cv-00407 OWW DLB)	
STATE WATER CONTRACTORS v. SALAZAR, *et al.* (1:09-cv-00480-OWW-GSA)	PARTIALLY CONSOLIDATED WITH: 1:09-CV-01201-OWW-DLB
COALITION FOR A SUSTAINABLE DELTA, *et al.* v. UNITED STATES FISH AND WILDLIFE SERVICE, *et al.* (1:09-cv-00422-OWW-GSA)	MEMORANDUM DECISION RE CROSS MOTIONS FOR SUMMARY JUDGMENT (DOCS. 548, 549, 550, 658, & 661)
METROPOLITAN WATER DISTRICT v. UNITED STATES FISH AND WILDLIFE SERVICE, *et al.* (1:09-cv-00631-OWW-DLB)	
STEWART & JASPER ORCHARDS *et al.* v. UNITED STATES FISH AND WILDLIFE SERVICE (1:09-cv-00892-OWW-DLB)	
FAMILY FARM ALLIANCE v. SALAZAR, *et al.* (1:09-CV-01201-OWW-DLB)	

TABLE OF CONTENTS

I. INTRODUCTION.....5
II. PROCEDURAL HISTORY.....6
III. STATUS OF THE SPECIES.....13
IV. SUMMARY OF MOTION.....14
A. Plaintiffs' Motion.....14
B. DWR's Motion.....16
V. STANDARD OF DECISION.....18

VI. BASIC LEGAL FRAMEWORK.....19
A. Review under the APA. 19
(1) Record Review. 19
(2) Deference to Agency Expertise. 20
(3) General Obligations Under the ESA. 22
(4) Best Available Science. 24
(5) Best Available Science Standards and the Application of Analytical/Statistical Methodologies. 30
VII. ANALYSIS.....31
A. Challenges to the Effects Analysis & Related Challenges to the RPA Actions. 31
(1) Legal Requirements for a Project Effects Analysis. 31
(2) Best Available Science Challenges to the Effects Analysis and Related Challenges to the Justification Provided for the RPA Actions 34
a. The BiOp's General Conclusion that Entrainment by Project Operations Adversely Affects Smelt Survival & Recovery is Supported by the Record. 36
b. Population Level Analysis/Life-Cycle Modeling. 44
c. FWS' Use of Raw Salvage Numbers. 53
(1) Federal Defendants' Argument that the Flow Prescriptions in Actions 1 and 2 are Otherwise Justified. 61
(2) Use of Raw Salvage Analyses in Justification for Action 3. 71
d. FWS's Comparison of CALSIM II Data to DAYFLOW Data. 74
(1) Was FWS's Decision to Compare Calsim II to Dayflow Model Runs a Violation of the Best Available Science Requirement? 84
(2) Does the Use of Dayflow to Represent the Baseline in the Project Effects Analysis Improperly Attribute Past Effects to the Projects? 99
(3) Use of Comparisons Between CALSIM and DAYFLOW Model Outputs to Justify Imposition of Component 3 (Action 4), the Fall X2 Action. 100

(3) Other Challenges to the Fall X2 Action. 104
a. Plaintiffs' Argument that Action 4 is an "Untested Hypothesis." 104
b. FWS' Reliance on the Feyrer Papers. 105
c. Do the Studies Cited in the BiOp Support FWS's Conclusion that Fall X2 Determines the Extent of Suitable Smelt Habitat? 108
(1) Feyrer (2007). 108
(2) The Feyrer (2008) Paper. 113
(3) The Bennett (2005) Article. 114
d. Does the Best Available Science Support the Assumption that X2 Is a Surrogate for Smelt Habitat? 115
a. Are Delta Smelt Habitat Limited? 117
b. FWS' Use of a Linear Model Instead of a Multiplicative Stock-Recruit Model 119
c. DWR's Challenge to the BiOp's Choice of X2 Location. 124
(4) Challenges to Turbidity Trigger. 126
(5) Challenges to the Incidental Take Limit/Selective Use of Data. 129
a. FWS's Exclusion of Certain Data Points When Analyzing Entrainment. 130
b. FWS's Use of Data to Examine the Relationship Between OMR Flows and Salvage and Exclusion of that Data from the Incidental Take Limit Analysis. 132
c. DWR's Additional Challenges the ITS. 139
(6) Challenges to the BiOp's Analysis of the Hydrodynamic Effects of the Projects. 141
a. Project Operations as a Driver of Hydrodynamic Conditions in the Delta. 142
b. Treatment of Other Stressors. 146
(1) Predation Analysis. 150
(2) Aquatic Macrophytes. 152
(3) Microcystis 154
(7) Indirect Effects Analysis. 155
a. Effect of Project Operations on Delta Smelt Food Supplies. 157
b. Pollution and Contaminants 162

(8) Critical Habitat as Independent Basis for RPA. 167

a. Identification of a Threshold For Adverse Modification/ Explanation of How Any Alleged Alteration To Critical Habitat Would Exceed that Threshold. 170

b. Reliance On Assumptions Of Indirect Effects Without Providing Evidence That These Indirect Effects Are Reasonably Certain To Occur. 174

c. Reliance on Analysis Of Entrainment and X2 in Support of the Adverse Modification Determination. 176

(9) Discretionary v. Nondiscretionary Actions. 178

B. Application of the RPA Regulations. 179

(1) FWS Did Not Explicitly Analyze Any of the Four Factors in the BiOp. 180

(2) Compliance with § 402.02. 181

a. Jeopardy Factor (Fourth Factor). 182

b. Non-Jeopardy Factors (Factors One Through Three). 183

c. There is no Procedural Requirement that FWS Accept, Consider, and/or Address Comments Regarding the BiOp or its RPA. 196

C. Stewart & Jasper Orchards' Argument Re: Reasonable and Prudent Measures. 196

D. Stewart & Jasper, et al.'s, Argument that FWS Illegally Arrogated Authority to Itself Over Bureau of Reclamation and California Department of Water Resources Operations. 198

E. Information Quality Act Claim. 200

(1) Legal Framework of the IQA. 200

(2) Right to Judicial Review Under the APA. 203

a. APA § 702(a)(2)'s Exception for Agency Action "Committed to Agency Discretion by Law" Bars Judicial Review in this Case. 205

(3) To the Extent FFA Bases Any of its Claims against Reclamation on the ESA, Such Claims are Subject to the ESA's Pre-Filing Requirements. 211

F. Renewed Claim That FWS Violated NEPA. 212

G. Reclamation's Liability under the ESA. 215

VIII. CONCLUSION.....218

I. INTRODUCTION

These consolidated cases arise out of the continuing war over protection of the delta smelt (*Hypomesus transpacificus*), an ESA-threatened species, and associated impacts to the water supply for more than half of the State of California. Plaintiffs, San Luis & Delta Mendota Water Authority ("SLDMWD") and Westlands Water District, Metropolitan Water District of Southern California, State Water Contractors ("SWC"), Coalition for a Sustainable Delta and Kern County Water Agency, Stewart & Jasper Orchards, Arroyo Farms, LLC, and King Pistacho Grove, and Family Farm Alliance, move for summary judgment on their numerous remaining claims against the United States Fish and Wildlife Service's ("FWS") December 15, 2008 Biological Opinion addressing the impacts of the coordinated operations of the federal Central Valley Project ("CVP") and State Water Project ("SWP") on the threatened delta smelt (*Hypomesus transpacificus*). Doc. 550. Plaintiff-in-Intervention, the California Department of Water Resources ("DWR") filed a separate motion for summary judgment on narrower grounds. Docs. 548 & 549. Federal Defendants, the United States Department of the Interior, FWS, and the United States Bureau of Reclamation ("Reclamation"), and Defendant Intervenors, Natural Resources Defense Council and The Bay Institute, oppose and cross move for summary judgment on all remaining claims. Docs. 658 & 661. Plaintiffs and DWR replied.

Docs. 697 & 695. The motion came on for hearing on July 8 & 9, 2010. After oral argument, the parties submitted supplemental briefing on a limited set of issues. Docs. 746-49.

II. PROCEDURAL HISTORY

FWS's 2005 biological opinion ("2005 Smelt BiOp") found that the proposed coordinated operations of the SWP and CVP will have no adverse effect on the continued existence and recovery of the Delta Smelt and its critical habitat. The 2005 BiOp was remanded to FWS as arbitrary and capricious. Order, *NRDC v. Kempthorne*, 1:05-cv-1207 (E.D. Cal. May 25, 2007), Doc. 323. Following an extensive evidentiary hearing, the Court issued an interim remedial order and Findings of Fact and Conclusions of Law ("Findings"), which covered, among other things, the effects on delta smelt of negative flows in Old and Middle Rivers ("OMR"), two distributary channels of the San Joaquin River. *See* Interim Remedial Order Following Summary Judgment and Evidentiary Hearing ("Int. Rem. Order"), *NRDC v. Kempthorne*, Doc. 560 (Dec. 14, 2007); Findings re: Delta Smelt ESA Remand and Reconsultation ("Int. Rem. Findings"), *NRDC v. Kempthorne*, Doc. 561 (Dec. 14, 2007).[1]

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[1] There is limited merit to Plaintiffs' contention that these prior findings are "not relevant." *See* Doc. 551 at 91. These findings are not dispositive, but cannot be ignored, as they are based on extensive scientific testimony subject to cross-examination by many of the Plaintiffs in the present case. The order remanded the 2005 BiOp back to FWS "for further consideration consistent with [the] Court's orders and the requirements of law." Int. Rem. Order at 2 (emphasis added).

Reclamation and DWR were ordered, among other things, to implement a winter "pulse flow" in OMR of no more negative than -2,000 cubic feet per second ("cfs"), and to "operate the CVP and SWP to achieve a daily average net upstream (reverse) flow in the OMR not to exceed 5,000 cfs on a seven-day running average" during a defined period in the spring. Int. Rem. Order at 5-7; *see also* Int. Rem. Findings at 15-20.

FWS issued a new delta smelt biological opinion on December 15, 2008 ("2008 Smelt BiOp" or "BiOp"). *See* Administrative Record ("AR") at 00001-00411.[2] This BiOp concluded that proposed CVP and SWP operations are "likely to jeopardize the continued existence of" the delta smelt and "adversely modify" its critical habitat. BiOp at 276-79. The BiOp includes a required Reasonable and Prudent Alternative ("RPA") designed to allow the projects' continued operations without causing jeopardy to the species or adverse modification to its critical habitat. *Id*. at 279-85. The RPA includes operational components designed to reduce entrainment of smelt during critical times of the year by controlling (limiting) water exports from the Delta by the Projects. *Id. at* 279-85.

Component 1, to protect of the adult delta smelt life stage, consists of two Actions related to OMR flows.

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[2] Citations to the 2008 delta smelt BiOp will be to the BiOp's original pagination, not Administrative Record page numbers.

- Action 1, to protect upmigrating delta smelt, is triggered during low and high entrainment risk periods based on physical and biological monitoring. Action 1 requires OMR flows to be no more negative than -2,000 cfs on a 14-day average and no more negative than -2,500 cfs for a 5-day running average. *Id. at* 280-82, 329-51.
- Action 2, to protect adult delta smelt that have migrated upstream and are present in the Delta prior to spawning. Action 2 is triggered immediately after Action 1 concludes or if recommended by the Smelt Working Group ("SWG"). Flows under Action 2 can be set within a range from -5,000 to -1,250 cfs, depending on a complex set of biological and environmental parameters. *Id. at* 281-82, 352-56.

Component 2 (Action 3), to protect larval and juvenile delta smelt, requires OMR flows to be kept between -1,250 and -5,000 cfs, after Component 1 is completed, when Delta water temperatures reach 12° Celcius ("C"), or when a spent female smelt is detected in trawls or at salvage[3] facilities. *Id. at* 282, 357-58. Component 2 continues until June 30 or when the Clifton Court Forebay water temperature reaches 25° C. *Id. at* 282, 368.

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[3] It is undisputed that Project pumping "kills Delta smelt by sucking them directly into the pumps; by drawing them into fish 'salvage' facilities which collect fish diverted from entering the pumps, a process that kills the smelt; and drawing smelt into the SWP's Clifton Court Forebay from which the fish cannot escape and where they will die even if they are not drawn into the salvage facilities or the pumps." Int. Rem. Findings ¶ 19.

Component 3 (Action 4), to improve habitat for delta smelt growth and rearing, requires sufficient Delta outflow to maintain average mixing point locations of Delta outflow and estuarine water inflow ("X2"[4]) from September to December, depending on water year type, in accordance with a specifically described "adaptive management process" overseen by FWS. *Id. at* 282-83, 369.[5]

Component 4 (Action 6) (Habitat Restoration), requires DWR to create or restore 8,000 acres of intertidal and subtidal habitat in the Delta and Suisun Marsh within 10 years. *Id. at* 283-84, 379.

Component 5 (Monitoring and Reporting), requires Reclamation and DWR to gather and report information to ensure proper implementation of the RPA actions, achievement of physical results, and evaluation of the effectiveness of the actions on the targeted life stages of delta smelt, so that the actions can be refined, if needed. *Id. at* 284-85, 328, 375.

The first of the six consolidated challenges to the BiOp was filed on March 3, 2009. Doc. 1. Plaintiffs moved for a

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[4] X2 is the location in the Delta where the salinity is two parts per thousand, measured as the distance upstream from the Golden Gate. *Consolidated Delta Smelt Cases*, 717 F. Supp. 2d 1021, 1029 (E.D. Cal. May 27, 2010); BiOp at 149.

[5] Action 5, which is not formally associated with any "Component" of the RPA, prohibits FWS from installing the Head of Old River Barrier, a physical barrier designed to reduce the number of out-migrating salmon smolts entering Old River, in the spring if delta smelt entrainment triggers are met. BiOp at 175, 377-78.

preliminary injunction on April 24, 2009 to prevent Reclamation from implementing Component 2 of the RPA, alleging that FWS violated the National Environmental Policy Act ("NEPA") and the ESA. *See* Doc. 31.

On May 22, 2009, the Court granted that motion in part, finding that Plaintiffs were likely to succeed on the merits of their NEPA claim and requiring FWS to make specific written findings to justify OMR flow restrictions. *See* Doc. 84; *see also* Doc. 94, Findings re Mot. for Prelim. Inj. (May 29, 2009). Defendants complied with that Order, submitting weekly notices of FWS's OMR flow decisions. *See, e.g.*, Doc. 111, Notice of OMR Flow Decision (June 11, 2009). The Court's May 2009 preliminary injunction ruling was not based on Plaintiffs' ESA claims. Doc. 94 at 43.

Plaintiffs amended their Complaint, joined and added claims against Reclamation, *see* Doc. 292, and moved for summary judgment on their NEPA claim, *see* Doc. 245. A November 13, 2009, ruling granted summary adjudication in part, based on Reclamation's failure to prepare an environmental impact statement before provisionally accepting and implementing the BiOp and its RPA Actions. Doc. 399.

Summary judgment for Defendants was granted on: (1) Stewart and Jasper Orchards' Commerce Clause claim that the ESA did not apply to protect delta smelt, a purely intra-state species, Doc.

339; and (2) claims that the BiOp violated regulations governing formulation of the RPA by not including required information in the BiOp text, Doc. 354.

Plaintiffs then filed three temporary restraining order motions over a six week period -– all of which were denied. *See* Docs. 555 & 583; *see also* 3/16/10 Hrg. Tr. at 86-88. Plaintiffs next sought a preliminary injunction against implementation of RPA Component 3. An evidentiary hearing was held from April 2, 2010 through April 7, 2010. Docs. 644, 652-54. Findings Re Plaintiffs' Request for Preliminary Injunction issued May 27, 2010 ("PI Decision"). Doc. 704. The PI Decision confirmed Plaintiffs had succeeded on their NEPA claim and found Plaintiffs were likely to succeed on the merits of their ESA claim:

> Although the premise underlying Component 2 -- that the species may be jeopardized by increased negative flows occasioned by export pumping -- has record support, FWS has failed to adequately justify by generally recognized scientific principles the precise flow prescriptions imposed by Component 2. The exact restrictions imposed, which are inflicting material harm to humans and the human environment, are not supported by the record, making it impossible to determine whether RPA Component 2 [is] overly protective. Judicial deference is not owed to arbitrary, capricious, and scientifically unreasonable agency action.

Id. at 122. Plaintiffs presented evidence under NEPA on the balance of the hardships that social dislocation, unemployment, and other threats to human health and safety were caused by interdiction of Plaintiffs' water supply. *See id*. at 123.

Countervailing irreparable harm was found, because "the species and its critical habitat[] are entitled to protection under the ESA." *Id*. at 124. Acknowledging the existence of legal and equitable grounds for injunctive relief, further evidence was requested on the "status of the species to assure that altered operations will not deepen jeopardy to the affected species or otherwise violate other laws." *Id*. at 125. Specifically, to establish "that Plaintiffs' proposed remedy of a flat -5,600 cfs ceiling on negative OMR flows will not jeopardize the continued existence of the species and/or adversely modify its critical habitat." *Id*.

A May 28, 2010 status conference sought to determine whether a mutually-agreeable interim operational plan could be implemented. Doc. 706. On June 22, 2010, the parties stipulated to a joint operational plan to maintain OMR flows so as not to be more negative than -5,000 cfs, unless certain, defined salvage triggers required a further reduction in OMR flows. Doc. 724.

After these dispositive motions were filed, the National Academy of Sciences, completed a comprehensive review of the BiOp, and concluded that the BiOp and the RPA Actions were "scientifically justified." *See* National Academy of Sciences, National Research Council, A Scientific Assessment of Alternatives for Reducing Water Management Effects on Threatened and Endangered Fishes in California's Bay Delta at 3. Doc. 635.

This post-decisional document is not part of the Administrative Record ("AR") and no legal justification exists to supplement the AR to include it.

Additionally, a scientific peer review panel was convened by the private consulting firm, Post Buckley Shuh and Jernigan ("PBS&J"), at the request of Plaintiff Family Farm Alliance ("FFA") in connection with FFA's administrative petition under the Information Quality Act ("IQA"). *See Family Farm Alliance v. Salazar*, 09-cv-1201 OWW-DLB (E.D. Cal.), Doc. 27, Ex. A. This document is part of the administrative record in the *Family Farm Alliance* IQA case, not the smelt AR. There is no basis to consider this document for non-IQA claims.

III. STATUS OF THE SPECIES

The delta smelt was listed as a threatened species under the ESA on March 5, 1993. 58 Fed. Reg. 12,854 (March 5, 1993). Critical habitat was designated for the delta smelt on December 19, 1994. 59 Fed. Reg. 65,256 (Dec. 19, 1994). Once an abundant species in the Bay-Delta ecosystem as recently as thirty years ago, the delta smelt is now in imminent danger of extinction. PI Decision, Finding of Fact ¶ 10. All the evidence shows a significant decline in smelt abundance since 2000, recently up to three orders of magnitude below historic lows. *Id*. The latest fall mid-water trawl ("FMWT") abundance index for the species was 17, the lowest level ever recorded. *Id*.

On April 7, 2010, FWS announced that reclassifying the delta smelt from a threatened to an endangered species was warranted, but precluded by higher priority listing actions. 75 Fed. Reg. 17,667 (Apr. 7, 2010). The direct mortality of delta smelt by entrainment at the CVP-SWP pumps, as well as the destruction and adverse modification of its habitat in the Delta caused by water exports, were important factors in this determination. *Id*. at 17,669, 17,671 ("The operation of State and Federal export facilities constitute a significant and ongoing threat to delta smelt through direct mortality by entrainment"). As a result of the "immediate and high magnitude threats" confronting the species, the delta smelt was assigned a listing priority number of 2.[6] *Id*. at 17,675.

IV. SUMMARY OF MOTION

A. Plaintiffs' Motion.

Plaintiffs' motion advances the following grounds and contentions:

(1) FWS failed to rely on the "best available science" by making fundamental scientific errors in its analysis of the impacts of Project Operations on the species by:

(a) Relying on raw salvage numbers in quantitative impact analyses;

[6] "Warranted but precluded" species are assigned listing priority numbers from 1 to 12, with 1 being the highest priority. *Id.* at 17,674.

(b) Failing to conduct a life cycle analysis;

(c) Comparing the results of two entirely different, incompatible flow and salinity models; and

(d) Selectively excluding certain data for one purpose, but then unjustifiably using it for another;

(2) The BiOp's Project Effects Analysis is arbitrary and capricious because FWS:

(a) Assumed that Project operations drive hydrological conditions in the Delta and did not explain or justify this attribution;

(b) Evaluated the impacts of other (i.e., non-Project) stressors erroneously and inconsistently; and

(c) Improperly characterized summer food supply suppression, invasive species, and pollution and contaminants as indirect effects of Project Operations;

(3) The BiOp is arbitrary and capricious because it does not distinguish between discretionary and nondiscretionary actions, improperly inflating the alleged effects of Project Operations;

(4) The BiOp's RPA is unlawful because FWS did not conduct the specific analyses required by the ESA and FWS' own RPA regulation, 50 C.F.R. § 402.02, because neither the

BiOp nor the AR demonstrate that FWS analyzed or applied the first three (of four) § 402.02 factors;

(5) FWS illegally arrogated to itself Project operating authority in derogation of Reclamation and DWR;

(6) FWS acted arbitrarily and capriciously by disregarding the Information Quality Act ("IQA") when preparing and issuing the BiOp;

(7) FWS violated NEPA by not considering the environmental impacts of issuing the BiOp and RPA.

(8) Reclamation violated its legal duties by accepting FWS' inherently flawed BiOp.

B. DWR's Motion.

DWR's attacks three aspects of the BiOp:

(1) By relying on a comparison of CALSIM II model runs with what the BiOp terms "historic" data (which was actually generated by the Dayflow model), the BiOp's analysis of the effects of the proposed action on smelt habitat does not yield meaningful information and violates the ESA's best available science requirement. This analysis further violates the APA because FWS did not adequately articulate any rational connection between the facts found based on these comparisons, and its conclusions regarding the Projects' effects on the smelt.

(2) Component 3 of the RPA, also referred to in the BiOp as Action 4, is intended to mitigate the effects of the proposed action on smelt habitat, by requiring the Projects to maintain X2 in specified locations, depending on the type of water year. The BiOp, however, lacks sufficient explanation as to the basis for the specific prescriptions imposed by this Component, in violation of the APA. Moreover, to the extent that the record reveals that these prescriptions are based, even in part, on the methods used in the effects analysis, they violate the ESA's "best available science" mandate.

(3) The Incidental Take Statement ("ITS") is defective. First, its estimates are based on the average take from water years 2006 through 2008, which predicts the ITS will likely be exceeded in half of all years. Second, FWS erroneously misapplied its own data with the result that the BiOp claims that the ITS was only exceeded in five of the previous sixteen years, rather than accurately stating that it was exceeded in eleven of the sixteen years. Third, the ITS take estimate is based on a data sample that is too small to provide a reasonable prediction of take under the RPA. These defects violate the ESA's "best available science"

requirement, the ESA's ITS requirements, and the APA.

V. STANDARD OF DECISION

Summary judgment is appropriate when the pleadings and the record demonstrate that "there is no genuine dispute as to any material fact and that the moving party is entitled to judgment as a matter of law." Fed. R. Civ. P. 56(c). The claims in this case involve FWS's issuance of a biological opinion, which is a final agency action subject to judicial review under the APA, 5 U.S.C. § 702. *Nat'l Wildlife Fed'n v. Nat'l Marine Fisheries Serv.*, 524 F.3d 917, 925 (9th Cir. 2008) ("*NWF v. NMFS II*"). A court conducting judicial review under the APA may not resolve factual questions, but instead determines "whether or not as a matter of law the evidence in the administrative record permitted the agency to make the decision it did." *Sierra Club v. Mainella*, 459 F. Supp. 2d 76, 90 (D.D.C. 2006) (quoting *Occidental Eng'g Co. v. INS*, 753 F.2d 766, 769 (9th Cir. 1985)). "[I]n a case involving review of a final agency action under the [APA] ... the standard set forth in Rule 56(c) does not apply because of the limited role of a court in reviewing the administrative record." *Id*. at 89. In this context, summary judgment becomes the "mechanism for deciding, as a matter of law, whether the agency action is supported by the administrative record and otherwise consistent with the APA standard of review." *Id*. at 90.

VI. BASIC LEGAL FRAMEWORK

A. Review under the APA.

Administrative Procedure Act ("APA") invalidation of a biological opinion requires Plaintiffs to prove that FWS's action was "arbitrary, capricious, an abuse of discretion, or otherwise not in accordance with law." 5 U.S.C. § 706(2)(A).

(1) Record Review.

APA review of a biological opinion is "based upon the evidence contained in the administrative record." *Arizona Cattle Growers' Ass'n v. FWS*, 273 F.3d 1229, 1245 (9th Cir. 2001). Judicial review under the APA must focus on the administrative record already in existence, not some new record made initially in a reviewing court. Parties may not use "post-decision information as a new rationalization either for sustaining or attacking the agency's decision." *Ass'n of Pac. Fisheries v. EPA*, 615 F.2d 794, 811-12 (9th Cir. 1980). Exceptions to administrative record review for technical information or expert explanation make such evidence admissible only for limited purposes, and those exceptions are narrowly construed and applied. *Lands Council v. Powell*, 395 F.3d 1019, 1030 (9th Cir. 2005).

Here, as evidentiary rulings explained, *see, e.g.*, Docs. 387, 392 (10/19/09 Hrg. Tr), 406, 407, 462, 740 (7/8/10 Hrg.), 750, expert testimony has been considered only for explanation of

technical terms and complex scientific subject matter beyond the Court's knowledge; and to understand the agency's explanations, or lack thereof, and the parties' arguments.

(2) Deference to Agency Expertise.

A Court must defer to the agency on matters within the agency's expertise, unless the agency completely failed to address some factor, consideration of which was essential to making an informed decision. *Nat'l Wildlife Fed'n v. Nat'l Marine Fisheries Serv.*, 422 F.3d 782, 798 (9th Cir. 2005) ("*NWF v. NMFS I*"). A court "may not substitute its judgment for that of the agency concerning the wisdom or prudence of the agency's action." *River Runners for Wilderness v. Martin*, 593 F.3d 1064, 1070 (9th Cir. 2009):

> In conducting an APA review, the court must determine whether the agency's decision is "founded on a rational connection between the facts found and the choices made ... and whether [the agency] has committed a clear error of judgment." *Ariz. Cattle Growers' Ass'n v. U.S. Fish & Wildlife*, 273 F.3d 1229, 1243 (9th Cir. 2001). "The [agency's] action ... need be only a reasonable, not the best or most reasonable, decision." *Nat'l Wildlife Fed. v. Burford*, 871 F.2d 849, 855 (9th Cir. 1989).

Id.

Although deferential, judicial review under the APA is designed to "ensure that the agency considered all of the relevant factors and that its decision contained no clear error of judgment." *Arizona v. Thomas*, 824 F.2d 745, 748 (9th Cir. 1987) (internal citations omitted). "The deference accorded an

agency's scientific or technical expertise is not unlimited." *Brower v. Evans*, 257 F.3d 1058, 1067 (9th Cir. 2001) (internal citations omitted).

> [An agency's decision is] arbitrary and capricious if [it] has relied on factors which Congress has not intended it to consider, entirely failed to consider an important aspect of the problem, offered an explanation for its decision that runs counter to the evidence before the agency, or is so implausible that it could not be ascribed to a difference in view or the product of agency expertise.

Motor Vehicle Mfrs. Ass'n of U.S. v. State Farm Mut. Auto. Ins. Co., 463 U.S. 29, 43 (1983); *see also Citizens to Preserve Overton Park, Inc. v. Volpe*, 401 U.S. 402, 416 (1971) (reviewing court may overturn an agency's action as arbitrary and capricious if the agency failed to consider relevant factors, failed to base its decision on those factors, and/or made a "clear error of judgment"), *overruled on other grounds by Califano v. Sanders*, 430 U.S. 99, 105 (1977)).

More generally, "[u]nder the APA 'the agency must examine the relevant data and articulate a satisfactory explanation for its action including a rational connection between the facts found and the choice made.'" *Humane Soc. of U.S. v. Locke*, --- F.3d ---, 2010 WL 4723195, *5 (9th Cir. 2010) (quoting *Motor Vehicle Mfrs. Ass'n*, 463 U.S. at 43). "The reviewing court should not attempt itself to make up for an agency's deficiencies: We may not supply a reasoned basis for the agency's action that the agency itself has not given." *Id.*

(3) General Obligations Under the ESA.

ESA Section 7(a)(2) prohibits agency action that is "likely to jeopardize the continued existence" of any endangered or threatened species or "result in the destruction or adverse modification" of its critical habitat. 16 U.S.C. § 1536(a)(2).

To "jeopardize the continued existence of" means "to engage in an action that reasonably would be expected, directly or indirectly, to reduce appreciably the likelihood of both the survival and recovery of a listed species in the wild by reducing the reproduction, numbers, or distribution of that species." 50 C.F.R. § 402.02; *see also NWF v. NMFS II,* 524 F.3d 917 (rejecting agency interpretation of 50 C.F.R. § 402.02 that in effect limited jeopardy analysis to survival and did not realistically evaluate recovery, thereby avoiding an interpretation that reads the provision "and recovery" entirely out of the text). An action is "jeopardizing" if it keeps recovery "far out of reach," even if the species is able to cling to survival. *NWF v. NMFS II,* 524 F.3d at 931. "[A]n agency may not take action that will tip a species from a state of precarious survival into a state of likely extinction. Likewise, even where baseline conditions already jeopardize a species, an agency may not take action that deepens the jeopardy by causing additional harm." *Id.* at 930.

To satisfy this obligation, the federal agency undertaking the action (the "action agency") must prepare a "biological

assessment" that evaluates the action's potential impacts on species and species' habitat. 16 U.S.C. § 1536(c); 50 C.F.R. § 402.12(a). If the proposed action "is likely to adversely affect" a threatened or endangered species or adversely modify its designated critical habitat, the action agency must engage in "formal consultation" with FWS to obtain its biological opinion as to the impacts of the proposed action on the listed species. *See* 16 U.S.C. § 1536(a)(2), (b)(3); *see also* 50 C.F.R. § 402.14(a), (g). Once the consultation process has been completed, FWS must give the action agency a written biological opinion "setting forth [FWS's] opinion, and a summary of the information on which the opinion is based, detailing how the agency action affects the species or its critical habitat." 16 U.S.C. § 1536(b)(3)(A); *see also* 50 C.F.R. § 402.14(h).

If FWS determines that jeopardy or destruction or adverse modification of critical habitat is likely, FWS "shall suggest those reasonable and prudent alternatives which [it] believes would not violate subsection (a)(2) of this section and can be taken by the Federal agency or applicant in implementing the agency action." 16 U.S.C. § 1536(b)(3)(A). "Following the issuance of a 'jeopardy' opinion, the agency must either terminate the action, implement the proposed alternative, or seek an exemption from the Cabinet-level Endangered Species Committee pursuant to 16 U.S.C. § 1536(e)." *Nat'l Ass'n of Home Builders*

v. Defenders of Wildlife, 551 U.S. 644, 652 (2008).

(4) Best Available Science.

Under the ESA, an agency's actions must be based on "the best scientific and commercial data available." 16 U.S.C. § 1536(a)(2); 50 C.F.R. § 402.14(g)(8) ("In formulating its Biological Opinion, any reasonable and prudent alternatives, and any reasonable and prudent measures, the Service will use the best scientific and commercial data available...."). A failure by the agency to utilize the best available science is arbitrary and capricious. *See Pac. Coast Fed'n of Fishermen's Assns. v. Gutierrez,* 606 F. Supp. 2d 1122, 1144 (E.D. Cal. 2008).

"The obvious purpose of the [best available science requirement] is to ensure that the ESA not be implemented haphazardly, on the basis of speculation or surmise." *Bennett v. Spear*, 520 U.S. 154, 176 (1997).

> While this no doubt serves to advance the ESA's overall goal of species preservation, we think it readily apparent that another objective [of the best available science requirement] (if not indeed the primary one) is to avoid needless economic dislocation produced by agency officials zealously but unintelligently pursuing their environmental objectives. That economic consequences are an explicit concern of the ESA is evidenced by § 1536(h), which provides exemption from § 1536(a)(2)'s no-jeopardy mandate where there are no reasonable and prudent alternatives to the agency action and the benefits of the agency action clearly outweigh the benefits of any alternatives. We believe the "best scientific and commercial data" provision is similarly intended, at least in part, to prevent uneconomic (because erroneous) jeopardy determinations.

Id. at 176-77.

A decision about jeopardy must be made based on the best science available at the time of the decision; the agency cannot wait for or promise future studies. *See Ctr. for Biological Diversity v. Rumsfeld*, 198 F. Supp. 2d 1139, 1156 (D. Ariz. 2002). The "best available science" mandate of the ESA sets a basic standard that "prohibits the [agency] from disregarding available scientific evidence that is in some way better than the evidence [it] relies on." *Am. Wildlands v. Kempthorne*, 530 F.3d 991, 998 (D.C. Cir. 2008) (citation omitted).

What constitutes the "best" available science implicates core agency judgment and expertise to which Congress requires the courts to defer; a court should be especially wary of overturning such a determination on review. *Baltimore Gas & Elec. Co. v. Natural Res. Defense Council*, 462 U.S. 87, 103 (1983) (a court must be "at its most deferential" when an agency is "making predictions within its area of special expertise, at the frontiers of science"). As explained in the *en banc* decision in *Lands Council*, 537 F.3d at 993, courts may not "impose on the agency their own notion of which procedures are best or most likely to further some vague, undefined public good." In particular, an agency's "scientific methodology is owed substantial deference." *Gifford Pinchot Task Force v. U.S. Fish & Wildlife Serv.*, 378 F.3d 1059, 1066 (9th Cir. 2004).

When specialists express conflicting views, an agency must have discretion to rely on the reasonable opinions of its own qualified experts even if, as an original matter, a court might find contrary views more persuasive." *Lands Council*, 537 F.3d at 1000 (quoting *Marsh v. Oregon Natural Res. Council*, 490 U.S. 360, 378 (1989)). Mere uncertainty, or the fact that evidence may be "weak," is not fatal to an agency decision. *Greenpeace Action v. Franklin*, 14 F.3d 1324, 1337 (9th Cir. 1992) (upholding biological opinion, despite uncertainty about the effectiveness of management measures, because decision was based on a reasonable evaluation of all available data); *Nat'l Wildlife Fed'n v. Babbitt*, 128 F. Supp. 2d 1274, 1300 (E.D. Cal. 2000) (holding that the "most reasonable" reading of the best scientific data available standard is that it "permits the [FWS] to take action based on imperfect data, so long as the data is the best available"). FWS "must utilize the 'best scientific ... data available,' not the best scientific data possible." *Building Indus. Ass'n v. Norton*, 247 F.3d 1241, 1246 (D.C. Cir. 2001), cited with approval in *Kern County Farm Bureau v. Allen*, 450 F.3d 1072, 1080-81 (9th Cir. 2006) ("Absent superior data occasional imperfections do not violate" the ESA best available data standard); *see also Defenders of Wildlife v. Babbitt*, 958 F. Supp. 670, 680 (D.D.C. 1997) (best available science standard does not require "conclusive evidence," only that agency use best

science available and not ignore contrary evidence).

The deference afforded under the best available science standard is not unlimited. For example, *Tucson Herpetological Society v. Salazar*, 566 F.3d 870, 879 (9th Cir. 2009), held that an agency may not rely on "ambiguous studies as evidence" to support findings made under the ESA. Because the studies did not lead to the conclusion reached by FWS, the Ninth Circuit held that these studies provided inadequate support in the administrative record for the determination made by FWS. *Id.*; *see also Rock Creek Alliance v. U.S. Fish & Wildlife Service*, 390 F. Supp. 2d 993, 1008 (D. Mont. 2005) (rejecting FWS's reliance on a disputed scientific report, which explicitly stated its analysis was not applicable to the small populations addressed in the challenged opinion). Alternatively, the presumption of agency expertise may be rebutted if the agency's decisions, although based on scientific expertise, are not reasoned, *Greenpeace v. NMFS*, 80 F. Supp. 2d 1137, 1147 (W.D. Wash. 2000), or if the agency disregards available scientific evidence better than the evidence on which it relies, *Kern County Farm Bureau*, 450 F.3d at 1080.

Courts routinely perform substantive reviews of record evidence to evaluate the agency's treatment of best available science. The judicial review process is not one of blind acceptance. *See, e.g., Kern County*, 450 F.3d at 1078-79

(thoroughly reviewing three post-comment studies and FWS's treatment of those studies to determine whether they "provide[d] the sole, essential support for" or "merely supplemented" the data used to support a listing decision); *Home Builders Ass'n of N. Cal. v. U.S. Fish and Wildlife Serv.,* 529 F. Supp. 2d 1110, 1120 (N.D. Cal. 2007) (examining substance of challenge to FWS's determination that certain data should be disregarded); *Trout Unlimited v. Lohn*, 645 F. Supp. 2d 929 (D. Or. 2007) (finding best available science standard had been violated after thorough examination of rationale for NMFS's decision to withdraw its proposal to list Oregon Coast Coho salmon); *Oceana, Inc. v. Evans*, 384 F. Supp. 2d 203, 217-18 (D.D.C. 2005) (carefully considering scientific underpinnings of challenge to FWS's use of a particular model, including post decision evidence presented by an expert to help the court understand the complex model, applying one of several record review exceptions articulated in *Esch v. Yeutter*, 876 F.2d 976, 991 (D.C. Cir. 1989), which are similar to those articulated by the Ninth Circuit).

Courts are not required to defer to an agency conclusion that runs counter to that of other agencies or individuals with specialized expertise in a particular technical area. *See, e.g., Am. Turnboat Ass'n v. Baldrige*, 738 F.2d 1013, 1016-17 (9th Cir. 1984) (NMFS's decision under the Marine Mammal Protection Act was not supported by substantial evidence because agency ignored data

that was product of "many years' effort by trained research personnel"); *Sierra Club v. U.S. Army Corps of Eng'rs*, 701 F.2d 1011, 1030 (2d Cir. 1983) ("court may properly be skeptical as to whether an EIS's conclusions have a substantial basis in fact if the responsible agency has apparently ignored the conflicting views of other agencies having pertinent experience[]") (internal citations omitted). A court should "reject conclusory assertions of agency 'expertise' where the agency spurns unrebutted expert opinions without itself offering a credible alternative explanation." *N. Spotted Owl v. Hodel*, 716 F. Supp. 479, 483 (W.D. Wash. 1988) (citing *Am. Turnboat Ass'n,* 738 F.2d at 1016).

In *Conner v. Burford*, 848 F.2d 1441, 1453-54 (9th Cir. 1988), the agency attempted to defend its biological opinions by arguing that there was a lack of sufficient information to perform additional analysis. In rejecting this defense, the Ninth Circuit held that "incomplete information ... does not excuse the failure to comply with the statutory requirement of a comprehensive biological opinion using the best information available," and noted that FWS could have completed more analysis with the information that was available. *Id.* at 1454.

> In light of the ESA requirement that the agencies use the best scientific and commercial data available ... the FWS cannot ignore available biological info or fail to develop projections of ... activities which may indicate potential conflicts between development and the preservation of protected species. We hold that the FWS violated the ESA by failing to use the best information available to prepare comprehensive biological opinions.

Id. (emphasis added).

(5) Best Available Science Standards and the Application of Analytical/Statistical Methodologies.

The above-described standards apply with equal force to the use and interpretation of statistical methodologies. As the D.C. Circuit in *Appalachian Power Co. v. EPA*, 135 F.3d 791 (D.C. Cir. 1998), explained in reviewing a challenge to a decision of the Environmental Protection Agency ("EPA") under the "arbitrary and capricious" standard of review:

> Statistical analysis is perhaps the prime example of those areas of technical wilderness into which judicial expeditions are best limited to ascertaining the lay of the land. Although computer models are "a useful and often essential tool for performing the Herculean labors Congress imposed on EPA in the Clean Air Act," [citation] their scientific nature does not easily lend itself to judicial review. Our consideration of EPA's use of a regression analysis in this case must therefore comport with the deference traditionally given to an agency when reviewing a scientific analysis within its area of expertise without abdicating our duty to ensure that the application of this model was not arbitrary.

Id. at 802.

The model must fit the available data. *See Nat'l Wildlife Fed'n v. EPA*, 286 F.3d 554, 565 (D.C. Cir. 2002) ("*NWF v. EPA*") (a court will only reject the choice of a model "when the model bears no rational relationship to the characteristics of the data to which it was applied"). For example, *Oceana*, 384 F. Supp. at 220, rejected a challenge to NMFS's use of a particular analytical model that used data drawn from existing literature, even though experts "suggested that reliable take limits cannot

be established without quantitative data gathered from 'in-water' surveys." Although NMFS conceded "a thorough quantitative analysis based on empirical estimates of population size would be a superior way to analyze the impact [] on [the species]," it was undisputed that "given the paucity of information on sea turtles and the difficulties of using the data that does exist, '[a] different or more complex model [than that used by NMFS] was not available and could not even be constructed.'" *Id*. Likewise, "the fact that a given model has some imperfections does not prevent it from constituting the 'best scientific information available.'" *Oceana v. Evans*, 2005 WL 555416, *16-*17 (D.D.C. Mar. 9, 2005)(citing 16 U.S.C. § 1851(a)(2))(approving NMFS's use of a model despite known limitations, where it was the only model available and the agency supplemented its analysis with other sources to address areas where the model was unable to make accurate predictions).

VII. ANALYSIS

A. Challenges to the Effects Analysis & Related Challenges to the RPA Actions.

(1) Legal Requirements for a Project Effects Analysis.

Under section 7(a)(2) of the ESA and the Joint Consultation Regulations, FWS must "[e]valuate the effects of the action and cumulative effects on the listed species or critical habitat." 50 C.F.R. § 402.14(g)(3). FWS must then "[f]ormulate its biological opinion as to whether the action, taken together with

cumulative effects,[7] is likely to jeopardize the continued existence of listed species or result in the destruction or adverse modification of critical habitat." § 402.14(g)(4). The effects of the action are defined as:

> the direct and indirect effects of an action on the species or critical habitat, together with the effects of other activities that are interrelated or interdependent with that action, that will be added to the environmental baseline.

§ 402.02.

The environmental baseline includes:

> the past and present impacts of all Federal, State, or private actions and other human activities in the action area, the anticipated impacts of all proposed Federal projects in the action area that have already undergone formal or early section 7 consultation, and the impact of State or private actions which are contemporaneous with the consultation in process.

Id. The baseline is described in FWS and NMFS's Joint Consultation Handbook[8] as:

> an analysis of the effects of past and ongoing human and natural factors leading to the current status of the species, its habitat (including designated critical habitat), and ecosystem, within the action area. The environmental baseline is a "snapshot" of a species' health at a specified point in time. It does not include the effects of the action under review in the consultation.

Consultation Handbook 4-22.

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[7] Cumulative effects are "those effects of future State or private activities, not involving Federal activities, that are reasonably certain to occur within the action area of the Federal action subject to consultation." 50 C.F.R. § 402.02.

[8] FWS and NMFS issued their final joint Endangered Species Handbook ("Handbook" or "Consultation Handbook") in 1999. 64 Fed. Reg. 31,285 (June 10, 1999). The entire Handbook is available at http://www.fws.gov/endangered/esa-library/pdf/esa_section7_handbook.pdf.

Once the baseline, the "direct and indirect effects" of the action, and the "effects of other activities that are interrelated or interdependent with that action" are determined, 50 C.F.R. § 402.02, FWS then is required to consider whether, in light of the environmental baseline, the effects of the action, taken together with cumulative effects, are likely to jeopardize the continued existence of the listed species, 50 C.F.R. § 402.14(g).

> [An] agency may not take action that will tip a species from a state of precarious survival into a state of likely extinction. Likewise, even where baseline conditions already jeopardize a species, an agency may not take action that deepens the jeopardy by causing additional harm.
>
> ....[The agency must] appropriately consider the effects of its actions "within the context of other existing human activities that impact the listed species." *ALCOA* [*v. Administrator, Bonneville Power Admin*], 175 F.3d [1156,] 1162 n. 6 [(9th Cir. 1999)](citing 50 C.F.R. § 402.02's definition of the environmental baseline). This approach is consistent with our instruction ... that "[t]he proper baseline analysis is not the proportional share of responsibility the federal agency bears for the decline in the species, but what jeopardy might result from the agency's proposed actions <u>in the present and future human and natural contexts</u>." [*PCFFA v. U.S. Bureau of Reclamation],* 426 F.3d [1082,] 1093 [(9th Cir. 2005)](emphasis added).

NWF v. NMFS II, 524 F.3d at 930 (emphasis in original).

To jeopardize means "to engage in an action that reasonably would be expected, directly or indirectly, to reduce appreciably the likelihood of both the survival and recovery of a listed

species." 50 C.F.R. § 402.02. The Consultation Handbook further provides that to "appreciably diminish the value: [means] to considerably reduce the capability of designated [critical habitat]." Consultation Handbook at 4-36. A related case found:

> interpretation of "appreciably" to mean any "perceptible" effect would lead to irrational results, making any agency action that had any effects on a listed species a "jeopardizing" action. This is not the law, as such an interpretation conflicts with other provisions of the ESA that permit incidental take of listed species.

PCFFA v. Gutierrez, 1:06-cv-00245 OWW GSA, Doc. 367 at 23-24 (citing 16 U.S.C. 1536(b)(4), 1539(1)(B)).

(2) Best Available Science Challenges to the Effects Analysis and Related Challenges to the Justification Provided for the RPA Actions.

Plaintiffs argue that the project effects analysis is predicated upon scientific errors that render the BiOp and its conclusion that project operations jeopardize the delta smelt arbitrary, capricious and an abuse of discretion:

> The Project Effects Analysis is the heart of the section 7 consultation process, providing the basis for FWS' jeopardy and adverse modification determinations and for formulating the RPA. In this case, FWS began the Project Effects Analysis of the 2008 Smelt BiOp with a remarkable assumption: "The following analysis assumes that the proposed CVP/SWP operations affect delta smelt throughout the year either directly through entrainment or indirectly through influences on its food supply and habitat suitability." BiOp at 203 (AR 000218.) This assumption plainly violates the "best available science" required by the ESA. The science, including the reports that FWS purports to rely on, shows that OMR flows and entrainment do not have any statistically significant effect on the delta smelt's

> population growth rate. Restricting flows has no effect on the delta smelt population's survival—such restrictions are a costly, but meaningless gesture. The same is true for [restrictions designed to control the position of] X2 [in the Fall].

Doc. 551 at 8.

Plaintiffs maintain that the best available science does not support FWS' "assumption" that "CVP/SWP operations affect delta smelt throughout the year either directly through entrainment or indirectly through influences on its food supply and habitat suitability." BiOp at 203. Plaintiffs maintain that the science demonstrates:

> (a) OMR flows have no statistically significant effect on the delta smelt population growth rate;
>
> (b) With respect to the adult population, only OMR flows more negative than -6,100 cfs will correlate to an increase in entrainment;[9]
>
> (c) The location of Fall X2 does not determine the extent and quality of suitable smelt habitat -- as with OMR flows, Fall X2 has no statistically significant effect on the population growth rate; and,
>
> (d) The CVP/SWP projects do not indirectly govern abiotic and biotic factors in the Delta that affect delta smelt abundance.

Doc. 551 at 11. Plaintiffs also maintain that there is no scientific support for the BiOp's assumption that the Projects control hydrodynamic conditions in the Delta, or for the BiOp's classification of non-Project causes of harm as "indirect

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[9] As this argument was supported exclusively by portions of the declaration of Dr. Richard B. Deriso that have been stricken, Doc. 750 at ¶ 3, this argument cannot be considered.

effects" of Project Operations. *Id*.

a. <u>The BiOp's General Conclusion that Entrainment by Project Operations Adversely Affects Smelt Survival & Recovery is Supported by the Record.</u>

The magnitude of diversions at the CVP and SWP pumping facilities influences flows throughout the Delta, including in the Old and Middle Rivers ("OMR"). BiOp at 160. When the level of diversion at the pumps is high, Old and Middle Rivers may flow backwards (in the opposite direction than they would under natural hydrological conditions) and toward the CVP and SWP natural conditions (called "negative" flows). *Id*. Negative OMR flows draw delta smelt present in the central and south Delta toward the pumps, and high negative flows increase the risk that they will be entrained at the pumps. *Id*. at 163, 253 (Figure E-7).

Unlike larger fish species, entrainment is lethal for weak-swimming delta smelt. *Id.* at 145. Relying on estimates of proportional entrainment presented by Dr. Wim Kimmerer in a 2008 paper entitled "Losses of Sacramento River Chinook Salmon and Delta Smelt to Entrainment in Water Diversions in the Sacramento-San Joaquin Delta," published in the journal, San Francisco Estuary & Watershed Science ("Kimmerer (2008)"), the BiOp concludes that "[t]otal annual entrainment of the delta smelt population (adults and their progeny combined) ranged from approximately 10 percent to 60 percent per year from 2002-2006."

Id. at 210. In years when low flows and high exports coincide with a spawning distribution of the delta smelt that includes the San Joaquin River, the loss of larval delta smelt due to entrainment can exceed 50% of the population. *Id*. at 164-65. Such losses do not occur every year, but FWS concluded the effect of these large larval loss events is "substantial when it does," particularly in light of the fact that the delta smelt is an annual fish. *Id*. at 165. Even one year where its spawning occurs "within the footprint of entrainment by the pumps" can lead to "a [severe] reduction in that year's production." *Id*.

The BiOp's Effects Analysis concludes that Project pumping operations have a "sporadically significant" adverse effect on smelt abundance:

> The population-level effects of delta smelt entrainment vary; delta smelt entrainment can best be characterized as a <u>sporadically significant</u> influence on population dynamics. Kimmerer (2008) estimated that annual entrainment of the delta smelt population (adults and their progeny combined) ranged from approximately 10 percent to 60 percent per year from 2002-2006. Major population declines during the early 1980s (Moyle et al. 1992) and during the recent POD years (Sommer et al. 2007) were both associated with hydrodynamic conditions that greatly increased delta smelt entrainment losses as indexed by numbers of fish salvaged. However, currently published analyses of long-term associations between delta smelt salvage and subsequent abundance do not support the hypothesis that entrainment is driving population dynamics year in and year out (Bennett 2005; Manly and Chotkowski 2006; Kimmerer 2008).

BiOp at 210 (emphasis added). This passage was based in large part on Kimmerer (2008), which states:

> Delta smelt may suffer substantial losses to export pumping both as pre-spawning adults and as larvae and early juveniles. In contrast to the situation for salmon, pre-salvage mortality has been constrained in the calculations for adult Delta smelt, and its effects eliminated from the calculations for larval/juvenile Delta smelt. Combining the results for both life stages, losses may be on the order of zero to 40 percent of the population throughout winter and spring. The estimates have large confidence limits, which could be reduced by additional sampling, particularly to estimate θ in Equation 18. If there is interest in improving these estimates further, some attempts should be made to examine the assumptions not fully tested above, particularly those used in extrapolating larval abundance to hatch dates.

AR 018877.

Plaintiffs argue that the BiOp misinterprets and misapplies Kimmerer's work. Dr. Bryan Manly, Plaintiffs' expert in the fields of biostatistics and population survey design, addressed the BiOp's statement that "delta smelt entrainment can best be characterized as a sporadically significant influence on population dynamics." Manly Decl., Doc. 397, at ¶ 7. Manly opines that "[t]his statement is unclear and confusing," and explains:

> If the Service meant only that abundance at a point in time during a single year may vary depending upon entrainment, then Kimmerer's estimates support that statement. But if, as appears more likely, the Service was relying upon Kimmerer's estimates to support a conclusion that entrainment sometimes causes abundance to vary significantly later in the same year or in following years, then the statement in the BiOp has no scientific basis.

Id. Kimmerer (2008) only estimated percentage losses of delta smelt within single year classes, and did not conclude that such

losses reduce population abundance from one year to the next. *Id*. at ¶ 8. In fact, Kimmerer (2008) contains a number of disclaimers, including the caveat that "export effects" on smelt are small relative to other factors affecting survival:

> Although the upper bound of [the 0-40% loss] range represents a substantial loss, the effect of this loss is complicated by subsequent variability in survival (Figure 17). If this variability is uncorrelated with entrainment losses, then these losses will contribute little to the variability in fall abundance index. The simplest way to evaluate this is by regression of fall midwater trawl index on winter–spring export flow, but this relationship is contaminated by the downward step change in abundance in approximately 1981–1982, together with the long-term upward trend in export flow (mainly up to the mid-1970s, *see* Kimmerer 2004). Including this step in a regression model eliminates the effect of export flow on the fall midwater trawl index (coefficient = -1.5 ± 2.4, 95% CL, 36 df). It seems unlikely that the downward step change was due to the earlier increase in export flow; furthermore, despite substantial variability in export flow in years since 1982, no effect of export flow on subsequent midwater trawl abundance is evident.
>
> This is not to dismiss the rather large proportional losses of delta smelt that occur in some years; rather, it suggests that these losses have effects that are episodic and that therefore their effects should be calculated rather than inferred from correlative analyses. In the absence of density dependence, using means in Figure 15 with natural mortality, fall abundance should have been reduced by ~ 10% during 1995–2005. This would have an equivalent effect of reducing the summer–fall survival index by 10%. This would have made little difference to fall abundance in the context of the approximately 50-fold variation in summer–fall survival (Figure 17), and would be difficult to detect through correlation.
>
> Although summer–fall survival appears to dominate variability in abundance of delta smelt in fall (Figure 17), this does not imply that control of export effects would be fruitless, as these effects can be

> considerable during dry years. Management of delta smelt should incorporate any opportunities that arise to improve habitat or food supply and to reduce any negative impacts of predation or toxic contamination. However, current evidence does not provide a clear path toward improving the status of delta smelt using these factors. Manipulating export flow (and, to some extent, inflow) is the only means to influence the abundance of delta smelt that is both feasible and supported by the current body of evidence, even though export effects are relatively small. The results presented here can be used to suggest when, and under what conditions, control of export effects would be most helpful.

AR 018878. Kimmerer (2008) concludes that even though correlative analysis revealed "no effect of export flow on subsequent midwater trawl abundance," there is reason to be concerned about episodic effects caused by "large proportional losses of delta smelt that occur in some years." *Id*. As a result, according to Kimmerer (2008), population level effects should be <u>calculated, rather than inferred from correlative analysis</u>. *Id*. After performing such a calculation, Kimmerer (2008) concluded that entrainment reduced "the summer-fall survival index by ~10%" during 1995-2005. *Id*. Although this 10% figure was small in the context of the 50-fold variation in summer-fall survival, Kimmerer (2008) nonetheless recommended controlling export effects on smelt because "[m]anipulating export flow (and to some extent, inflow) is the <u>only means</u> to influence the abundance of delta smelt that is both feasible and supported by the current body of evidence, even though export effects are relatively small." *Id*. (emphasis added).

Dr. Manly is correct that Kimmerer (2008) does not support the position that entrainment has a "sporadically significant" effect on delta smelt abundance from one year to the next. <u>However, contrary to Dr. Manly's suggestion, the BiOp does not rely on Kimmerer (2008) for this premise</u>. The BiOp qualifies its reliance on Kimmerer (2008), consistent with the narrow scope of Kimmerer's findings:

> The population-level effects of delta smelt entrainment vary; delta smelt entrainment can best be characterized as a sporadically significant influence on population dynamics. Kimmerer (2008) estimated that <u>annual</u> entrainment of the delta smelt population (adults and their progeny combined) ranged from approximately 10 percent to 60 percent <u>per year</u> from 2002-2006. Major population declines during the early 1980s (Moyle et al. 1992) and during the recent POD years (Sommer et al. 2007) were both associated with hydrodynamic conditions that greatly increased delta smelt entrainment losses as indexed by numbers of fish salvaged. <u>However, currently published analyses of long-term associations between delta smelt salvage and subsequent abundance do not support the hypothesis that entrainment is driving population dynamics year in and year out</u> (Bennett 2005; Manly and Chotkowski 2006; Kimmerer 2008).

BiOp at 210 (emphasis added). It was not unreasonable for FWS to rely on Kimmerer (2008) to conclude that salvage events may be "sporadically significant." Plaintiffs' argument that FWS misinterpreted Kimmerer (2008) is unfounded. Kimmerer (2008) explains why, despite the absence of a statistically significant correlation between export pumping and the subsequent year's smelt population (i.e., between export pumping and the population growth rate), the demonstrated "sporadically significant" loss of

smelt within year classes could significantly contribute to the species' jeopardy. FWS reasonably relied on Kimmerer (2008) for this finding.

Applying Kimmerer's estimates of entrainment and other data, the BiOp analyzed the effect Project operations have on the frequency of relatively large loss events. For larval and juvenile delta smelt:

> Kimmerer (2008) proposed a method for estimating the percentage of the larval-juvenile delta smelt population entrained at Banks and Jones each year. These estimates were based on a combination of larval distribution data from the 20-mm survey, estimates of net efficiency in this survey, estimates of larval mortality rates, estimates of spawn timing, particle tracking simulations from DWR's DSM-2 particle tracking model, and estimates of Banks and Jones salvage efficiency for larvae of various sizes. Kimmerer estimated larval-juvenile entrainment for 1995-2005. We used Kimmerer's entrainment estimates to develop multiple regression models to predict the proportion of the larval-juvenile delta smelt population entrained based on a combination of X2 and OMR....

BiOp at 220. The BiOp predicts that "the proposed action will decrease the frequency of years in which estimated entrainment is [less than or equal to] 15 percent. Thus, over a given span of years, the project as proposed will increase larval-juvenile entrainment relative to 1995-2005 levels. This will have an adverse effect on delta smelt based on their current low population levels." BiOp at 222.

For adult delta smelt:

> The median OMR flows from the CALSIM II modeled scenarios were more negative than historic OMR flow for

all WY types except critically dry years (Figure E-3; see Table E-5b for all differences). Overall, proposed OMR flows are likely to generate increases in population losses compared to historic years (Figure E-5 and Figure E-6). For example, the frequency of years when population losses are less than 10 percent from most modeled studies (except studies 7.0 and 8.0) is less than 24 percent compared to historic estimates that only exceed 10 percent in approximately half of the years.

The most pronounced differences occur during wet years, where median OMR flows are projected to be approximately 400 to 600 percent (-7100 to -3678 cfs) higher than historical wet years (-1032 cfs). Generally, wet years are marked by low salvage and population losses. However, the proposed operations during wet year are predicted to cause up to a 65 percent increase in smelt salvage and lower probability that population losses will be below 10 percent.

The proposed operation conditions likely to have the greatest impact on delta smelt are those modeled during above normal WYs. The modeled OMR flows for the above normal WYs ranged between -8155 and -6242 cfs, a 33 to 57 percent decrease from the historic median of -5178 cfs. Though the predicted salvage would only be about 15-20 percent higher than historic salvage during these years (Table E-5c), the modeled OMR flows in these years would increase population losses compared to historic years.

In below normal and dry WYs, proposed OMR flows are also modeled to decrease from historic medians. Predicted salvage levels are likely to increase between 2 and 44 percent. More importantly, the modeled median flows from all studies in these WY types range between -5747 and -7438 cfs. Modeled OMR flows at these levels are predicted to increase salvage and increase the population losses from historic levels as well.

During critically dry years, the median OMR flows for studies 7.0, 7.1, 8.0, 9.1, 9.4, and 9.5 are less than -5,000 cfs. These studies have predicted salvage lower than historic salvage and are not likely to generate larger population losses compared to historic years. The models might overestimate salvage during critical dry years when smelt are unlikely to migrate towards

> the Central Delta due to lack of turbidity or first flush. Thus, the effects of critical dry operations on delta smelt take are probably small and lower than estimated.
>
> In summary, adult entrainment is likely to be higher than it has been in the past under most operating scenarios, resulting in lower potential production of early life history stages in the spring in some years. While the largest predicted effects occur in Wet and Above Normal WYs, there are also likely adverse effects in Below Normal and Dry WYs. Only Critically Dry WYs are generally predicted to have lower entrainment than what has occurred in the recent past.

BiOp at 212-13.

This approach is consistent with Kimmerer (2008). The BiOp does not focus on whether there is a statistically significant correlation between OMR flows and the population growth rate.[10] Rather, following Kimmerer (2008), the BiOp focuses on predicting the frequency of large salvage events and concluded that Project operations increase their frequency. It was not arbitrary, capricious, or clear error for FWS to base its jeopardy conclusion in part on these predictions of relative increases in entrainment. *See* BiOp at 276.

b. Population Level Analysis/Life-Cycle Modeling.

Plaintiffs maintain the BiOp's failure to employ a life-

[10] FWS did rely on a study by Manly and Chotkowski that found a statistically significant correlation between OMR flows and smelt abundance, albeit a small one. *See* BiOp at 159 ("Manly and Chotkowski (2006; IEP 2005) found that monthly or semi-monthly measures of exports or Old and Middle rivers flow had a reliable, statistically significant effect on delta smelt abundance; however, individually they explained a small portion (no more than a few percent) of the variability in the fall abundance index of delta smelt across the entire survey area and time period.").

cycle model ignored the best available science. Doc. 551 at 21-22. Using a quantitative[11] life-cycle model[12] is a recognized (the best) method to evaluate the effects of an action upon a fish population's growth rate. Dr. Richard B. Deriso[13] opined that a population growth rate analysis is the generally accepted method utilized by fisheries biologists to evaluate the impact of a stressor on a fish species' population. Declaration of Dr. Richard B. Deriso, Doc 401, at ¶ 36; *see also* Declaration of Dr. Ray Hilborn[14], Doc. 393, at ¶¶ 7-16 (agreeing that life-cycle models are the accepted method in population dynamics to evaluate anthropogenic effects on the probability of growth or decline of a species); Declaration of Ken B. Newman[15], Doc. 484, at ¶ 8 (agreeing with "utility of life history models for assessing population level effects of SWP/CVP operations."). Dr. Hilborn explained that a <u>quantitative</u> population dynamics/life cycle model can help distinguish human actions that have a significant impact on population size from those that have little impact on population size, because competition for a resource that is independent of the human activity may cause significant mortality

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[11] The BiOp used a relatively simple, non-quantitative, conceptual life-cycle model. *See* BiOp at 203. It is undisputed that no quantitative life cycle model was employed.

[12] The experts use the term "population dynamics model," "life history model," and "life cycle model" interchangeably.

[13] Dr. Deriso is an expert in the field of quantitative ecology and its application to fisheries management. Deriso Decl., Doc. 396, at ¶¶ 5-10.

[14] Dr. Hilborn is an expert in aquatic and fishery sciences. Hilborn Decl., Doc. 393, at ¶ 1.

[15] Dr. Newman is an expert in mathematical statistics employed by FWS in Stockton, California.

at one stage in the species' life cycle, meaning that human actions that kill fish at that life stage may have little impact on the population level later in the life history. Hilborn Decl., Doc. 393 at ¶ 15.

Federal Defendants knew of the value of life-cycle modeling. At a March 8, 2007 meeting on the OCAP ESA Re-consultation, attended by FWS employees, the importance of using a life cycle model was emphasized and inquiry made about the progress to date. AR 016016 - 016017. During the Delta Smelt Action Evaluation Team meeting on August 8, 2008, that Team recognized that population models for delta smelt already had been developed, and that those models were a starting point for quantitative analyses when combined with appropriate assumptions. AR 011381-011382; *see also* AR 010023, 010027-010029.

There is considerable dispute over whether an appropriate life-cycle model (i.e., one sufficient to perform the types of analyses that would be helpful in the BiOp) existed at the time the BiOp issued. Dr. Newman declares:

> Despite the utility of life history models and despite the information that the various surveys provide about different life history stages, <u>an adequately realistic quantitative delta smelt life history model that has been fit using fish survey data does not exist</u>. The BiOp did in many places (e.g., pp 146, 184, 203) consider the full life history of delta smelt but considerations were via conceptual models in contrast to quantitative models with parameters estimated from data. <u>Part of the difficulty is that there are currently no off-the-shelf computational programs for fitting such a model to data and one must develop</u>

> customized, computer intensive software. The need to model the spatial and temporal changes in population abundances and to account for the different sources of uncertainty makes model formulation and fitting complex. In particular, uncertainty in survey data, due to random sampling error and bias, complicates model fitting. Capture probabilities differ between surveys, the probabilities are largely unknown (despite efforts made to estimate them, for example, for FMWT data, see Newman 2008 (Administrative Record "AR" at 19782-19799)), and capture and fish presence probabilities are thus confounded. Furthermore, given the patchiness and heterogeneity of the spatial and temporal distribution of delta smelt and the relatively low capture probabilities (whatever they might be), the sampling errors associated with survey data can be quite large (Newman 2008 (AR at 19782-19799)). Failure to account for sampling errors may result in biased parameter estimates (including wrongly concluding density dependence; Shenk et al. 1998). *The difficulties are not insurmountable, but concentrated research efforts are required*. I know of three such efforts currently underway and at varying stages of development: (1) an individual-based model with a spatial component by Drs. Wim Kimmerer, San Francisco State University, William Bennett, University of California at Davis, Stephen Monismith, Stanford University, and Kenneth Rose, Louisiana State University; (2) a population-level life history model using information from multiple surveys by Dr. Mark Maunder, Inter American Tropical Tuna Commission; (3) similar to Maunder, a life history model with a spatial component based on multiple surveys' data has been conceptually sketched by me and others in the NCEAS POD working group. Given sufficient time and appropriate technical resources, including personnel, to focus on model formulation and fitting, these models might be available within a year.

Newman Decl., Doc. 484 at ¶ 5.

All of the experts agreed with Dr. Newman that, at the time the BiOp was issued, there was no "off-the-shelf" life-cycle model to apply to delta smelt. Considerable dispute exists over how long it should have taken FWS to develop a competent model.

It is undisputed that basic life-cycle models such as the Ricker model can be applied to fisheries data sets in relatively short order. Deriso Decl., Doc. 605, at ¶ 52. Dr. Deriso opined that FWS had all the data necessary to perform a life-cycle analysis. Deriso Decl., Doc. 401, at ¶ 70. Dr. Hilborn stated that a relatively complex life-cycle model that "follow[s] the size structure of delta smelt through their life history and fit this into the observed size structure" would "require no more than a few months time to construct, evaluate and use in a biological opinion." Hilborn Decl., Doc. 600 at ¶ 14. Dr. Punt, a 706 Expert with expertise in fish population dynamics and biostatistics, *see* Doc. 394 at 2, stated "[i]t is surprising that a population dynamics model was not developed for delta smelt for the BiOp.... The model developed by Bennett could have been extended to more fully account for the biology of delta smelt and fitted to data to assess the population-level effects of impact of the project." Doc. 633-1 at 3.

Federal Defendants' expert, Mr. Feyer disagrees:

> Developing a quantitative population model is a challenging and complex exercise that could not have been completed by USFWS within the timeframe required to issue the 2008 BiOp. The work requires a substantial investment of resources and individuals with very specialized skills. The process to develop, test, peer-review, and apply such models often takes years. For instance ... the development of models for Columbia River salmon ... took no less than three years to complete.
>
> Because of the recognized urgent need for such tools,

there are on-going efforts to develop quantitative population models for delta smelt. For instance, Bennett (2005) presented preliminary results from a stage-structured model he is developing to examine tradeoffs among sources of mortality acting on different cohorts and life stages. *See* AR at 17004-74. The development of this model is part of a broader comprehensive effort by a team of researchers including Dr. Kenneth Rose of Louisiana State University, Dr. Wim Kimmerer of San Francisco State University, Dr. William Bennett of the University of California at Davis, and Dr. Stephen Monismith of Stanford University, who are in the early stages of developing, testing, and applying particle-tracking models, an individual-based model, and a matrix projection model. The development of these particular models is very promising but has also been faced with many challenges. Perhaps the most critical challenge has been a freeze on project funding by the State of California; it is uncertain if the funding will be reinstated. Another example is the work I have been personally involved with at NCEAS. The NCEAS team has used Bayesian changepoint techniques and multivariate autoregressive modeling to identify factors contributing to the decline of delta smelt and other species. The results of this work will be published in two papers in an upcoming issue of the journal Ecological Applications. I am aware of at least two other independent efforts of modeling the effects of various stressors on delta smelt that are also under development. Unfortunately, none of the work I mention above was available when the 2008 BiOp was being prepared. To my knowledge, no comprehensive quantitative population dynamics model for the delta smelt has been developed, subjected to peer-review, and published.

...[Q]uantitative population models are grounded in what is known about the biology of a species, and processes that may plausibly affect its abundance.... Although there is a substantial amount of data available on delta smelt, a key problem is that much of the sample data has increasingly contained zero values. These zeros are a reflection of declining population abundance. Such low numbers make it more difficult to acquire more recent information about the factors that drive delta smelt population dynamics, such as survival probabilities by life history stage, movement patterns and spatial distribution, and fecundity or reproductive

> success. It is thus becoming increasingly difficult to not only simply estimate such factors, but also increasingly difficult to model how these factors are affected by environmental and anthropogenic processes such as those considered in the 2008 BiOp. The estimation of delta smelt population size exemplifies this problem. Newman (2008), see AR at 19782-99, recently published a sample design-based procedure for estimating the population abundance of pre-adult and adult delta smelt. However, the resulting estimates of population size were quite imprecise. This was caused, in part, by limitations of the available data to estimating capture probabilities and gear efficiency.
>
> ... I agree ... that population dynamics models have been used to evaluate consequences of various stressors on a wide range of species and human impacts. I also agree that there is sufficient data to develop such a model for delta smelt, as demonstrated by the examples I provided above. However, although some are in development, the fact remains that no such model has been fully developed, peer-reviewed and made available for application. Thus, in the absence of such models, I disagree that that the techniques used by USFWS were inconsistent with generally-accepted scientific standards and practices. To the contrary, in the absence of such a model, and because one could not be developed during the time allowed for this consultation, the techniques used by USFWS do reflect generally-accepted scientific standards and practices.

Decl. of Frederick V. Feyrer[16], Doc. 541, at ¶¶ 30-33. Plaintiffs do not suggest any party that participated in the preparation of the OCAP Biological Assessment ("OCAP BA" or "BA") or commented on the public review drafts of the BiOp during the consultation submitted to FWS a quantitative life cycle model or the results of such an analysis using a life cycle model for delta smelt.

The ESA does not require FWS's to generate new studies. In

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[16] Mr. Feyrer is a Reclamation Fish Biologist with an M.S. in biology. He has extensive experience researching and advising on fisheries management issues in the San Francisco Estuary. Feyrer Decl., Doc. 481, at ¶ 1.

Southwest Center for Biological Diversity v. Babbitt, 215 F.3d 58 (D.C. Cir. 2000), the district court found "inconclusive" the available evidence regarding FWS's decision not to list the Queen Charlotte goshawk, and held that the agency was obligated to find better data on the species' abundance. The D.C. Circuit reversed, emphasizing that, although "the district court's view has a superficial appeal ... this superficial appeal cannot circumvent the statute's clear wording: The secretary must make his decision as to whether to list a species as threatened or endangered 'solely on the basis of the best scientific and commercial data available to him....' 16 U.S.C. § 1533(b)(1)(A)." *Id*. at 61 (emphasis added); *see also American Wildlands v. Kempthorne*, 530 F.3d 991, 998 (D.C. Cir. 2008) (the "best available data" standard "requires not only that the data be attainable, but that researchers in fact have conducted the tests").

Plaintiffs advocate a narrow reading of both *Southwest Center* and *American Wildlands*, arguing these cases only mean that the agency is not required to gather new data in the field regarding a species if such information is not already available. Doc. 697 at 22. Plaintiffs object that "[n]either of these cases supports Defendants' position that FWS could disregard the smelt abundance data that were already in its possession and fail to undertake the necessary statistical analyses to satisfy its

statutory mandate to determine 'whether the action ... is likely to jeopardize the continued existence of the species.' 50 C.F.R. § 402.14(g)(4)." *Id.*

Plaintiffs cite no authority suggesting that the non-existence of an analytical model should be treated any differently from the non-existence of raw field data. FWS did not have an off-the-shelf form of "statistical analysis" it could apply to determine the effects of Project Operations on the delta smelt population. Although life-cycle modeling is standard practice in the field of fisheries biology, and a life-cycle model is being (and should have been) developed for delta smelt, <u>it is undisputed that an appropriate life cycle model had not been developed at the time the BiOp issued</u>. FWS must apply the best "available" science; not the best science possible. FWS's failure to apply a life cycle model did not per se violate the ESA or the APA.

It is undisputed that application of a quantitative life cycle model is the preferred scientific methodology. Based on the preponderating expert testimony, FWS had the time and ability to prepare the necessary life-cycle model. FWS made a conscious choice not to use expertise available within the agency to develop one. A court lacks authority to require completion of a life-cycle model. In light of uncontradicted expert testimony that life-cycle modeling is necessary and feasible, FWS's failure

to do so is inexplicable.

c. FWS' Use of Raw Salvage Numbers.

Plaintiffs argue that FWS's use of raw salvage numbers in its quantitative justification for the flow prescriptions in Actions 1 and 2 constitutes a failure to apply the best available science. Action 1, designed to protect upmigrating delta smelt, is triggered during low and high entrainment risk periods based on physical and biological monitoring. Action 1 requires OMR flows to be no more negative than -2,000 cubic feet per second ("cfs") on a 14-day average and no more negative than -2,500 cfs for a 5-day running average. BiOp at 280-81, 329-30. Action 2, designed to protect adult delta smelt that have migrated upstream and are residing in the Delta prior to spawning, is triggered immediately after Action 1 ends or if recommended by the Smelt Working Group ("SWG"). Flows under Action 2 can be set within a range from -5,000 to -1,250 cfs, depending on a complex set of biological and environmental parameters. *Id. at* 281-82, 352-56.

The BiOp provides a quantitative justification for these specific flow prescriptions in Attachment B, entitled "Supplemental Information related to the Reasonable and Prudent Alternative." The following subsection entitled, "Justification for Flow Prescriptions in Action 1," is critical to the present challenge and is reproduced here in its entirety:

Justification for Flow Prescriptions in Action 1

Understanding the relationship between OMR flows and delta smelt salvage allows a determination of what flows will result in salvage. The OMR-Salvage analysis herein was initiated using the relationship between December to March OMR flow and salvage provided by P. Smith and provided as Figure B-13, below. Visual review of the relationship expressed in Figure B-13 indicates what appears to be a "break" in the dataset at approximately -5,000 OMR; however, the curvilinear fit to the data suggest that the break is not real and that the slope of the curve had already begun to increase by the time that OMR flows reached -5,000 cfs.

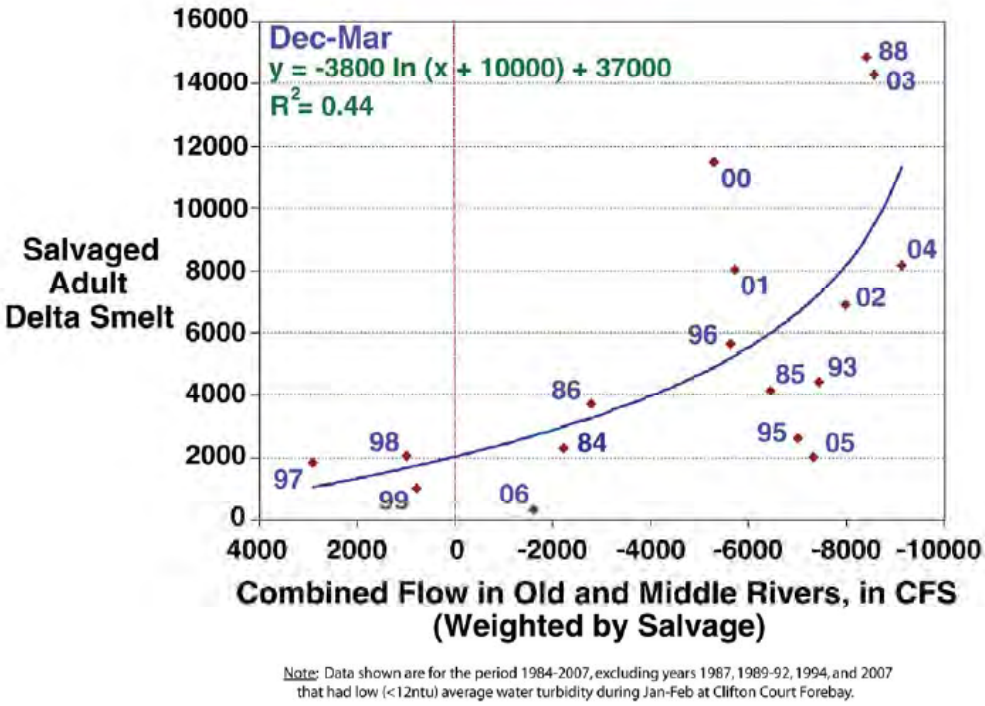

Figure B-13. OMR-Salvage relationship for adult delta smelt. (source, P. Smith). Data from this figure were the raw data used in the piecewise polynomial regression analysis.

Further, a nonlinear regression was performed on the dataset, and the resulting pseudo-R^2 value was 0.44—suggesting that although the curvilinear fit is a reasonable description of the data, other functional relationships also may be appropriate for describing the data. Fitting a different function to the data could also determine the location where salvage increased, i.e. identify the "break point" in the relationship between salvage and OMR flows. Consequently, an analysis was performed to determine if the apparent break at -5,000 cfs OMR was real. A piecewise polynomial regression, sometimes referred to as a multiphase model, was used to establish the change (break) point in the dataset.

A piecewise polynomial regression analysis with a linear-linear fit was performed using data from 1985 to 2006. The linear-linear fit was selected because it was the analysis that required the fewest parameters to be estimated relative to the amount of variation in the salvage data. Piecewise polynomial regressions were performed using Number Cruncher Statistical Systems (© Hintz, J., NCSS and PASS, Number Cruncher Statistical Systems, Kaysville UT).

The piecewise polynomial regression analysis resulted in a change point of -1162, i.e. at -1162 cfs OMR, the slope changed from 0 to positive (Figure B-14). These results indicate that there is a relatively constant amount of salvage at all flows more positive than -1162 cfs but that at flows more negative than -1162, salvage increases. The pseudo-R^2 value was 0.42, a value similar to that obtained by P. Smith in the original analysis.

To verify that there was no natural break at any other point, the analysis was performed using a linear-linear-linear fit (fitting two change points). The linear-linear-linear fit resulted in two change points, -1,500 cfs OMR and -2,930 cfs OMR. The -1,500 cfs value is again the location in the dataset at which the slope changes from 0 to positive. The pseudo-R^2 value is 0.42 indicating that this relationship is not a better description of the data. Because of the additional parameters estimated for the model, it was determined that the linear-linear-linear fit was not the best function to fit the data, and it was rejected. No formal AIC analysis was performed because of the obvious outcome.

A major assumption of this analysis is that as the population of Delta smelt declined, the number of fish at risk of entrainment remained constant. If the number of fish in the vicinity of the pumps declined, fewer fish would be entrained and more negative OMR flows would result in lower salvage. This situation would result in an overestimate, i.e. the change point would be more positive. In fact, if the residuals are examined for the relationship in Figure B-13 above, the salvage for the POD years 2002, 2004, 2005, and 2006 are all below the line. 2003 is above the line although the line is not extended to the points at the top of the figure, and these data points occur when the curve becomes almost vertical. The negative residuals could be a result of a smaller population size available for entrainment and salvage. This could be verified by normalizing the salvage data by the estimated population size based on the FMWT data.

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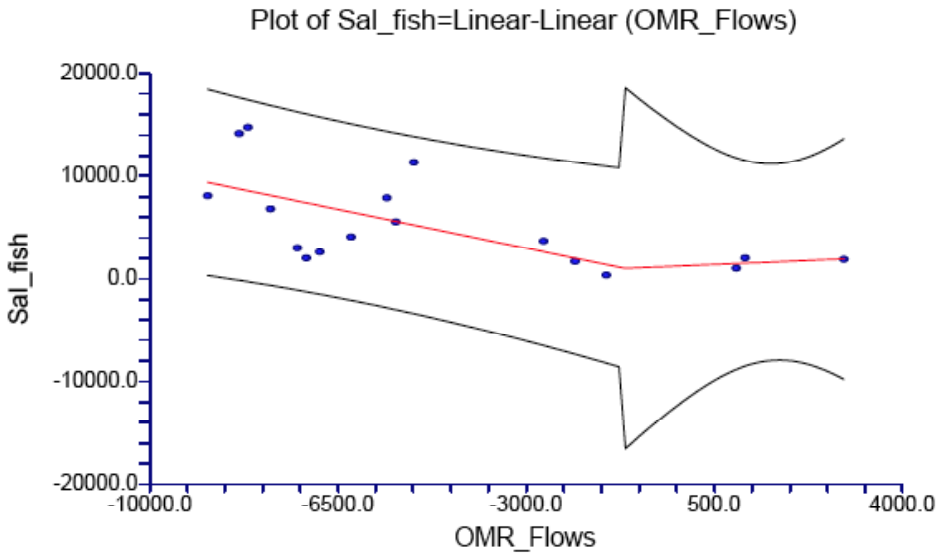

Figure B-14. Piecewise polynomial regression of OMR flows and salvage. The change point is the location at which the two regression lines meet; -1,162 cfs OMR.

The original values of OMR and salvage could have been measured with error due to a number of causes, consequently the values used in the original piecewise polynomial analysis could be slightly different than the "true" values of salvage and OMR flow. Consequently, a second analysis was undertaken to examine the effect of adding stochastic variation to the OMR and salvage values in the piecewise polynomial regression analysis. The correlation between OMR and salvage in the original dataset was -0.61 indicating that the more negative the OMR, the greater the salvage. Consequently, it was necessary to maintain the original covariance structure of the data when adding the error terms and performing the regressions. The original covariance structure of the OMR–salvage data was maintained by adding a random error term to both parameters. The random error term was added to OMR and a correlated error term was added to salvage. The expected value of the correlated errors was -0.61.

The error terms were selected from a normal distribution with a mean of 1.0 and a standard deviation of 0.25 which provided reasonable variability in the original data. Operationally this process generated a normal distribution of OMR and salvage values in which the mean of the distributions were the original data points. Additional analyses were performed with standard deviations of 0.075, 0.025, and 0.125. Smaller standard deviations in the error term resulted in estimates of the change point nearer to the original estimate of -1,162 cfs. This is to be expected as the narrower the distribution of error terms, the more likely the randomly selected values would be close to the mean of the distribution. The process was repeated one hundred times, each time a new dataset was generated and a new piecewise polynomial regression was performed. The software package @Risk (© Palisade Decision Tools) was used to perform the Monte Carlo simulations. Latin

> hypercube sampling was used to insure that the distributions of OMR and salvage values were sampled from across their full distributions. The parameter of interest in the simulations was the change point, the value of the OMR flow at which the amount of salvage began to increase. Incorporating uncertainty into the analysis moved the change point to -1,800 cfs OMR, indicating that at flows above -1683, the baseline level of salvage occurred but with flows more negative than -1683, salvage increased.

BiOp 347-51 (emphasis added).

The analyses contained in Figures B-13 and B-14 serve, *inter alia,* as justification for Action 1: setting "break points" above and below which entrainment rates noticeably change. These break points are the foundation for the tiered flow restrictions in RPA Action 1. Cay Collette Goude[17] stated in her expert declaration that the analysis conducted by Dr. Michael Johnson, set forth in Figure B-13, found inflection points where entrainment started to increase with more negative OMR flows, and that the inflection point "was -1,800 cfs OMR when uncertainty was factored into the analysis." Doc. 470, at ¶ 22. The BiOp does not explain in the "Justification for Flow Prescriptions in Action 1" or elsewhere how or why this -1,800 cfs figure relates to the -2,000 cfs upper limit imposed by Action 1.[18]

Action 2 calls for flows to be set within a range from

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[17] Ms. Goude is the Assistant Field Supervisor for the Endangered Species Program in the Sacramento Fish and Wildlife Office, U.S. Fish and Wildlife Service. Goude Decl., Doc. 470, at ¶ 1.

[18] In explaining actions designed to protect juvenile smelt, Ms. Goude makes reference to another portion of Appendix B, which sets forth the justification for Action 3's restrictions to protect larval smelt. There, the BiOp states that "entrainment risk grows exponentially at OMR flows increasingly more negative than -2,000 cfs." BiOp at 381 (cited in Goude Decl. at ¶ 24). This conclusion appears to be based upon computer modeling using the Particle Tracking Method ("PTM"). The BiOp does not state that PTM modeling was used to formulate the flow prescriptions imposed by Action 1.

-5,000 to -1,250 cfs, depending on a complex set of biological and environmental parameters. BiOp *at* 281-82, 352-56. Although Appendix B describes and justifies Action 2 separately from Action 1, there is no independent section justifying the flow prescriptions imposed by Action 2. Instead, there is a sub-section entitled "Justification for Guidelines in Setting Prescriptions of Action 2" which fixes biological and environmental parameters the SWG is to use in setting flows within the -5,000 cfs to -1,250 cfs range. *See* BiOp at 355. There is no independent quantitative or qualitative justification for the upper and lower limits of that range. In fact, the "Justification for Guidelines in Setting Prescriptions of Action 2" section contains the following statement:

> Flow requirements defined within Action 2 follow the same protectiveness criterion established during Action 1, as adjusted to reflect real-time conditions and predicted entrainment risk relative to the anticipated distribution and abundance of year-class delta smelt; and reflecting their behavioral propensity to hold in their chosen spawning habitat. These are allowed to vary based upon assessment of available data as described in the adaptive process described in the Introductions to Actions section above.

BiOp at 356.

Plaintiffs complain that the "Justification for Flow Prescriptions in Action 1" section does not represent the best available science because it is based upon analyses of gross (or "raw") salvage (i.e. the absolute number of fish salvaged over a given time period). The use of raw salvage data, as opposed to

salvage data scaled to population size, is problematic because raw salvage figures do not account for the size (or relative size) of the smelt population. Deriso Decl., Doc. 401, at ¶ 28. The BiOp admits as much, and concedes that the analysis assumes that "as the population of Delta smelt declined, the number of fish at risk of entrainment remained constant." BiOp at 349. Considering raw salvage numbers alone provides no means of distinguishing an event in which 10,000 fish are salvaged out of a population of 20,000 from an event in which 10,000 fish are salvaged from a population of 20 million. Deriso Decl., Doc. 401, ¶ 28.

There is widespread agreement among the scientific experts that the use of normalized salvage data rather than gross salvage data is the standard accepted scientific methodology among professionals in the fields of fisheries biology/management. Doc. 633-1 at 7, 10 (the 706 experts concluded that, although it is not inherently unreasonable to consider the analysis in Figure B-13, it would be unreasonable to rely on that analysis as the <u>only</u> basis for imposing flow restrictions); Deriso Decl., Doc. 401 at ¶¶ 51-56 (FWS's reliance on Figure B-13 to conclude that as negative OMR flows increase, more adults are salvaged is "scientifically flawed because raw salvage numbers do not have a directly proportional effect on population and do not take into account the overall size of the population...."); Newman Decl.,

Doc. 484 at ¶ 11 (concurring with Dr. Deriso's "general notion of scaling salvage by some measure of population size.").

FWS was aware that raw salvage data posed this obvious problem. The BiOp itself recognized the necessity of normalizing raw salvage data:

> To provide context to determine the magnitude of effect of pre-spawning adult direct mortality through entrainment within any given season (as measured by salvage), it is necessary to consider two important factors.....¶ The second factor to consider when relating salvage to population-level significance is that the total number salvaged at the facilities does not necessarily indicate a negative impact on the overall delta smelt population.

BiOp at 338. The August 26, 2008, draft meeting notes of FWS's Delta Smelt Action Evaluation Team state:

> When analyzing the importance of entrainment to the species population structure or decline, the relevant fact to consider is the percentage of the population being removed via entrainment. Salvage data, by itself, may not be sufficient to help one understand the percentage of the population being removed via entrainment.

AR 010023. The Independent Peer Review of FWS's draft Effects Analysis for the BiOp also recommended to FWS that it "normalize[]" salvage to population size:

> The panel suggests that the use of predicted salvage of adult smelt should be normalized for population size. Total number salvaged is influenced by a variety of factors, particularly the number of fish in the population.... Expressing salvage as a normalized index may help remove some of the confounding of the temporal trends during the baseline.

AR 008818. FWS used normalized salvage data in other parts of the BiOp, including the calculation of the Incidental Take Limit, evidencing its ability to do so. *See* Deriso Decl., Doc. 401, at

¶ 55 (citing BiOp at 386).

FWS nowhere explains its decision in the BiOp to use gross salvage numbers in Figures B-13 and B-14, and does not explain why it selectively used normalized salvage data in some parts of the BiOp but not in others. *See* Doc. 633-1 at 10 (Dr. Thomas Quinn, a 706 Expert with expertise in fisheries biology, estuarine ecology, and fish migration and movement, *see* Doc. 394 at 2, stated: "it is not clear why such an adjustment [of salvage to population size] was not made for the data examined in this report."). This was arbitrary, capricious, and represents a failure to utilize the best available science in light of universal recognition that salvage data must be normalized. This significant error must be corrected on remand.

(1) Federal Defendants' Argument that the Flow Prescriptions in Actions 1 and 2 are Otherwise Justified.

Federal Defendants argue that the specific flow prescriptions in Actions 1 and 2 are supported by more than just Figures B-13 and B-14. By portraying a negative as a positive, Federal Defendants point out that nothing in the BiOp suggests Figures B-13 and B-14 are in fact being used to draw conclusions about what is happening to the delta smelt population as a whole. Doc. 660 at 32. The BiOp concedes that "when relating salvage data to population-level significance [ ] the total number salvaged at the facilities does not necessarily indicate a

negative impact upon the overall delta smelt population." BiOp at 338. Instead, Federal Defendants suggest that the raw salvage numbers are used in "tandem" with other population-based analyses. Other sections of the BiOp demonstrate that salvage by the Project pumping facilities can have a "sporadically significant" effect on the delta smelt population.

However, Federal Defendants concede that neither the research supporting the "sporadically significant" finding nor any related discussion in the BiOp generate the kind of "operational metric... needed so that Project pumping can be managed to prevent the entrainment numbers that these other population analyses deem necessary for avoiding population level effects." Doc. 660 at 32-33. Federal Defendants argue that the raw salvage analyses contained in Figures B-13 and B-14 are used solely to generate these "operational metrics":

> That is where raw salvage comes in – it works in tandem with these other population-based analyses, which Plaintiffs disregard. <u>Specifically, Figures B-13 and B-14 are included to illustrate that the Projects quickly lose the ability to manage entrainment and salvage risk once OMR flows become more negative than -5000 cfs</u>. This is the level at which it is believed that entrainment losses or the take level can be effectively managed. *See* BiOp at 366 (explaining that the function of the OMR flow targets is to manage entrainment risk).

Id. at 33. This argument does absolutely nothing to overcome the fact that the use of raw salvage in the analyses depicted in figures B-13 and B-14 is scientifically unacceptable. Those

figures cannot accurately depict when the Projects "lose the ability to manage entrainment and salvage risk," because they do not scale salvage to population size. These figures do not take into account the possibility that one data point used to generate the curves depicted may have been collected in a year when the delta smelt population was 1,000,000, making it more likely that larger numbers of smelt would be present near the pumps to be salvaged, while another data point might have been collected during a year in which the population was 10,000, making it inherently less likely that large numbers of smelt would be found in salvage. The present record suggests that such metrics are meaningless as management tools. They cannot be used to set specific flow prescriptions. FWS was offered the opportunity to, but has not justified its approach.

At the same time, Federal Defendants contend that at least some of the "break points" reflected in the specific flow prescriptions of Components 1 and 2 are based on information unrelated to Figures B-13 and B-14. For example, in the justification for Action 3, which is designed to protect larval & juvenile smelt, the BiOp relies upon Particle Tracking Model ("PTM") results to explore the likelihood of entrainment of particles in the south Delta (used to represent that portion of the smelt population located in the south Delta) that would likely be entrained at various levels of negative OMR flow. This

is referenced as "entrainment risk":

> The most efficient protective measure for protecting the resilience and not precluding the recovery of the delta smelt population specific to the larval/juvenile lifestage is to prevent entrainment of fish in as large a portion of the Central Delta as is practical. Results of PTM modeling focusing on protections at station 815 (Prisoner's Point) indicates that precluding entrainment of larval/juvenile delta smelt at this station would also protect fish at station 812 (Fisherman's Cut) and other stations north and west (downstream) of station 815. While the target entrainment at station 815 would ideally also be zero, there appears to be little additional entrainment protection (less than 5 percent) at OMR flows at -750 cfs (the strictest level addressed by Interim Remedies). However, entrainment risk grows exponentially at OMR flows increasingly more negative than -2000 cfs.
>
> Figure B-16 displays injection points for modeled particle tracking runs that were conducted in February 2008 with injection points at Stations 711, 809, 812, 815, 902, 915. This figure plots projected relationships for OMR flows by injection point, including entrainment probabilities for station 815 (over 30 days).
>
> The results from these runs indicate an approximate <5 percent entrainment risk at OMR flow not more negative than -2000 cfs. At a requirement of -3,500 cfs OMR flow, entrainment risk at station 815 is roughly 20 percent over each 30 day interval. Assuming cumulative entrainment is additive, over a roughly four month (~120 days) interval in which Action 3 would be under effect, consistently operating at -3,500 OMR would yield a net entrainment probability placing at risk approximately 80 percent of the larval/juvenile subpopulation utilizing the South Delta at and below Station 815. If immigration of larval smelt from the Central or North Delta into the zone of entrainment during spring were to occur, the population-level risk would be even greater. Such entrainment levels are potentially a significant adverse risk to delta smelt population.

BiOp at 366-68.

Although it seems logical that the PTM results and the "entrainment risk" PTM attempts to estimate have some applicability to the protection of adult smelt, the BiOp does not

rely upon these results to justify Actions 1 or 2. *NWF v. NMFS II*, 524 F.3d at 932, n.10 (a court "may not consider [a] post hoc justification, or infer 'an analysis that is not shown in the record.'")(quoting Gifford Pinchot Task Force, 378 F.3d at 1074, and citing *PCFFA v. U.S. Bureau of Reclamation,* 426 F.3d 1082, 1091 (9th Cir. 2005) ("[W]e cannot infer an agency's reasoning from mere silence," and "an agency's action must be upheld, if at all, on the basis articulated by the agency.")).

Federal Defendants also point out that Action 1 is based on "the historical observation that the first 'winter flush' moves delta smelt into portions of the delta where they are particularly vulnerable to entrainment, for biological and hydrological reasons that are well documented." Doc. 660 at 23 (citing BiOp at 333-36). Federal Defendants argue:

> As the multiple sources of information relied upon by the BiOp on this point demonstrate, pumping reductions during these critical vulnerability periods will demonstrably reduce entrainment and entrainment risk. *See id*. According to the BiOp, the piece-wise regression set forth in Figure B-14 of the BiOp was used to provide some indication of what level of exports would reduce entrainment during these first flush events, and not, as Plaintiffs assert, to analyze the impacts of salvage relative to the population. *See* BiOp at 350.

Doc. 660 at 23. The BiOp arguably supports the assertion that a "winter flush" can move smelt into areas of the delta where they are particularly vulnerable. *See* BiOp at 331. However, nothing in the discussion of the timing, characteristics, or indicators of the winter flush explains why -5,000 cfs was set as the

ceiling on negative OMR flows, rather than some other figure. That justification appears to come exclusively from Figures B-13 and B-14, which rely upon the flawed analyses of raw salvage.

Finally, Federal Defendants attempt to justify the use of raw salvage numbers in calculating the -5,000 cfs ceiling by a convoluted argument that Kimmerer's work proves raw salvage trends generally follow population trends. Kimmerer's work did evaluate the population-level effects of project operations. The BiOp explains:

> This effects analysis evaluates the proposed action operations by exploring long-term trends in Delta outflow, or X2, and OMR flows during March-June and comparing these to hydrodynamic conditions expected based on CALSIM II modeling presented in the biological assessment. <u>The analysis uses the larval-juvenile entrainment estimates provided by Kimmerer (2008) and flow and export projections from the biological assessment to estimate the annual percentages of the larval/juvenile delta smelt population expected to be entrained</u>....
>
> Kimmerer (2008) proposed a method for estimating the percentage of the larval-juvenile delta smelt population entrained at Banks and Jones each year. These estimates were based on a combination of larval distribution data from the 20-mm survey, estimates of net efficiency in this survey, estimates of larval mortality rates, estimates of spawn timing, particle tracking simulations from DWR's DSM-2 particle tracking model, and estimates of Banks and Jones salvage efficiency for larvae of various sizes. Kimmerer estimated larval-juvenile entrainment for 1995-2005. We used Kimmerer's entrainment estimates to develop multiple regression models to predict the proportion of the larval/juvenile delta smelt population entrained based on a combination of X2 and OMR.

BiOp at 219-220 (emphasis added). The BiOp used a similar approach for adult delta smelt:

> Kimmerer (2008) calculated that entrainment losses of adult delta smelt in the winter removed 1 to 50 percent

> of the estimated population and were proportional to OMR flow, though the high entrainment case might overstate actual entrainment. Given there are demonstrated relationships between smelt entrainment and salvage with OMR flows (Kimmerer 2008; Grimaldo et al. accepted manuscript), this effects analysis evaluates the proposed action operations by comparing the long-term trends in OMR flows to OMR flows in the CALSIM II modeling presented in the biological assessment. For both approaches, predictions of salvage and total entrainment losses were made using OMR flow since it was the best explanatory variable of each. The effects of proposed operations were determined by comparing actual salvage and entrainment losses with predictions of these parameters under modeled OMR flows.

BiOp at 211 (emphasis added). Kimmerer did calculate proportional population-level losses for both adults and juveniles. *See id.*; *see also* BiOp at 212, 250-252, 262 (presenting model simulation results in Figures E4-E6 and E16 which estimate proportional population losses based on entrainment). It is undisputed, however, that Kimmerer did not generate any operational metrics or attempt to calculate the point above or below which OMR flows would have particular effects on the smelt population. As a result, there was no basis to rely on Kimmerer's work alone to justify the specific OMR flows imposed by Actions 1 and 2. Federal Defendants point to a section of the BiOp's Effect's Analysis that concludes that because "over a given span of years, the project as proposed will increase larval/juvenile entrainment relative to 1995-2005 levels," "[t]his will have an adverse effect on delta smelt based on their current low population levels." BiOp at 222. However, this conclusion references Figure E-18, which attempts to

estimate the likelihood of having an event that would entrain a significant proportion of the smelt population, thereby evaluating the effect of particular circumstances on the smelt population. *See* BiOp at 264. This language provides no support for Federal Defendants' assertion that the BiOp connects population level effects to raw salvage figures.

Federal Defendants assert "Kimmerer (2008), like the BiOp, concluded that once raw entrainment numbers approach a certain level, population-level effects will occur." Doc. 660 at 25 (citing BiOp at 159, 164-65, 210; AR at 18854-18880). Federal Defendants describe this as the "Kimmerer Approach," and argue:

> The Kimmerer (2008) study shows that salvage trends generally follow population loss trends. *See* BiOp at 206-207; *see also* AR at 18854-18880. Salvage data is then used to ascertain the pumping level at which entrainment risk can no longer be managed to a level that prevents harm to the population as a whole. See BiOp at 338. Using the Kimmerer approach, by managing salvage, the BiOp manages population-level losses.

Doc. 660 at 25. This description is not supported by the record. The BiOp does not rely upon Kimmerer (2008) or any other source to conclude that salvage trends generally follow population loss trends. This is FWS's invention to support its arbitrary flow limit.

FWS nowhere explains in the BiOp or the AR how the sporadically significant population-level effects identified in Kimmerer (2008) factored into the quantitative analysis that led to the -5,000 cfs OMR flow limit imposed in RPA Action 2.

Nowhere does the BiOp or the record explain how the analysis in Fig. B-13 "works in tandem" with the purported numeric results of Kimmerer (2008), and nowhere does the BiOp or the record state that Fig. B-13 was intended to create an "operational metric" to manage pumping to avoid "certain raw entrainment numbers." This is an abdication of the duty to satisfy the basic APA requirement that the agency "articulate[] a rational connection between the facts found and the choice made." *Ariz. Cattle Growers' Ass'n,* 273 F.3d at 1236.

Federal Defendants argue that, even if FWS had used a scaled salvage index to calculate the OMR flow ceiling, the results would not have been appreciably different. For the purposes of demonstrating the difference between the analysis presented in the BiOp and a population-normalized analysis, Dr. Deriso analyzed the relationship between normalized salvage and OMR flows. He initially concluded that there is "no statistically significant relationship between OMR flows and adult salvage for flows less negative than -6,100 [cfs] at the very least." Deriso Decl., Doc. 401 at ¶¶ 62-65.[19] Federal Defendants' expert criticized Dr. Deriso's alternative analysis in a number of ways, including that Dr. Deriso failed to correct for potentially large

[19] Dr Deriso testified: "specifying that the ceiling on [OMR] flows should have been set at no lower than negative 6100 cfs" was stricken as post hoc extra record evidence. However, no party moved to strike Dr. Newman's similar, post hoc analysis. Dr. Deriso's analysis is considered here only as a counterpoint to Dr. Newman's, not to prove the validity of -6,100 as the appropriate ceiling.

sampling errors. Newman Decl., Doc. 484, at ¶ 12. Dr. Newman ran his own analysis, applying a different standard statistical methodology to the same data used by Dr. Deriso, and got different results regarding the "inflection point" where OMR flows had an increasing impact on the population-normalized salvage rate. *Id*. & Ex. C (identifying inflection point at -4,000 cfs, which is within the OMR flow target ranges established in the BiOp). Ultimately, however, Dr. Newman agreed that an analysis utilizing raw salvage numbers (i.e., not adjusted for relative population size) is scientifically inappropriate. *Id*. at ¶ 11. That other researchers were able to produce generally consistent inflection points through the use of more appropriate statistical methodologies does not excuse FWS's failure to do so. The difference between a -6,100 cfs ceiling and a -4,000 cfs ceiling is very substantial in the amount of lost annual water supply, with resulting adverse effects on human welfare and the human environment. FWS was required to perform an accurate scientific analysis and justify its ultimate decision regarding the imposition of a water flow ceiling.[20]

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[20] Federal Defendants point out that the BiOp also relied on the 2006 Manly and Chotkowski study, which found a statistically significant relationship between exports and smelt abundance as measured by Fall Midwater Trawl ("FMWT") catches, *see* AR 019672 (cited in BiOp at 156), as well as the Interagency Ecological Program's 2007 Synthesis Report on the Pelagic Organism Decline Team, which stated that "... entrainment of adults and larvae (top-down effects) are particularly important to the delta smelt population...." AR 016922 (emphasis added); *see also* Goude Decl., Doc. 470, at ¶¶ 6-7. However, none of these studies correlate raw salvage to population-level losses, nor do they otherwise justify the imposition of the particular flow

(2) Use of Raw Salvage Analyses in Justification for Action 3.

Action 3, which is designed to "[m]inimize the number of larval delta smelt entrained at the facilities by managing the hydrodynamics in the Central Delta...," limits net daily OMR flow to no more negative than -1,250 to -5,000 cfs, based on a 14-day running average with a simultaneous 5-day running average within 25 percent of the applicable requirement for OMR. BiOp at 357. Action 3 establishes guidelines the SWG is to use when recommending where to set the OMR flow level within this range. *Id*. The BiOp anticipates that during most conditions, OMR flows will range between -2,000 and -3,500 cfs. *Id*. at n. 10. During certain years of higher or lower predicted "entrainment risk," flows as low as -1,250 or as high as -5,000 may be recommended. *Id*.

Plaintiffs do not challenge the basis for the low end of the range (-1,250 cfs) or the criteria used to formulate recommendations within the middle of the range. Plaintiffs do argue that the upper end of the range (-5,000 cfs) is based solely on FWS's raw salvage analysis and should be invalidated.

The BiOp explains in the section of Attachment B addressing Action 3 that "[t]wo scenarios span the range of circumstances likely to exist during Action 3":

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regime the BiOp imposes.

> First, *the* low-entrainment risk scenario. There may be a low risk of larval/juvenile entrainment because there has been no evidence of delta smelt in the South and Central Delta or larval delta smelt are not yet susceptible to entrainment. *In this scenario, negative OMR flow rates as high as -5,000 cfs may occur as long as entrainment risk factors permit*.
>
> The second scenario, the high-entrainment risk *scenario*, is one in which either (a) there is evidence of delta smelt in the South and Central Delta from the SKT and/or 20mm survey, or (b) there is evidence of ongoing entrainment, regardless of other risk factors. In this case, OMR should be set to reduce entrainment and/or the risk of entrainment as the totality of circumstances warrant.
>
> Usually, if the available distributional information suggests that most delta smelt are in the North or North/Central Delta, then OMR flow can be chosen to minimize Central Delta entrainment. However, if the distributional information suggests there are delta smelt in the Central or South Delta, then OMR flows will have to be set lower to reduce entrainment of these fish. If delta smelt abundance is low, distribution cannot be reliably inferred. Therefore, the adaptive process is extremely important. The SWG may recommend any specific OMR flow within the specified range above.

BiOp at 358 (underlined emphasis in original; emphasis in italics added). The Action 3 discussion does not provide an independent justification for the choice of -5,000 cfs as the upper limit for OMR flows under the low entrainment risk scenario. Federal Defendants suggest that the upper limit is justified in the Delta Smelt OCAP Team's notes, which indicate that "[a]t -5,000 OMR, the model shows 40% entrainment at station 815." AR 009459. This is a reference to the PTM model results. There are two major problems with Federal Defendants' reliance on this

statement. First, it is contained within a section of the Delta Smelt OCAP Team notes entitled "Actions 1 and 2." AR 009457-60. Even if this statement was made in reference to Action 3, it does not justify using -5,000 cfs as the upper limit. The PTM study assumed an upper limit of -5,000 cfs and never considered any flow ranges above that. Nor is it made clear why 40% particle entrainment is a rational threshold of significance, as opposed to some lower or higher threshold. In sum, the PTM study does not justify the imposition of -5,000 cfs as an upper limit in Actions 1, 2, or 3.

The "Action #3" section of the Team's notes does contain an explanatory statement regarding the source of the -5,000 cfs upper boundary for Action 3: "The -5,000 OMR cap was established by Wanger." AR 009463; *see also* AR 009462 ("[t]he group discussed the merits of using the -5,000 OMR per Wanger Order"). It is unclear how FWS can rely directly on a provisional court order, entered as a remedial stopgap measure pending comprehensive scientific analysis, to establish the scientific basis for an RPA. The subject Order was the result of an Interim Remedies proceeding in the challenge to the previous Delta Smelt BiOp. After an evidentiary hearing, it was determined from the then available data that "the number of Delta smelt entrained at the CVP and SWP export facilities begins to rise significantly when negative flows on the OMR exceed approximately -5,000 cfs.

[Tr. 641:14-642:5; 725:16-17; DWR Ex. D ¶ 4; DWR Ex. G ¶ 34; SWC Ex. N]." *NRDC v. Kempthorne*, 1:05-cv-1207, Doc. 561, Int. Rem. Findings, at ¶ 38. The finding was based on two studies of the relationship between OMR flows and smelt salvage: (1) a non-linear model presented by Sheila Greene of DWR; and (2) the linear model created by Peter Smith, which became the basis for Figure B-13. Both of these analyses utilized raw salvage data. AR 009251 (Green's analysis); *see also* 1:05-cv-1207, Doc. 399, Decl. of Jerry Johns, Ex. B and C; 1:05-cv-1207, Doc. 419, Decl. of Christina Swanson, at 12, Fig. 8. That raw salvage studies were previously relied upon by the Court, when no others were available, does not validate their use in the 2008 Smelt BiOp.

d. <u>FWS's Comparison of CALSIM II Data to DAYFLOW Data.</u>

The BiOp's effects analysis used analytical methods and data, "including the CALSIM II model outputs provided in the appendices of Reclamation's 2008 OCAP BA, historical hydrologic data provided in the DAYFLOW database, statistical summaries derived from 936 unique 90-day particle tracking simulations published by Kimmerer and Nobriga (2008), and statistical summaries and derivative analyses of hydrodynamic and fisheries data published by Feyrer et al. (2007), Kimmerer (2008), and Grimaldo et al. (accepted manuscript)." BiOp at 204.

CalSim II is a computer model developed jointly by DWR and

Reclamation. Declaration of Aaron Miller,[21] Doc. 548-1, at ¶ 5. The model simulates SWP and CVP operations and is the standard planning tool for evaluating project operations. *Id*. at ¶ 6. CalSim II has been continuously updated since it was first applied in 2002. *Id*. at ¶ 8. CalSim II simulates SWP and CVP reservoir operations, project exports and water deliveries, flow through the Delta, and salinity requirements in the Delta, including the location of X2. *Id*. at ¶ 7.

CalSim II uses historic hydrologic data from October 1922 to September 2003, including precipitation, runoff into reservoirs and inflow into the Delta from unimpaired streams. Miller Decl., Doc. 548-1, at ¶ 10 & n.1. The model further assumes a level of development, which reflects water demand resulting from particular levels of urban population, agricultural production, and wildlife refuge needs, *id*. at ¶ 10, along with the effect of environmental regulations and programs, *id*. at ¶ 27; BiOp at 207. CalSim II is capable of estimating the position of X2. Miller Decl., Doc. 548-1, at ¶ 14.

The BiOp considered a number of CalSim II studies, either directly or indirectly:

- Study 6.0 was designed to represent the assumptions used in the 2004 OCAP BA within the updated CalSim II model

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[21] Mr. Miller is DWR's Technical Senior Water Resource Engineer and possesses expertise in CALSIM II and Dayflow modeling. Miller Decl., Doc. 548-1, at ¶¶ 1-3.

framework in order to highlight changes from the previous model framework. This Study models a 2005 level of development and includes steps to account for operations under CVPIA (b)(2) and Joint Point of Diversion[22]. *See* OCAP BA at 9-32 (AR 010729).

- Study 6.1 is similar to 6.0, except that the 2005 Trinty River Record of Decision is removed, and the Joint Point of Diversion is not accounted for. *Id*.
- Study 7.0 was developed as the baseline study for the OCAP BA. Study 7.0 represents existing conditions, and assumes a 2005 level of development and a full environmental water account ("EWA")[23]. BiOp at 207.
- Study 7.1 is a near-future conditions study. It assumes a 2005 level of development and a limited EWA. BiOp at 207-08.
- Study 8.0 is a future conditions study. It assumes a 2030 level of development and a limited EWA. BiOp at 208.

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[22] State Water Resources Control Board Decision 1641 granted Reclamation and DWR the ability to "use/exchange each Project's diversion capacity capabilities to enhance the beneficial uses of both parties...." with certain conditions. BiOp at 26.

[23] The EWA was originally designed to compensate CVP and SWP contractors for loss of water to facilitate reduced diversions from the Delta at times when at risk fish species may be harmed. BiOp at 34. "Typically the EWA replaced water loss due to curtailment of pumping by purchase of surface or groundwater supplies from willing sellers and by taking advantage of regulatory flexibility and certain operational assets." *Id*. However, at the time the BiOp was issued, the agencies that manage the EWA were undertaking environmental review to determine the future of the EWA. *Id*. As a result, the BiOp treats EWA as a "limited" asset in some circumstances. *Id*.

- The 9.0 series of studies represents climate change scenarios. BiOp at 208.

The OCAP BA suggested using Calsim II Study 7.0 as the current baseline and Study 6.1 as the historical baseline for evaluating the impacts of project operations. BiOp at 204. However, the BiOp rejected this suggestion because, although "changes were expected between Study 6.1 and Studies 7.0 and 7.1," the modeled results were "nearly identical." *Id.* FWS concluded from this result that Calsim II could not accurately generate an empirical baseline. *See id*. at 204-06. Instead, FWS chose to "use actual data to develop an empirical baseline," including the use of the Dayflow model to "develop[] historical time series data for hydrologic variables." BiOp at 206. Dayflow is a model that estimates historic outflow based on historic precipitation, inflow, and exports, and estimates of delta island diversions. Dayflow also provides an estimate for the location of X2. Miller Decl., Doc. 548-1, at ¶¶ 14-15.

In the BiOp, FWS purports to quantify adult entrainment by comparing OMR flows from CalSim II studies to historic OMR flows during 1967-2007. BiOp at 212-13. The BiOp depicts these results in Tables E-5a, E-5b, and E-5c:

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Table E-5a. Historic and CALSIM II modeled median winter (Dec-Mar) OMR flows by water year type

Water year type	Historic	7	7.1	8	9	9.1	9.2	9.3	9.4	9.5
Wet	-1033	-5256	-5498	-5699	-5684	-5500	-3999	-3678	-7066	-6100
Above Normal	-5178	-7209	-7923	-8073	-8156	-7595	-6863	-6934	-7861	-7723
Below Normal	-2405	-6461	-7208	-7009	-6599	-6420	-5647	-6736	-6721	-6343
Dry	-5509	-6443	-6931	-6692	-6620	-6353	-6831	-7438	-5785	-5760
Critical	-5037	-4547	-4931	-4980	-5051	-4588	-5320	-5194	-4260	-3845

Table E-5b. Winter OMR Flow percent difference from historic median value to CALSIM II model median value

Water year type	7	7.1	8	9	9.1	9.2	9.3	9.4	9.5
Wet	408.92%	432.37%	451.84%	450.36%	432.50%	287.16%	256.13%	584.15%	490.63%
Above Normal	39.21%	53.01%	55.90%	57.49%	46.67%	32.53%	33.91%	51.80%	49.13%
Below Normal	168.62%	199.68%	191.41%	174.35%	166.90%	134.75%	180.05%	179.42%	163.72%
Dry	16.95%	25.81%	21.48%	20.17%	15.32%	24.01%	35.02%	5.01%	4.57%
Critical	-9.74%	-2.12%	-1.14%	0.27%	-8.92%	5.61%	3.11%	-15.44%	-23.68%

Table E-5c. Percent difference from historic median salvage to predicted salvage based on Dec-Mar OMR flows from CALSIM II studies

Water year type	Study 7	Study 7.1	Study 8	Study 9	Study 9.1	Study 9.2	Study 9.3	Study 9.4	Study 9.5
Wet	45.64%	48.26%	50.43%	50.26%	48.27%	32.05%	28.59%	65.20%	54.76%
Above Normal	15.15%	20.49%	21.60%	22.22%	18.04%	12.57%	13.10%	20.02%	18.99%
Below Normal	38.17%	45.20%	43.33%	39.46%	37.78%	30.50%	40.76%	40.61%	37.06%
Dry	6.80%	10.36%	8.62%	8.09%	6.15%	9.63%	14.05%	2.01%	1.83%
Critical	-3.70%	-0.81%	-0.43%	0.10%	-3.39%	2.13%	1.18%	-5.87%	-9.00%

Tables E-5b and E-5c depict changes in OMR flows and entrainment using the Dayflow-generated historic data as the baseline and comparing that to CalSim II study results. In addition, the BiOp utilized an equation taken from Kimmerer's 2008 paper to estimate the population loss of delta smelt under the various modeled scenarios. The results of these calculations were depicted in Figures E-5 and E-6:

Figure E-5. Frequency distribution of predicted adult delta smelt entrained at Banks and Jones for predicted estimates from historic data (1967-1994), actual estimates from Kimmerer (2008) for years 1995-2006, and those estimated from CALSIM II model data by study.

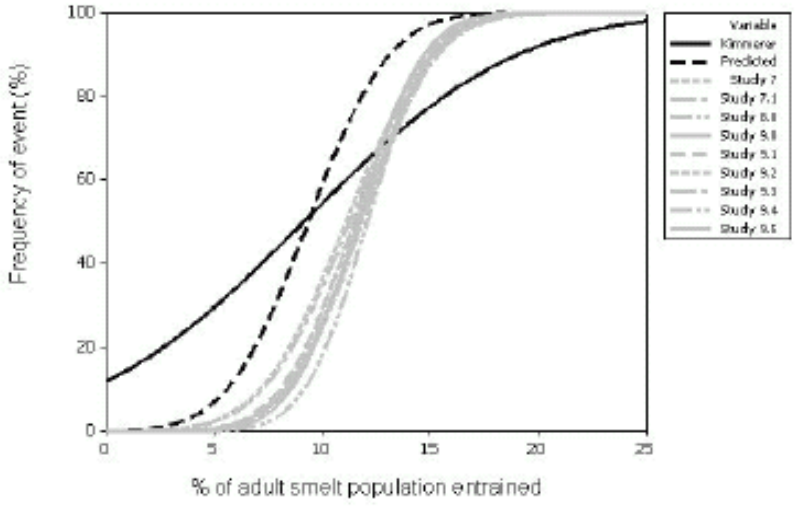

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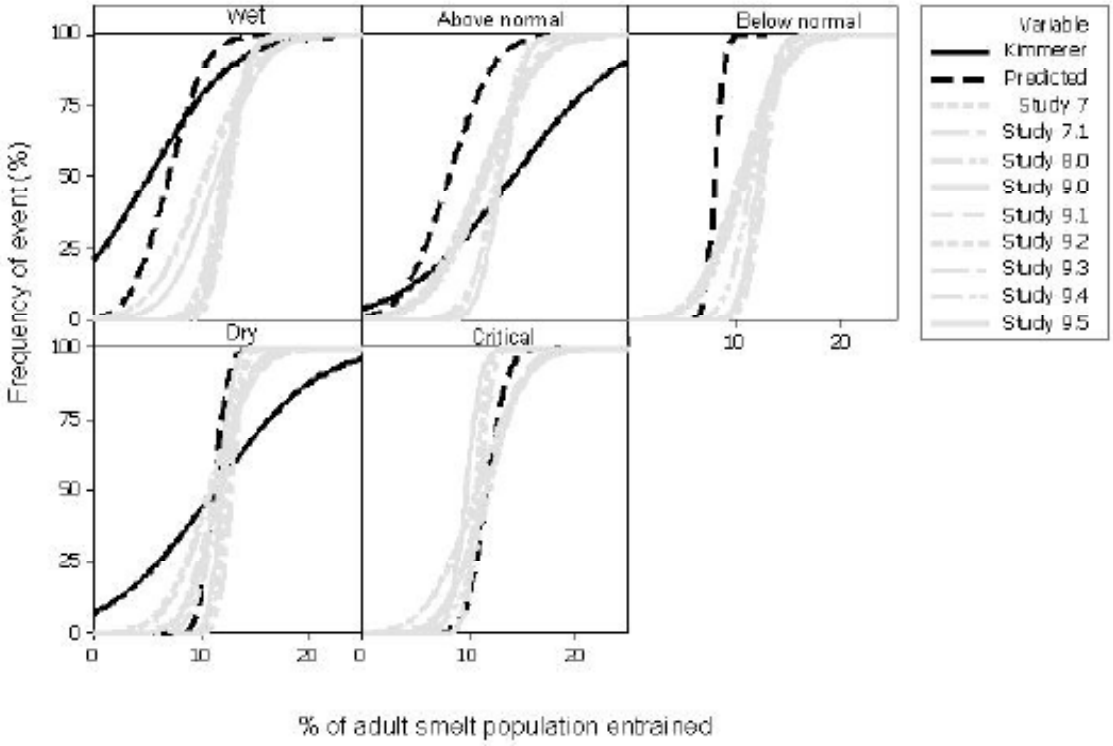
Figure E-6. Same as E-5 but by water year type. Kimmerer (2008) estimates did not include below normal or critical dry water year types.



BiOp at 251-52. The accompanying text explains the significance of these results to the analysis:

> The median OMR flows from the CALSIM II modeled scenarios were more negative than historic OMR flow for all WY types except critically dry years (Figure E-3; see Table E-5b for all differences). Overall, proposed OMR flows are likely to generate increases in population losses compared to historic years (Figure E-5 and Figure E-6). For example, the frequency of years when population losses are less than 10 percent from most modeled studies (except studies 7.0 and 8.0) is less than 24 percent compared to historic estimates that only exceed 10 percent in approximately half of the years.
>
> The most pronounced differences occur during wet years, where median OMR flows are projected to be approximately 400 to 600 percent (-7100 to -3678 cfs)

> higher than historical wet years (-1032 cfs). Generally, wet years are marked by low salvage and population losses. However, the proposed operations during wet year are predicted to cause up to a 65 percent increase in smelt salvage and lower probability that population losses will be below 10 percent.
>
> The proposed operation conditions likely to have the greatest impact on delta smelt are those modeled during above normal WYs. The modeled OMR flows for the above normal WYs ranged between -8155 and -6242 cfs, a 33 to 57 percent decrease from the historic median of -5178 cfs. Though the predicted salvage would only be about 15-20 percent higher than historic salvage during these years (Table E-5c), the modeled OMR flows in these years would increase population losses compared to historic years.
>
> In below normal and dry WYs, proposed OMR flows are also modeled to decrease from historic medians. Predicted salvage levels are likely to increase between 2 and 44 percent. More importantly, the modeled median flows from all studies in these WY types range between -5747 and -7438 cfs. Modeled OMR flows at these levels are predicted to increase salvage and increase the population losses from historic levels as well.
>
> During critically dry years, the median OMR flows for studies 7.0, 7.1, 8.0, 9.1, 9.4, and 9.5 are less than -5,000 cfs. These studies have predicted salvage lower than historic salvage and are not likely to generate larger population losses compared to historic years. The models might overestimate salvage during critical dry years when smelt are unlikely to migrate towards the Central Delta due to lack of turbidity or first flush. Thus, the effects of critical dry operations on delta smelt take are probably small and lower than estimated.

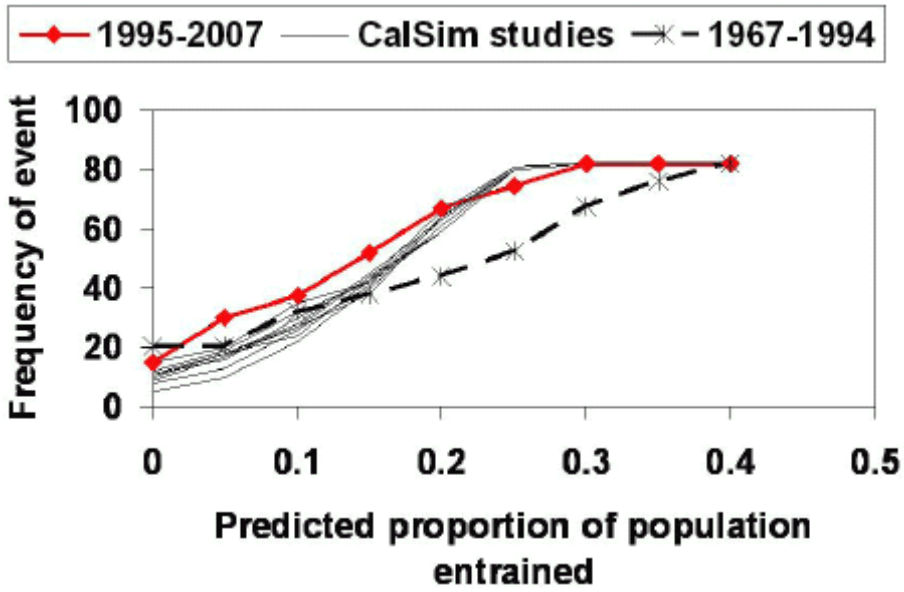
BiOp at 212-13.

Based on these comparisons of CalSim II data and Dayflow-generated historic data, the BiOp concludes, “adult entrainment is likely to be higher than it has been in the past under most operating scenarios, resulting in lower potential production of

early life history stages in the spring in some years." BiOp at 213.

The BiOp performed comparisons of CalSim II data to Dayflow-simulated historic baseline data to quantify the effects of the action on larval and juvenile delta smelt. *See, e.g.,* BiOp at 219 (examining effect of action on larval and juvenile entrainment: "[t]he analysis is based on comparison of historical (1967-2007) OMR and X2 to the proposed action's predictions of these variables provided in ... [CalSim] studies 7.0, 7.1, 8.0, and 9.0-9.5"). Figure E-18 depicts several sets of calculations of the frequency at which certain percentages of the delta smelt population would be entrained:

Figure E-17. Frequency distribution of estimated proportions of larval-juvenile de smelt entrained at Banks and Jones for 1967-1994 and 1995-2007. The data were extrapolated to an 82-year period to make them comparable to the CALSIM II out



BiOp at 264. The black dashed line depicts entrainment estimates for Dayflow-generated historic data from 1967 to 1994, the red

line with diamonds depicts entrainment estimates for Dayflow-generated historic data from 1995-2007, and the fine lines depict the various entrainment estimates based on Calsim II data. Based on these calculations, the BiOp concludes that "the proposed action will decrease the frequency of years in which estimated entrainment is ≤ 15 percent. Thus, over a given span of years, the project as proposed will increase larval juvenile entrainment relative to 1995-2005 levels. This will have an adverse effect on delta smelt based on their current low population levels." BiOp at 222.

A separate BiOp analysis purports to quantify the effects of the project operations on delta smelt habitat by comparing CalSim II model projections of the location of X2 under the proposed operations to the median location of X2 over the historical period 1967-2007, as simulated by Dayflow. BiOp at 235-36. Based on this comparison, the BiOp concludes "[t]he median X2 [locations] across the CalSim II modeled scenarios were 10-15 percent further upstream than actual historic X2 (Figure E-19)." *Id.* at 235. In reliance on these percent differences between CalSim II-created data and historical data, the BiOp concludes: "proposed action operations are likely to negatively affect the abundance of delta smelt." *Id.* at 236.

According to Plaintiffs, the comparison of Calsim II to Dayflow outputs distorts the BiOp in several key ways:

(1) The comparison of outputs of these two models in the Project Effects analysis is, *ipso facto*, a violation of the best available science requirement.

(2) To use Dayflow, which represents historical conditions, to generate the baseline for the Project Effects analysis, improperly attributes past effects to the Projects;

(3) Because the flawed comparison was used to support imposition of Component 3 (Action 4) (a/k/a the "fall X2" action), that Action is invalid.[24]

(1) Was FWS's Decision to Compare Calsim II to Dayflow Model Runs a Violation of the Best Available Science Requirement?

Mr. Aaron Miller opines that outputs from a CalSim II study should not be compared to outputs from the Dayflow model because the assumptions used in the two models are significantly different. Miller Decl., Doc. 548-1, at ¶¶ 22-55. He identified the following key differences between the models:

- Level of Development: The CalSim II model assumes a constant level of development. In contrast, the Dayflow model incorporates a continuous change in the

[24] In some of the briefs, this third argument is presented with Plaintiffs' other challenges to the Fall X2 action. It is most logical and efficient to address this issue with Plaintiffs' challenges to the use of the Calsim II versus Dayflow comparisons in the Project Effects Analysis.

Plaintiffs also argue that the BiOp improperly attributes all (or substantially all) of the observed, historical upstream shift of X2 to Project Operations. It is preferable to address these contentions with related arguments in Part VII.A.(6).

level of development because the Dayflow model is using historical information as input. When comparing models to determine the effect of project operations, the best scientific practice is to keep the assumed level of development constant. *Id.* at ¶¶ 31-38.

- Regulatory Assumptions: CalSim II assumes a constant regulatory environment, whereas Dayflow uses a regulatory environment that has changed over time. Over the past 40 years, numerous regulatory programs have altered the way the projects are operated, including D-1485, D-1641, the Central Valley Project Improvement Act ("CVPIA"), the 1995 Water Quality Control Plan, and the EWA. These differences "further undermine the reliability of comparing historically based Dayflow values to the Calsim II model results." *Id*. at ¶¶ 39-41.
- Time Step: CalSim II operates on a monthly time step, whereas Dayflow operates on a daily time step. *Id*. at ¶ 42.
- Operational/Computational Guidelines: The Dayflow model incorporates real-world conservative operational tactics designed to avoid violating applicable regulations. In contrast, the CalSim II model operates strictly to that regulation. *Id*. at ¶ 44. Operating

conservatively results in higher modeled outflow. *Id*.

- Year Range: The Dayflow model uses a different historic time window than CALSIM II. The BiOp used values from 1967 to 2007 as inputs into the Dayflow model, while 1922 to 2003 were used for Calsim II. *Id*. at ¶ 52. This introduces additional error into any comparison between outputs of these two models because the time period used for the Dayflow model had a higher percentage of wet or above normal years, as compared to the time period covered by Calsim II. *Id*. at ¶ 53.
- Method for Calculating position of X2: The artificial neural network ("ANN") and the Kimmerer Monismith equation ("KM equation") are two methods of estimating X2. *Id*. at ¶ 46. The CalSim II studies used ANN to estimate the position of X2, while the Dayflow model uses the KM equation. *Id*. at ¶ 47. Holding all other variables constant, but varying the method (ANN v. KM) used, produces inconsistent results. At locations less than 75 kilometers ("km") from the Golden Gate, the KM equation results in an X2 estimate greater than (or farther upstream than) the ANN estimate. In contrast, at locations greater than 75 km from the Golden Gate, the KM equation provides an estimate less than the ANN estimate. *Id*. at 11, Fig. 2.

Mr. Miller opined that best scientific practice is to compare models that use consistent assumptions and methodologies. *See id*. at ¶¶ 38, 51, 54; *see also id*. at ¶ 41. The approach taken in the BiOp, quantitatively comparing Calsim II runs to Dayflow model outputs "introduces significant error into the analysis." *Id*. at ¶ 56.

Dr. Punt, a 706 Expert added that "[i]n principle, there is nothing wrong with fitting a model using a set of OMR/X2 valued from one model and making predictions using OMR/X2 values which are based on the output from a different model, as long as the two sets of values are calibrated.... Not calibrating the two sets of model outputs will lead to some bias in the inferences, with the level of bias dependent on the net effect of all the differences between the 'historical' and Calsim II values for the same years." Doc. 633-1 at 15.

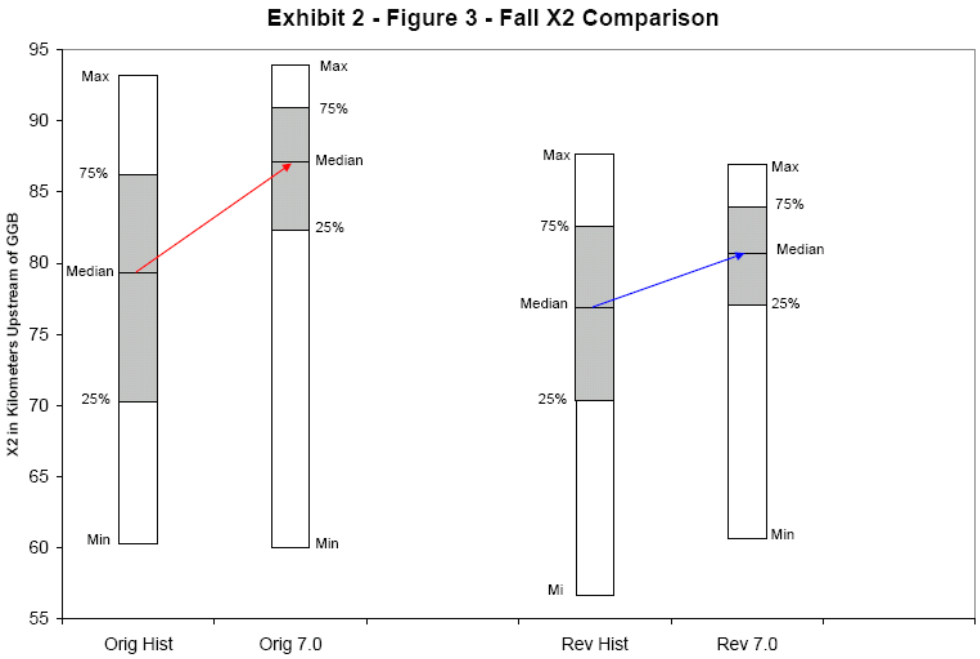
Mr. Derek Hilts, a FWS employee who previously served as "Engineer-in-Charge" of CVP/SWP modeling for Reclamation, disagrees with Mr. Miller's general opinion that comparing Calsim II and Dayflow outputs is *per se* scientifically unreliable, noting that the OCAP BA's Appendix D specifically compared Calsim II and Dayflow runs for the purposes of testing "Calsim II's ability to simulate the CVP/SWP system reasonably well." Decl. of Derek Hilts, Doc. 540, at ¶ 11. But, as Mr. Miller explains, this type of "validation comparison" is designed to "help

establish the credibility of the CalSim II model by showing that the model moves water, simulates operation of the export pumps, and so forth, with the same general timing and magnitude as actual historical data show." Second Miller Decl., Doc. 597, at ¶ 12. In fact, Mr. Miller points out that the detailed validation data contained in the OCAP BA demonstrate that, although Calsim II outputs generally track historical data, they "do not precisely match the actual historical data." *Id*. at ¶ 12. Because validation is "looking only at the general operational performance of the model," a validation comparison "does not need to control for the effects of all the differences in the model and the historical measurements...." *Id*. at ¶ 13.

More specifically, Mr. Hilts disagrees with Mr. Miller's critique that the divergent methods of calculating the position of X2 render the comparison used in the BiOp scientifically inappropriate. Mr. Hilts does not dispute Mr. Miller's conclusion that the KM and ANN equations produce marginally different outcomes. Instead, Mr. Hilts criticizes Mr. Miller for failing to "assert that any such error would have changed the conclusions drawn in the BiOp." Doc. 540 at ¶ 19.

Assumedly to demonstrate that the conclusion would not have changed, Mr. Hilts revisited the calculations in the BiOp, using the KM equation in <u>both</u> models to produce revised estimates of

the position of X2.[25] In performing this analysis, Mr. Hilts also attempted to correct for one of the other purported sources of bias -- the inconsistent year range -- as well as for a few incorrect data points found in the underlying data used in the BiOp. Doc. 540 at ¶¶ 17-18. This revised analysis, which is presented in Exhibit 2, Figure 2 to Mr. Hilts' declaration, is replicated below:



Doc. 540, Exhibit 2, Figure 2. According to Mr. Hilts, this figure demonstrates the "same general upstream movement" of X2 "discussed in the 2008 BiOp." *Id*. at ¶ 17.[26]

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[25] Mr. Hilts chose to use KM instead of ANN because "[w]orking with ANN is very complex"; "using ANN to estimate X2 had just been introduced to Calsim II when the 2008 OCAP BA was completed"; and "few outside DWR know how to work with [ANN]." Doc. 540 at ¶ 15.

[26] Mr. Miller rejoins that Mr. Hilts' revised analysis contains several errors. *See* Doc. 597 at ¶ 18(b)-(c). Even assuming, *arguendo*, Mr. Hilts' analysis was accurately performed, the comparison of Calsim II to Dayflow

Recognizing that his revised analysis demonstrates the same general upstream shift as the BiOp, Mr. Hilts criticizes Mr. Miller for failing to "quantify the effect of the alleged biases ostensibly embedded in the X2 comparison presented in the BiOp." *Id*. at ¶ 7. Federal Defendants contend that even if the Calsim II to Dayflow comparison introduced bias, that bias was not significant. However, the record suggests otherwise.

Recognizing that it is not possible to quantify all aspects of the error caused by the comparison of Calsim II runs to Dayflow output, Mr. Miller's reply declaration endeavored to quantify the bias in his reply declaration. *See* Second Miller Decl., Doc. 597. As with Mr. Hilts' revised calculations, Mr. Miller compared the results reported in the BiOp (Calsim II runs applying the ANN equation and Dayflow runs using the KM equation), to a revised set of results using the KM equation instead of ANN in the Calsim II runs. *Id*. at ¶ 14. Mr. Miller's analysis shows that project operations will cause an upstream shift in X2. Mr. Miller explained that the BiOp's comparison reflected a difference between the reported historic median of X2 [79 km] and the study 7.0 median [87 km] of 10% [(87 km - 79 km)/79]. Mr. Miller concluded that the median X2 for the CalSim 7.0 study using the KM equation (instead of using ANN) was 84 km (instead of 87 km). Finally, he identified the percent

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generates significant bias that is not addressed in the BiOp.

difference between the reported historic median estimate of X2 using the KM equation [79 km] and the CalSim study 7.0 median estimate of X2 using the KM equation [84 km] to be 6% [(84 km–79 km)/79 km]. *Id*. at ¶ 14; BiOp at 235-36. From this, Mr. Miller concluded 40% of the difference between X2 as estimated by study 7.0 and the historical X2 baseline reported in the BiOp is error attributed entirely to the use of the KM equation to calculate the historical baseline X2 and the ANN equation to calculate the CalSim II study 7.0 results. *Id*. at ¶ 15. It is unknown which portion of the remaining 60% of difference is attributable to the proposed action, and which portion is due to the other identified biases. *Id*. at ¶ 16. Dr. Punt expressed a corroborating opinion, estimating that the bias created by failing to calibrate the models "seems non-trivial" and opining that it could be "as large as the differences seen in Figure E-19," the figure in the BiOp depicting the purported 10% shift in X2 between the historic/Dayflow runs and the Calsim II runs. Doc. 633-1 at 16.

Following a similar methodology, using the BiOp's Figure E-20 equation, Mr. Miller calculated the reduction in suitable habitat consistent with the change in the position of X2. A comparison of CalSim II study 7.0 with study 7.1 yielded a reduction in habitat area of 128 hectares (or 2.8%), and a comparison of study 7.0 with study 8.0 yielded a reduction in habitat area of 289 hectares (or 6.2%). Doc. 597 at ¶ 20; BiOp

at 266.

Mr. Miller opined that all errors/biases could have been avoided by comparing CalSim II study 7.0 -- designed as a current conditions baseline -- instead of the "historical" baseline in the BiOp, to the near-future 7.1 study.[27] However, Mr. Hilts points out that comparing Calsim II Study 7.0 to 7.1 and 8.0 is simply "not responsive to the need for comparisons with historical X2 locations," because none of the Calsim II simulations represent Delta conditions that existed from 1967 – 2007. Doc. 540 at ¶ 9. "With the Fall X2 comparison, []FWS wanted to investigate whether the continuation of the recent, as well as future, CVP/SWP operations would result in less or deteriorated habitat for delta smelt relative to the habitat that prevailed historically." *Id*. at ¶ 8. "The CalSim II simulations that Mr. Miller would have the FWS use do not" accomplish this. *Id*.

The theoretical problems with using a Calsim II to Calsim II comparison were manifest. As discussed above, when CalSim II was used to model current Project operations, and these results were then compared to the results of a CalSim II modeling run purportedly simulating past operations, the results "were nearly

[27] Mr. Miller performed a Calsim II to Calsim II comparison. The results indicate a 0.7 km upstream movement of X2, with a 0.8% change in X2 from current to near-current conditions. In a comparison of Calsim II Study 7.0 to Study 8.0 (a 2030 level of development scenario), X2 moved upstream only 1.1 km (1.2 % change). Doc. 597 at ¶20; BiOp at 235, 265. In contrast, the BiOp estimated approximately 8.7 km and 9.1 km changes, respectively, using Dayflow data as the baseline. BiOp at 265 (Figure E-19).

identical" despite significant operational changes in current operations as compared to past. BiOp at 204-205. The BiOp explains that "[t]he inaccuracies in CalSim [led FWS] to use actual data to develop an empirical baseline." *Id.* at 206.[28] FWS contends it had legitimate reasons to rely on a Calsim II to Dayflow comparison instead of a Calsim II to Calsim II comparison.

In light of the known and material resulting disparity, FWS's decision to use a Calsim II to Dayflow comparison to quantitatively justify its jeopardy and adverse modification conclusions, without attempting to calibrate the two models or otherwise address the bias created, was arbitrary and capricious and ignored the best available science showing that a bias was present. The BiOp specifically relied upon the quantitative nature of the Calsim II to Dayflow comparisons in many places. For example, in reference to the X2 shift and resulting effects on smelt habitat:

> The median X2 across the CALSIM II modeled scenarios were 10-15 percent further upstream than actual historic X2 (Figure E-19). Median historic fall X2 was 79km, while median values for the CALSIM II modeled scenarios ranged from 87 to 91km. The CALSIM II modeled scenarios all had an upper range of X2 at about 90km. The consistent upper cap on X2 shows that water quality

[28] The Independent Peer Review of the BiOp's Effects Analysis also noted and was "surprised at" the fact that the historical baseline "differed greatly" from CalSim II Study 7.0 simulated results. AR 008817. The Peer Review reasoned that this discrepancy "raises the question of how representative Study 7.0 is of current and near-future conditions." *Id.*

> requirements for the Delta ultimately constrain the upper limit of X2 in the simulations. These results were also consistent across WY types (Figure E-19) with the differences becoming much more pronounced as years became drier. Thus, the proposed action operations will affect X2 by shifting it upstream in all years, and the effect is exacerbated in drier years.

BiOp at 235. The BiOp does not explain to what extent the ultimate jeopardy/ adverse modification conclusions were based upon the calculated magnitude (10-15 percent) of the X2 shift, rather than the existence of a shift. It cannot be determined whether the BiOp would have reached the same conclusion had this bias not been present.

Federal Defendants concede but understate that "the two models are not perfectly calibrated, and a slight transformation of the data occurs when the analysis switches from one model to the other, the BiOp acknowledges this slight shift." Doc. 660 at 36. Nevertheless, FWS concluded in its "scientific judgment [] that the CalSim [II]-to-Calsim [II] output was far worse." *Id.* (citing BiOp at 207). Federal Defendants argue this was a choice between "one comparison that yielded a slight calibration issue and another that completely masked altogether the variable sought to be compared...." and that "it would have been irrational for the Service to proceed with [a Calsim II to Calsim II comparison" after discovering its flaws. *Id.* This may be the case, but it does not follow that what FWS did with the Calsim II to Dayflow comparisons was rational or based upon the best available

science.

FWS had actual notice of scientific concerns with comparing historical data to CalSim II simulated data. DWR Deputy Director Jerry Johns, on October 24, 2008, submitted comments to FWS on the draft effects analysis, generally cautioning against the comparison of modeled data with actual data:

> USFWS is using historic data for comparison to CalSim II simulations. Great caution should be taken when comparing actual data to modeled data. CalSim II modeling should be used in a comparative mode. In other words, it should be used to compare one set of model runs to another. For example, it would be appropriate to compare CalSim II modeling of one demand alternative to another to analyze the incremental effects.

AR 008671; *see also* AR 008668 (further explaining unreliability problems comparing historic and modeled data). Although neither Mr. Miller nor any interested party suggested that comparing Dayflow to Calsim II data was a scientifically invalid methodology prior to the issuance of the BiOp, the BiOp does not recognize the essential methodological defect, or explain how any of the conclusions it reached account for it. Nor does the BiOp explain how it is able to attribute the changes in X2 it found between the "historic" baseline and the CALSIM studies to the proposed action, and not to any of the other differences between the Dayflow and Calsim II models. Instead, FWS only rationalizes that it opted to use the "historic" baseline rather than CALSIM Study 7.0 as the baseline because, "the CALSIM monthly simulation model does not capture a precise Delta operation.... [Thus], the

inaccuracies in CALSIM lead us to use actual data to develop an empirical baseline." BiOp at 204 & 206. This statement may explain the reasons for FWS's decision, but it does not justify its ultimate conclusion.

This is of particular concern because DWR, a joint operator of the projects communicated its scientific and operational concerns based on known available science. DWR and Reclamation have legal obligations to allocate water supply reasonably and responsibly, not solely to save the species. As discussed in below at Part VII.B, FWS's focus on its responsibilities to the species appears to have caused it to ignore its own regulations' obligations to consider impacts to the overall water supply and additional uses. The potential impacts of inaccurate quantitative analyses in the BiOp cannot be understated.

Defendants argue FWS's decision to compare the two models to quantify the shift of X2 was a reasonable scientific decision, even though other experts may disagree. Doc. 660 at 17-19; Doc. 661-3 at 13-14. Federal Defendants cite *Lands Council*, 537 F.3d at 993, to justify FWS's modeling decisions as entitled to deference, because it is a matter "within its area of special expertise, at the frontiers of science."[29] As a general rule,

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[29] *Lands Council* also held that an agency is not required "to conduct any particular test or to use any particular method, so long as 'the evidence ... provided to support [its] conclusions, along with other materials in the record,' ensure that the agency 'made no clear error of judgment that would render its action arbitrary and capricious.'" *League of Wilderness Defenders-*

choices regarding modeling methods are exactly the sort of choices that, under the APA, are left to the expert agency in the exercise of its discretion. *NWF v. EPA*, 286 F.3d at 565. A court "may reject an agency's choice of a scientific model only when the model bears no rational relationship to the characteristics of the data to which it is applied." *Id*. at 565 (internal quotations and citations omitted). *Lands Council* instructs that a court is "not free to impose on the agency [its] own notion of which procedures are best.... Nor may [it] impose procedural requirements not explicitly enumerated in the pertinent statutes." 537 F.3d at 993 (internal citations and quotations omitted); *id*. at 1000 (finding agency did not act arbitrarily "in relying on its own data and discounting the alternative evidence offered" by plaintiffs because "[w]hen specialists express conflicting views, an agency must have discretion to rely on the reasonable opinions of its own qualified experts even if, as an original matter, a court might find contrary views more persuasive") (citations omitted).

In *NWF v. EPA*, the EPA evaluated several regulatory options for economic feasibility, applying a particular model to predict

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Blue Mountains Biodiversity Project v. U.S. Forest Serv., 549 F.3d 1211, 1218 (9th Cir.2008) (quoting *Lands Council*, 537 F.3d at 993). But *Lands Council* and *Blue Mountains Biodiversity Project* arose under the National Forest Management Act ("NMFA") and/or the National Environmental Policy Act ("NEPA"), neither of which include the additional requirement, found in the ESA, that the agency use the "best available science." Although *Lands Council's* general holding that a court must be deferential to an agency's choice of methodology in an area of its expertise, the agency is not free to ignore the best available science.

whether businesses were likely to go bankrupt under the weight of additional regulation. NWF criticized the model on several grounds, including that the model had "an error rate of at least 15%." *Id*. at 565. The D.C. Circuit examined and rejected each critique, reasoning that none called into question the model's reliability. *Id*.

Here, however, undisputed expert testimony offered by DWR, a co-operator of the Projects, calls into question the manner by which FWS utilized the two models to evaluate the impact of project operations on the position of X2. The Calsim II model was developed by DWR and Reclamation as a planning tool to simulate State Water Project and Central Valley Project operations. DWR, one of the agencies with special expertise in the use and application of Calsim II, *see* BiOp at 207; Miller Decl., Doc. 548-1, at ¶ 5-7, raised cautions and objects to the manner in which FWS used the model. Federal Defendants do not rebut the undisputed expert evidence that using such comparisons for quantitative purposes is scientifically improper. All experts in this case agree that data from two different models should not be compared without calibration. Doc. 633-1 at 13-17 (706 expert report); Miller Decl., Doc. 548-1, ¶¶ 22-55; Second Miller Decl., Doc. 597, ¶¶ 4-22. In other words, even though no superior set of models have been identified, the chosen models were indiscriminatly used without addressing an important factor,

the potential (and apparently real and significant) bias created when the results of two different computer models were used to perform quantitative comparisons. Unlike *NWF v. EPA,* where the agency applied a model that was deemed reliable, here, FWS has not addressed or explained the material bias created by its methodological choices. It cannot be determined whether FWS would have reached the same result had the bias been considered or addressed. FWS must do so on remand.

(2) Does the Use of Dayflow to Represent the Baseline in the Project Effects Analysis Improperly Attribute Past Effects to the Projects?

DWR asserts that FWS's use of an "historical baseline" was per se unlawful because the ESA's implementing regulations "require the Service to use current operations, not past operations, as the baseline for its effects analysis." Doc. 548 at 7-8. In support of this contention, DWR cites 50 C.F.R. § 402.02, which defines the "environmental baseline" to include:

> the past and present impacts of all Federal, State, or private actions and other human activities in the action area, the anticipated impacts of all proposed Federal projects in the action area that have already undergone formal or early section 7 consultation, and the impact of State or private actions which are contemporaneous with the consultation in process.

See also Consultation Handbook at 4-22 (baseline includes "effects of past and ongoing human and natural factors leading to the current status of the species") (emphasis added). In addition, DWR cites *NWF v. NMFS II*, 524 F.3d at 930, which held

that an agency action "only 'jeopardize[s]' a species if it causes some new jeopardy." (Emphasis added.) DWR argues that "[b]ecause [FWS's] baseline looks to decades past, it cannot be used as a basis for assessing any 'new jeopardy" posed by Project operations going forward." Doc. 548 at 8.[30]

DWR oversimplifies the issue. FWS's BiOp sought to determine whether ongoing and future coordinated operations of the CVP and SWP would cause jeopardy to the delta smelt or adversely affect its critical habitat. Arbitrarily setting the baseline at 2008, when the BiOp's analysis was finalized, would not have captured the impacts of then-ongoing project operations. The agency had discretion to use a historic baseline.

(3) Use of Comparisons Between CALSIM and DAYFLOW Model Outputs to Justify Imposition of Component 3 (Action 4), the Fall X2 Action.

In addition to utilizing comparisons of Calsim II and Dayflow data in the Project Effects section to demonstrate that Project Operations affect the location of X2, the BiOp relies on these comparisons to justify the imposition of RPA Component 3 (Action 4, or the "Fall X2 action"). The BiOp's "Justification" section discussing Action 4 references the Calsim II to Dayflow comparison:

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[30] Plaintiffs advance the related argument that FWS's use of a historic baseline caused FWS to mix the effects of the OCAP with the effects of all the other changing factors that occurred during the historical period of 1967 to 2007 represented by the Dayflow data. Doc. 551 at 24. However, the post-record expert testimony provided in support of this argument was stricken. Doc. 750 at 3, at ¶9.

> The Effects section clearly indicates there will be significant adverse impacts on X2, which is a surrogate indicator of habitat suitability and availability for delta smelt in all years (Figures E-19 and E-25 in Effects section).... The action is focused on wet and above normal years because these are the years in which project operations have most significantly adversely affected fall (Figure E-27 in Effects section) and therefore, actions in these years are more likely to benefit delta smelt.

BiOp at 373. Figures E-19 and E-25 compare historic X2 locations simulated by Dayflow to conditions under planned project operations simulated by Calsim II:

Figure E-19. X2 (km) during September to December based on historic data and CALSIM II model results. The center line in the box is the median and the outer box boundaries are the first and third quartiles.

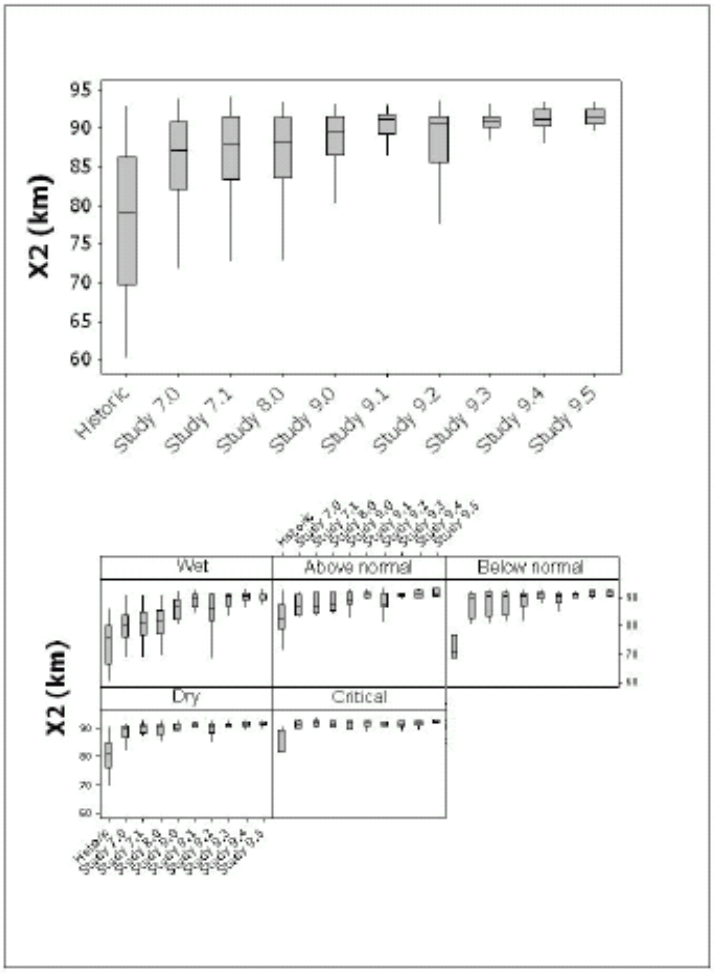
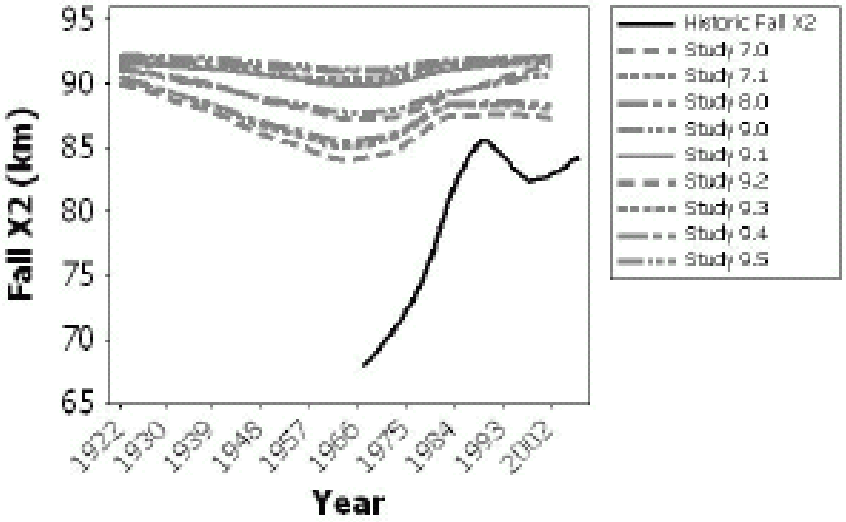


Figure E-25. Smoothed trend lines for the time series of historic and CALSIM II-modeled fall X2.



BiOp at 265, 271.

Undisputed expert testimony establishes the likelihood that the comparison of Dayflow to Calsim II data introduced significant error into the analysis that forms the basis for Figures E-19 and E-25. Mr. Miller concluded 40% of the difference between X2 as estimated by study 7.0 and the historical X2 baseline reported in the BiOp is error attributed entirely to the use of the KM equation to calculate the historical baseline X2 and the ANN equation to calculate the CalSim II study 7.0 results. Second Miller Decl., Doc. 597, at ¶ 15. It is unknown which portion of the remaining 60% of difference is attributable to the proposed action, and which portion is due to the other identified biases. *Id*. at ¶ 16. Dr. Punt gave a consistent opinion, estimating that the bias created by failing to calibrate the models "seems non-trivial" and

opining that it could be "as large as the differences seen in Figure E-19," the figure in the BiOp depicting the shift in X2 between the historic/Dayflow runs and the Calsim II runs. Doc. 633-1 at 16.

Federal Defendants do not respond directly to these assertions of bias. Instead, they point out that the historical X2 data was not the only basis for Action 4. Doc. 660 at 49. The BiOp describes multiple sources of information that were considered:

> This analysis of the effects [of the] proposed CVP and SWP operations on the delta smelt and its critical habitat uses a combination of available tools and data, including the CALSIM II model outputs provided in the appendices of Reclamation's 2008 Biological Assessment, historical hydrologic data provided in the DAYFLOW database, statistical summaries derived from 936 unique 90-day particle tracking simulations published by Kimmerer and Nobriga (2008), and statistical summaries and derivative analyses of hydrodynamic and fisheries data provided by Feyrer et al. (2007), Kimmerer (2008), and Grimaldo, et al. (accepted manuscript).

BiOp at 204; *see also* Feyrer Decl., Doc. 541, at ¶ 17. Additionally, "[t]he Service's examination of habitat suitability during fall is derived from published literature and unpublished information linking X2 to the amount of suitable abiotic habitat for delta smelt (Feyrer et al. 2007, 2008)." BiOp at 234. The BiOp expressly recognizes that the modeling does not precisely represent historic X2, as do the peer-reviewed studies on which the BiOp relies in part for this component. *See* BiOp at 204; AR 018278-018306 (Feyrer, *et al*. (2008)).

The justification for Action 4 relies heavily on the

quantitative analyses presented in Figures E-19 and E-25. *See* BiOp at 373. Whether Action 4, which has substantial adverse impacts on the water supply, is justified in the absence of the quantitative analysis cannot be determined. These questions are too serious to go unanswered and must be remanded to the agency for further explanation and/or correction.

(3) Other Challenges to the Fall X2 Action.

Plaintiffs raise additional challenges to the justification for the Fall X2 action, arguing "neither the BiOp nor the record demonstrate that Component 3 (Action 4) is necessary to avoid jeopardy to the delta smelt or destruction or adverse modification of its critical habitat, or that it will materially benefit the species or its habitat." Doc. 697 at 25.

a. Plaintiffs' Argument that Action 4 is an "Untested Hypothesis."

Plaintiffs maintain that Action 4 is nothing more than an "untested hypothesis," emphasizing that FWS acknowledges the need to assess the efficacy of Action 4 over time:

> The Service shall conduct a comprehensive review of the outcomes of the Action and the effectiveness of the adaptive management program ten years from the signing of the biological opinion, or sooner if circumstances warrant. This review shall entail an independent peer review of the Action. The purposes of the review shall be to evaluate the overall benefits of the Action and to evaluate the effectiveness of the adaptive management program. At the end of 10 years or sooner, this action, based on the peer review and Service determination as to its efficacy shall either be continued, modified or terminated.

BiOp at 283.

This does not render Action 3 a mere "hypothesis," nor does this "demonstrat[e] the absence of a rational connection between Action 4 and an increase in smelt abundance." Doc. 697 at 25. It is not inconsistent to find an action necessary, while also calling for an evaluation whether that action actually produced the expected outcomes. It is of no moment that in a research paper Mr. Feyrer referred to the X2 requirement as "the hypothesis that the combined effects of pre-adult abundance and the amount of suitable abiotic habitat (or X2) during autumn affect recruit abundance the following summer." AR 018285 (Feyrer unpub. 2008). He is a scientist gathering further information about the relationship between X2 and smelt population dynamics. The record does not suggest this is scientifically improper. It was not clearly erroneous for FWS to rely upon Feyrer's 2008 research paper.

b. FWS' Reliance on the Feyrer Papers.

FWS based its effects analysis of X2 in part[31] on two

[31] Plaintiffs argue that "FWS based its effects analysis of X2 entirely on two articles written by Feyrer, et al." Doc. 551 at 34 (emphasis added). Federal Defendants point to pages 152 to 179 of the BiOp to demonstrate that FWS considered a broad range of other materials in analyzing X2. However, these pages are not part of the BiOp's Effects Analysis nor the description and justification for Action 4. Rather, they describe FWS's view of the delta smelt's status and description of the environmental baseline. The portion of the BiOp that actually examines the purported relationship between X2 and smelt habitat states that FWS's "evaluation of habitat suitability considered three specific elements: X2, total areas of suitable abiotic habitat, and the predicted effect on delta smelt abundance the following summer." BiOp at 234-

articles written by Feyrer et al., which purported to show a correlation between X2 in the autumn and subsequent delta smelt abundance. *See* BiOp at 235-38 (citing Feyrer et al. (2007); Feyrer et al. (2008)). Plaintiffs argue that these articles did not represent the best available science because "the correlation they claimed to find was driven by the presence of a single unrepresentative data point." Doc. 551 at 34. Even assuming the scientific validity of the 2007 and 2008 Feyrer analysis, Plaintiffs contend the BiOp's X2 conclusions far exceed what the articles scientifically support. *Id.*

Plaintiffs' letter, responding to a draft of the BiOp, identified a purported flaw in the Feyrer et al. (2008) analysis: the supposed correlation between Fall X2 and delta smelt abundance Feyrer et al. was driven by the presence of a single, apparently outlier, data point. Removing that data point resulted in a finding of no statistically significant

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35. The description of the first of these three elements refers to the "CALSIM II modeled results" and "Feyrer 2007, 2008." BiOp at 235. Similarly, the second step of the evaluation, modeling the location of X2 purportedly to determine the "total surface area of suitable abiotic habitat," also relied on "modeled X2" and the Feyrer 2008 paper. BiOp at 235. Finally, in the third step of the evaluation, FWS allegedly used the modeled X2 data to estimate the effect of Project operations on delta smelt abundance. BiOp at 236. This third step cited extensively to the Feyrer (2007) article and a Feyrer 2008 paper, along with a citation to Bennett (2005). Facially, the X2 analysis relied on the modeled X2 data, Feyrer's work, and Bennett's 2005 paper.

Plaintiffs suggest that the modeled X2 data did not constitute a separate justification for Action 4 because the reason FWS gave in the BiOp for presenting the Calsim II model results in a monthly time step was "to be consistent with previous analyses (Feyrer 2007, 2008)." BiOp at 235. But, this does not mean that the Calsim II data was somehow dependent upon Feyrer's work. Rather, that data was presented in such a way to be consistent with the way Feyrer analyzed data. In the final analysis, Action 4 did rely extensively, but not exclusively, on Feyrer's articles.

relationship between Fall X2 and the abundance of delta smelt. *See* SLDMWA & SWC Letter to NMFS and FWS (Oct. 20, 2008) at 2 (AR 006407). As the letter noted, "a correlation solely reliant upon a single data point cannot reasonably be considered as an actual indicator of cause." *Id*. Plaintiffs' argument continues:

> That there was no statistically significant relationship between X2 and delta smelt abundance during the 1987-2007 period should not have been surprising given that Feyrer et al. found no statistically significant relationship between the two factors for the 1968-1986 period or for the entire 1968-2007 period. Feyrer et al. (2008) at 14 (AR 018291). Nor was it surprising considering that—as the Feyrer et al. (2008) article conceded—the existing best available science on delta smelt showed no direct correlation between the location of Fall X2 and delta smelt abundance. Feyrer et al. (2008) at 8 ("[P]revious analyses have not shown simple relationships between X2 and delta smelt abundance.") (AR 018285).

Doc. 551 at 35.

Federal Defendants respond:

> [U]nless data points are excluded to control for a specific variable, or for some other explicit reason that is central to measuring the relationship at issue, there is no scientific reason to remove a data point from an analysis just because it changes the result. In any event, removing the data point challenged by Plaintiffs does not appreciably change the result – the result goes from a 95% probability the relationship is not due to chance to a 92% probability that the relationship is not due to chance. Moreover, this is an argument that can go both ways. Removing other individual data points would increase the statistical significance.

Doc. 660 at 44. Federal Defendants are correct that removing a data point simply because it changes the result would be arbitrary. Plaintiffs do not point to any scientific basis, let

alone an undisputed one, for excluding the so-called "outlier" point, other than that it is an outlier. Plaintiffs do not show the point is erroneous or identify competing studies that reach different opinions from Feyrer that FWS failed to consider. This is a scientific dispute among experts over which the agency is owed deference.

c. Do the Studies Cited in the BiOp Support FWS's Conclusion that Fall X2 Determines the Extent of Suitable Smelt Habitat?

The BiOp concludes that to avoid jeopardy the RPA Actions must "[i]mprove fall habitat for delta smelt by managing [] X2 through increasing Delta outflow during fall when the preceding water year was wetter than normal." BiOp at 369; *see also* BiOp at 374 ("Outflow during fall determines the location of X2, which determines the amount of suitable abiotic habitat available to delta smelt (Feyrer et al. 2007, 2008)."). Plaintiffs argue that none of the articles FWS cited in the BiOp actually support FWS's conclusion that the location of X2 determines the amount of suitable habitat for the delta smelt. *See* Doc. 551 at 39-41.

(1) Feyrer (2007).

Plaintiffs first criticize the BiOp's reliance on a 2007 Canadian Journal of Fisheries and Aquatic Sciences paper by Feyrer, Nobriga, and Sommer, three scientists then working for Plaintiff DWR, entitled, "Multidecadal trends for three declining fish species: habitat patterns and mechanisms in the San

Francisco Estuary, California, USA." AR 018266-77. That paper used a generalized additive model to assess the relationship between changes in environmental quality for delta smelt (particularly salinity and turbidity) and the abundance of delta smelt. *Id*.

The paper demonstrated that a statistically significant relationship existed between salinity and turbidity in the fall months and the abundance of juvenile delta smelt the following summer for the period of 1987-2004. *Id*. This time period was chosen because it corresponded to the invasion of the *Corbula amurensis* clam which has resulted in significant ecological changes to the Delta. AR 018270. The results demonstrated that 63 percent of sampling stations showed statistically significant declines in environmental quality in the fall, with the western and southeastern regions of the Delta suffering the most substantial long term declines in habitat quality, while the area at the confluence of the Sacramento and San Joaquin Rivers least affected by the changes in fall habitat quality. *Id*.

The Feyrer (2007) analysis uses the results of a 2005 study by William Bennett published in the Journal of San Francisco Estuary and Watershed Science, which concluded: "Factors defining the carrying capacity for juvenile delta smelt are unknown, but may include a shrinking volume of physically suitable habitat combined with a high density of competing planktivorous fishes

during late summer and fall." AR 017004.

The BA acknowledged the results of this 2007 study, including the conclusion that fall habitat conditions have population level effects:

> Based on a 36-year record of concurrent midwater trawl and water quality sampling, there has been a long-term decline in fall habitat environmental quality for delta smelt (Feyrer et al. 2007). The long-term environmental quality declines for delta smelt are defined by a lowered probability of occurrence in samples based on changes in specific conductance arid Secchi depth. Notably, delta smelt environmental quality declined recently coinciding with the POD (Figure 7-8). The greatest changes in environmental quality occurred in Suisun Bay and the San Joaquin River upstream of Three Mile Slough and southern Delta (Figure 7-9). There is evidence that these habitat changes have had population-level consequences for delta smelt. The inclusion of specific conductance and Secchi depth in the delta smelt stock-recruit relationship described above improved the fit of the model, suggesting adult numbers and their habitat conditions exert important influences on recruitment.

AR 010626; *see also* AR 10628-29 (reproducing maps and graphics showing habitat declines and geographic distribution of declines from Feyrer (2007)).

The conclusions in Feyrer (2007) were also recognized in the January 2008 report on the Pelagic Organism Decline by the Interagency Ecological Program, which reached nearly identical conclusions about the effects of declining fall habitat quality on delta smelt abundance. *See* AR 016938, 016954, 016957.

Plaintiffs level several criticisms at Feyrer (2007) and the BiOp's use of the study. First, Plaintiffs complain that the Feyrer study "repeatedly states that the article supports only the 'hypothesis' that EQ (a metric devised by Feyrer that

incorporates two factors – secchi depth and temperature – in addition to salinity) is 'an important predictor of delta smelt abundance during the 1987-2004 post-*Corbula* period.'" Doc. 697 at 29 (citing AR 018271). The use of the term "hypothesis" does not undermine Feyrer's conclusions, as articulating a hypothesis is a step in the scientific method.

Plaintiffs next point out that while Feyrer (2007) found a statistically significant relationship between the location of X2 and delta smelt abundance from 1987-2004, there was no statistically significant correlation for the twenty years prior to *Corbula's* arrival (1968-1986). AR 018271. The article acknowledged "[b]iotic variables, most notably competition, predation, and food availability, could have also played a major role in controlling the distribution" of delta smelt and "[t]he recent step change in the abundance of pelagic fish suggests that salinity alone may not be sufficient to explain long-term trends in estuarine management." AR 018275. The article confirms that even when considering specific conductance (i.e., X2), secchi depth, and temperature together, those three factors collectively only predict 25.7% of future delta smelt occurrence. AR 018271. Finally, the article concludes that "the degree to which EQ could be used for management purposes remains unclear." AR 018275.

Tucson Herpetological Society, 566 F.3d 870, held that an agency may not rely on "underdeveloped and unclear" studies to

support ESA findings. There, an earlier FWS finding concluded that population dynamics information for the flat-tailed horned lizard was "limited and inconclusive." *Id*. at 878. Nevertheless, FWS relied on these uncertain studies to infer that the lizard population remained viable throughout most of its range. *Id*. The Ninth Circuit found that FWS's "affirmative[] reli[ance] on ambiguous studies as evidence of persistence..." to be unreasonable because "the studies do not lead to the conclusion that the lizard persists in a substantial portion of its range and therefore cannot support the Secretary's conclusion." *Id.* at 879.

FWS's reliance on Feyrer (2007) is distinguishable. Although Feyrer (2007) acknowledges that multiple factors may be contributing to the delta smelt's decline, the study affirmatively finds a statistically significant, albeit limited, correlation between the fall location of X2 and subsequent delta smelt abundance. This finding is not uncertain. It acknowledges the context of a complex ecosystem in which many factors may impact the species. Feyrer's X2 analysis explains only 25.7 percent of subsequent year abundance. This is not a *de minimis* impact. (It goes, rather, to the agency's overemphasis on X2 to impose a significantly restrictive fall RPA component.) Plaintiffs cite no studies that demonstrate the cause of the remaining 74.3 percent variation in abundance. FWS's reliance on

Feyrer (2007) was not *per se* unreasonable, however, FWS's use of the study to justify operational restrictions is more questionable.

(2) The Feyrer (2008) Paper.

A 2008 paper by the same authors (Feyrer, Nobriga, Sommer), along with Ken Newman of FWS, appeared in the Estuaries and Coasts journal. *See* AR 018278-306. This expanded upon the 2007 research, used statistical analyses, including both Ricker and Beverton-Holt type models, to compare Fall X2, habitat area for and subsequent abundance of delta smelt. *Id*. Like Feyrer (2007), it concluded that fall habitat quality had a statistically significant effect on subsequent delta smelt abundance, determining that the model incorporating prior abundance and X2 accounted for 66 percent of the variability in subsequent abundance. *Id*. The authors identified a number of reasons why the location and extent of fall habitat affected subsequent abundance:

> First, positioning X2 seaward during autumn provides a larger habitat area which presumably lessens the likelihood of density-dependent effects (e.g., food availability) on the delta smelt population. For example, food availability during autumn for adult haddock (*Melanogrammus aeglefinus*) likely improves juvenile recruitment the following year (Friedland et al. 2008). Second, a more confined distribution may increase the probability of stochastic events that increase mortality rates of adults. For delta smelt, this includes both predation, as well as anthropogenic effects such as contaminants or water diversion loss (Sommer et al. 2007).

AR 018293. The study concluded: "Comparing the first ten years

of the time series to the last ten years, the amount of suitable abiotic habitat for delta smelt during autumn has decreased anywhere from 28% to 78%, based upon the least and most restrictive habitat definitions, respectively." AR 018293-94.

Like Feyrer (2007), Feyrer (2008) narrowly considered abiotic factors alone, and limited its focus on X2. Feyrer (2008) concludes that manipulating X2 might affect delta smelt populations, but that "the specific mechanisms by which X2 affects delta smelt remain poorly understood." AR 018294. Because of this uncertainty, Feyrer (2008) recommended that any "'real world' applications of [its] results should incorporate an adaptive management approach, allowing resource manager[s] to adjust actions in response to new data collected on delta smelt habitat conditions and use." *Id*.

Other than arguing that Feyrer (2008), like Feyrer (2007), used the "outlier" data point, Plaintiffs submitted no other substantive criticism of Feyrer (2008). FWS made no error in considering Feyrer (2008).

(3) <u>The Bennett (2005) Article.</u>

Plaintiffs criticize the BiOp's citation of Bennett (2005), because, like the Feyrer studies, this article does not conclude that salinity or the location of X2 is a <u>determinative</u> factor in delta smelt abundance. Bennett (2005) specifically addresses: "[w]hat is the impact of human activities, particularly water

export operations, on population abundance?" AR 017061. Bennett (2005) surveyed available data and concluded: "[t]his synthesis of the available information cannot answer th[is] vital management question." AR 017062. "The lack of appropriate data ... impedes efforts to resolve th[is] issue ...." AR 017004.

The BiOp does not rely on Bennett (2005) as the "be all end all" to address the management question. The BiOp cites Bennett (2005) for a series of factual assertions, including the premise that: "There is a statistically significant stock-recruit relationship for delta smelt in which pre-adult abundance measured by the FMWT positively affects the abundance of juveniles the following year in the TNS." BiOp at 178. Plaintiffs do not disagree that Bennett supports this assertion. *See* AR 017035 (reviewing various studies finding a relationship between X2 position and smelt abundance). Plaintiffs have not demonstrated that the BiOp misrepresented Feyrer (2007), Feyrer (2008), or Bennett (2005), or that any of these studies are not part of the best available science.

d. Does the Best Available Science Support the Assumption that X2 Is a Surrogate for Smelt Habitat?

Plaintiffs object that FWS' use of X2 as a "surrogate" indicator for delta smelt habitat suitability is not supported by the best available science, arguing: "FWS stretched the limited findings of Feyrer et al. (2007 & 2008) far beyond defensible

application, converting a tentative finding that the location of X2 might influence habitat suitability into a definite conclusion that X2 alone determines the area and extent of delta smelt habitat for delta smelt." Doc. 551 at 38.

Feyrer (2007) discussed its limitations: "[T]he degree to which EQ [Feyrer's three-part index of environmental quality, which included salinity] could be used for management purposes is unclear.... salinity alone may not be sufficient to explain long-term trends in estuarine management." AR 018275. Feyrer (2008) concluded, "[o]ur results suggest that managing estuarine flow or X2 during autumn can have positive effects on delta smelt habitat and abundance." AR 018292. The FWS BiOp relied on these two studies to conclude: "Outflow during fall determines the location of X2, which determines the amount of suitable abiotic habitat available to delta smelt (Feyrer et al. 2007, 2008)." BiOp at 374. This is one scientific interpretation of X2's role. It may be a "stretch" or unjustified expansion of Feyrer (2007) or Feyrer (2008), however, when all the disputed X2 studies are considered, X2 has a measurable effect on smelt abiotic habitat.[32]

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[32] The BiOp asserts that Component 3 will improve smelt habitat "quality and quantity" in the fall. BiOp at 282. Plaintiffs point out that FWS has explicitly recognized that delta smelt habitat must be defined to encompass, in addition to space and salinity, food, water, air, light, minerals, or other nutritional or physiological requirements; cover or shelter; sites for breeding; habitats that are protected from disturbance or are representative of the historic geographical and ecological distributions of a species, including physical habitat, water, and river flow. 59 Fed. Reg. 65,256, 65,259 (Dec. 19, 2004). Plaintiffs complain that "X2 is a metric that describes only a two-dimensional space consisting of a particular salinity at

a. Are Delta Smelt Habitat Limited?

Plaintiffs assert that FWS ignored available evidence SLDMWA and SWC presented to FWS indicating that delta smelt are particularly unlikely to be habitat-limited, given their record low abundance. SLDMWA-SWC Letter at 5-6, AR 006410-006411.

It is unquestioned that delta smelt survey results show decreasing abundance throughout the 2000s, with their current abundance at a historic low. BiOp at 154. In addition, the BiOp notes that "most life stages of the delta smelt are now distributed across a smaller area than historically," and recognizes that this is likely due to multiple factors, including channelization, conversion of Delta islands to agriculture, water project operations, salinity, turbidity, high summer water temperatures, and predacious species. BiOp at 152-53, 157. Plaintiffs argue that "simply because the delta smelt may currently occupy lesser spatial area than they did previously, does not mean that forcing a relocation or expansion of X2 will impact the species beneficially or at all." Doc. 697 at 33. Most of Plaintiffs' evidence submitted to support this argument

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a specific depth in the Delta's channels; it is not coterminous with the dynamic three-dimensional space that supports the abiotic and biotic components that define delta smelt habitat." Doc. 697 at 35. In support of this assertion, Plaintiffs refer to many statements in the studies cited in the BiOp, indicating that X2 does not explain all variability in delta smelt abundance and/or distribution. *Id*. Those very same studies and the BiOp acknowledge that, while X2 does not explain everything, it explains enough to consider X2 a proxy for critical habitat and to structure management prescriptions around X2. That X2 is an imperfect proxy is relevant to the degree of uncertainty and justification FWS provides for the specific RPA prescriptions imposed.

has been stricken. *See* Doc. 750 at ¶ 8 (striking paragraphs 14-17 of the Declaration of Charles H. Hanson, Doc. 395). Plaintiffs insist that the BiOp itself admits that the delta smelt is not currently habitat-limited, citing pages 237 and 374. Page 237 makes such an admission, but it is qualified:

> Combined, these effects of project operations on X2 will have significant adverse direct and indirect effects on delta smelt. Directly, these changes will substantially decrease the amount of suitable abiotic habitat for delta smelt, which in turn has the possibility of affecting delta smelt abundance through the depensatory density-dependant mechanisms outlined above. Because current abundance estimates are at such historic low levels, depensatory density-dependence can be a serious threat to delta smelt despite the fact that the population may not be perceived to be habitat limited. It is clear from published research that delta smelt has become increasingly habitat limited over time and that this has contributed to the population declining to record-low abundance levels (Bennett 2005; Baxter et al. 2008; Feyrer et al. 2007, 2008; Nobriga et al. 2008). Therefore, the continued loss and constriction of habitat proposed under future project operations significantly threatens the ability of a self-sustaining delta smelt population to recover and persist in the Estuary at abundance levels higher than the current record-lows.

(Emphasis added). Pages 374-75 state:

> The persistence of this significant hydrologic change to the estuary threatens the recovery and persistence of delta smelt. Outflow during fall determines the location of X2, which determines the amount of suitable abiotic habitat available to delta smelt (Feyrer et al. 2007, 2008). The long-term upstream shift in X2 during fall has caused a long-term decrease in habitat area availability for delta smelt (Feyrer et al. 2007, 2008), and the condition will persist and possibly worsen in the future. This alone is a significant adverse effect on delta smelt.
>
> However, the problem is further complicated because

> there are several lines of published peer reviewed scientific research that link habitat alteration to the decline of delta smelt (Bennett 2005; Feyrer et al. 2007; Nobriga et al. 2008). An important point regarding this action is that because of the current, extremely low abundance of delta smelt, it is unlikely that habitat space is currently a limiting factor. However, it is clear that delta smelt have become increasingly habitat limited over time and that this has contributed to the population attaining record-low abundance levels (Bennett 2005; Baxter et al. 2008; Feyrer et al. 2007, 2008; Nobriga et al. 2008). Further, as detailed in the Effects section, persistent degraded or worsened habitat conditions are likely to contribute to depensatory density-dependent effects on the delta smelt population while it is at historical low levels, and would at some point in the proposed term of this project, limit delta smelt recovery.

While "admitting" that the delta smelt may not be habitat-limited, the smelt has become "increasingly habitat-limited over time," contributing to the population's decline, and that worsening habitat conditions may limit smelt recovery. Plaintiffs have not presented any record best available scientific evidence not considered by FWS that contradicts this conclusion.

b. FWS' Use of a Linear Model Instead of a Multiplicative Stock-Recruit Model .

Plaintiffs next argue that FWS committed a serious scientific error by employing a linear additive model to determine the effect of Fall X2 on delta smelt abundance. *See* BiOp at 268, Figure E-22. Dr. Deriso opines that FWS' use of the linear additive model ran counter to decades of established scientific consensus that linear models are not effective for

modeling fish populations. Deriso Decl., Doc. 396, at ¶ 80. He claims that standard practice in fisheries management is to use a multiplicative stock-recruit model, such as the Beverton-Holt or Ricker models, both of which are among the standard tools of the relevant science. *Id*. at ¶ 83; *see also* Hilborn, Decl., Doc. 393, at ¶ 31.

The BiOp estimated the effect of X2 on delta smelt abundance by using an updated version of the linear-additive model developed in Feyrer (2008). BiOp at 236. The result was Fig. E-22, which shows a linear relationship between X2 and delta smelt abundance such that juvenile abundance (which is measured using the Spring Tow-Net Survey) is equal to the sum of a constant number, plus the previous year's Fall Midwater Trawl Survey (times a constant number), minus X2 (times a constant number). BiOp at 268. Put simply, FWS' calculation found that A = B + C – D. Deriso Decl., Doc. 396, at ¶ 78.

Dr. Deriso explains the two fundamental problems with using an additive model. First, a linear additive model can produce the biologically implausible result that the total absence of adults in one year (i.e., no mature smelt to mate and lay eggs) could still result in the model indicating the presence of newborn smelt the next year. *Id*. at ¶ 80. As Dr. Deriso explains, this nonsensical result is the product of basic mathematical structure: if A (number of juveniles) = B

(constant) + C (adults) – D (Fall X2), then A can be positive even if C is zero, as long as B is larger than D. *See id*.

The second fundamental problem with a linear additive model is that it treats X2 as a purely "additive factor," meaning that an increase of X2 by one unit will always reduce the delta smelt population by a certain number, no matter how large or small the total population may be. *Id*. at ¶ 81. Dr. Deriso's critique implies that if changes in X2 are harmful to delta smelt, it is logical to expect that a change in X2 would affect a considerably higher absolute number of delta smelt in a population of 1,000,000 than in a population of 1,000. *See id*.

Use of a multiplicative stock-recruit model solves both of these deficiencies. *Id*. at ¶¶ 84-85. Multiplicative models are the textbook standard for modeling fish and other populations. *See* Deriso Decl., Doc. 396, at ¶ 43 n.3 (citing a representative sample of studies making use of multiplicative stock-recruit models); *see also, e.g.*, Bennett (2005) at 28-29 (using a multiplicative stock-recruit model for smelt abundance), AR 017031-017032; *see also* Hilborn Decl., Doc. 393, at ¶¶ 30-31. Multiplicative stock-recruit models are preferred because they can better reflect the biological realities and idiosyncrasies of the fish species of concern. *See* Deriso Decl., Doc. 396, at ¶ 83. This is because survival processes are inherently multiplicative: the fraction of individuals that survive to a

given age will naturally be the product of all of the previous daily survival rates since birth. *Id*. Dr. Hilborn opined that the linear additive "approach is totally inconsistent with accepted practice in population dynamics." Hilborn Decl., Doc. 393, at ¶ 30.

Plaintiffs point to several record documents critical of FWS's modeling approach. For example, several Plaintiffs sent comment letters recommending the use of a logarithmic model. *See* AR 006406. In addition, the Peer Review Panel expressed general concerns with the linear model, stating "the model may be inappropriate for the data being used." AR 008819.

FWS noted in the BiOp that although the regression model works for 56 percent of the data points, the residuals are "not normally distributed." BiOp at 236. FWS continued, "[t]he pattern of the residuals suggests that some type of transformation of the data would help to define a better fitting model (Figure E-22). This analysis did not explore different data transformations." *Id*. Plaintiffs maintain that "exploring" different data transformations would not require FWS to conduct independent studies or to develop any new types of mathematical models, but rather would only require plugging existing data into the standard model used by fisheries biologists throughout the world. *See* Deriso Decl. ¶ 89.

Federal Defendants respond that this critique is much ado

about nothing because, even though linear additive models can produce "biologically infeasible results" in some situations, the data set employed in the BiOp could not have created such a problem. *See* Newman Decl., Doc. 484, at ¶ 19 (explaining that "for the given range of FMWT index and X2 values, the model-fitted values remained positive" using the linear model). Dr. Newman opined that "linear models are often used as approximations to more realistic nonlinear models, and often over the range of covariate values of interest the nonlinear model may in fact be relatively linear." *Id*.

A court "may reject an agency's choice of a scientific model 'only when the model bears no rational relationship to the characteristics of the data to which it is applied." *NWF v. EPA*, 286 F.3d at 565; *see Nat'l Ass'n of Metal Finishers v. EPA*, 719 F.2d 624, 657 (3rd Cir. 1983) ("the choice of scientific data and statistical methodology to be used is best left to the sound discretion of the [agency]") *rev'd* on other grounds *sub nom.*, *Chem. Mfrs. Ass'n v. NRDC*, 470 U.S. 116 (1985).

Here, Plaintiffs critique raises a scientific dispute among experts. Dr. Newman's declaration provides evidence that the linear model used in the BiOp is not totally inappropriate. *See* Newman Decl., Doc. 484, at ¶ 19. It requires refinement, which FWS said it did. Newman's declaration also points out that the re-analysis by Dr. Deriso, using Deriso's model of choice, yields

a result that also exceeds the 0.05 threshold of statistical significance. *Id*.

Feyrer's 2007 analysis was published in a peer-reviewed scientific journal. Although the BiOp's Effect's Analysis Peer Review questioned the model, the reviewers did not recommend that the analysis or action be excluded; instead, that panel broadly supported implementation of the Fall X2 action, based in part on the analysis using the linear model, provided that the BiOp impose requirements for continued refinement of the analysis and implementation of the action by adaptive management. It is a close call. Absent agency bad faith, Plaintiffs have not established that this modeling dispute proves FWS violated the best available science standard.

c. DWR's Challenge to the BiOp's Choice of X2 Location.

RPA Component 3 (Action 4) requires the Projects to be operated to maintain X2 during the fall months at a location no greater than 74 km upstream from the Golden Gate Bridge following wet water years, and no greater than 81 km upstream following above normal water years. BiOp at 282-283. The rationale for this Component rests in large part on the Calsim II Dayflow comparison articulated in the Effects Analysis and discussed above. *See* BiOp 373-375, (explaining that the Effects section "clearly indicates there will be significant adverse impacts on X2"). As already determined, in the absence of calibration of

the two models, the Calsim II to Dayflow comparison has the potential to introduce significant, if not overwhelming, bias to the analysis that the BiOp nowhere discussed or corrected. The X2 action must be remanded to the agency for further consideration.

DWR also argues the X2 action is unlawful for a different reason, arguing that "[a]lthough the BiOp explains why Action 4 is to be implemented only in certain water year types, *see* BiOp 373-75, it fails completely to explain or justify the requirement that X2 be held at the locations specified." Doc. 548 at 9. Federal Defendants have not identified any record evidence that provides such an explanation. This total lack of explanation violates the APA's requirement that FWS "examine the relevant data and articulate a satisfactory explanation for its action including a rational connection between the facts found and the choice made." *Motor Vehicle Mfrs. Ass'n v. State Farm Mutual Auto. Ins. Co.*, 463 U.S. 29, 43 (1983). This failure also violates FWS's own Consultation Handbook implementing the ESA, which requires: "When a reasonable and prudent alternative consists of multiple activities, it is imperative that the opinion contain a thorough explanation of how each component of the alternative is essential to avoid jeopardy and/or adverse modification." ESA Handbook at 4-43. The BiOp violates this requirement because it fails to explain why it is essential to

maintain X2 at 74 km and 81 km, respectively, as opposed to any other specific location.

(4) Challenges to Turbidity Trigger.

In their opening brief, Plaintiffs argue that one of the underlying tenants of Component 1 -- the link between turbidity and smelt presence -- has been "revealed as wholly arbitrary and capricious." Doc. 551 at 29. Action 1 of RPA Component 1 is triggered when "first flush conditions" occur, which are demonstrated by elevated river inflow and turbidity. BiOp at 280-81. The BiOp claims turbidity is an appropriate "on-ramp" indicator for Action 1, because delta smelt presence and densities are correlated with turbid water, i.e., more delta smelt are found in turbid water than in clearer water, and so as turbid waters move towards CVP/SWP pumps, delta smelt must as well, which warrants severe pumping restrictions. *See* BiOp at 150-51, 280-81, 329-30.

Plaintiffs argue that after issuing the disputed BiOp and the RPA, FWS "recanted its confidence in the usefulness of turbidity as such an indicator" in a December 2009 "Interim Federal Action Plan for the California Bay-Delta" ("Federal Action Plan") to which FWS was a signatory. Doc. 551 at 29. That Federal Action Plan, which was attached to the Declaration

of Ronald Milligan[33] in Support of Federal Defendants' Opposition to Plaintiffs' Motion for Interim Remedy/Preliminary Injunction ("Milligan Decl."), Doc. 471, ¶ 11 & Exh. 3 at 10, contains the following discussion of a "2-Gates Fish Protection Demonstration Project":

> [The P]roject was proposed as a scientific experiment to test the hypotheses that delta smelt follow turbidity and that smelt entrainment at the pumps could be prevented by keeping turbid water away from the pumps.... Once in place, the gates would be operated to reduce turbidity near the State and Federal pumps, and an evaluation could then be made of whether turbidity is, in fact, an accurate predictor of the presence of smelt.

Id. (emphasis added). Plaintiffs complain that "FWS cannot simultaneously view turbidity as only a hypothetical indicator of delta smelt presence, and also as a scientifically defensible basis to develop an RPA with significant water costs. The two positions are fundamentally contradictory, resulting in an arbitrary RPA." Doc. 551 at 30.

Plaintiffs are mistaken. First, the turbidity indicator is not an automatic trigger for RPA Component 1:

> In order to prevent or minimize such entrainment, Action 1 shall be initiated on or after December 20 if the 3 day average turbidity at Prisoner's Point, Holland Cut, and Victoria Canal exceeds 12 NTU, or if there are three days of delta smelt salvage at either facility or if the cumulative daily salvage count is above the risk threshold based upon the 'daily salvage index' approach described in Attachment B.... <u>However, the SWG can recommend a delayed start or interruption</u>

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[33] Mr. Milligan is the Manager of Reclamation's Central Valley Operations Office, with responsibility for the day to day operations of the CVP. Milligan Decl., Doc. 471, at ¶ 1.

> based on conditions such as delta inflow that may affect vulnerability to entrainment.

BiOp at 281 (emphasis added).

FWS's reliance on turbidity as a potential indicator of smelt presence or movement was justified. The BiOp explains these physical conditions provide foraging, reproductive, and other behavioral and biological benefits to delta smelt. Turbid waters make it more difficult for delta smelt to be preyed upon, BiOp at 150-51, and also make it easier for delta smelt to forage for their prey, *id.* (citing 2004 study by Baskerville-Bridges). The preference of delta smelt for turbid waters has been verified in laboratory conditions with captive delta smelt, BiOp at 150 (citing a 2008 review by Nobriga and Herbold), and also in the field, where studies have observed "a negative correlation between the frequency of delta smelt occurrence in survey trawls during summer, fall and early winter and water clarity," *id.* (citing 2007 study by Feyrer and 2008 study by Nobriga). Increased turbidity is a documented indicator of improved habitat quality for delta smelt. Plaintiffs have provided any available science on the subject that was not considered. It was reasonable for the FWS to rely upon turbidity in RPA Component 1 as a potential predictor of delta smelt movement and adult delta smelt distribution.

The Federal Action Plan does not undermine this conclusion. As a threshold matter, the Plan is an extra-record document.

Even if it were part of the record, it does nothing to call the FWS's reliance on turbidity into question. The quote from the Plan relied upon by Plaintiffs describes the "2 Gates Fish Protection Demonstration Project," a forthcoming project designed to examine whether turbidity can be physically manipulated through barge-mounted gate structures, in an effort to keep delta smelt away from the influence of the pumps so that export pumping can be increased for the benefit of Plaintiffs and other agricultural concerns. Federal Action Plan at 10. The Action Plan will result in FWS and Reclamation continuing to study turbidity. *See* Federal Action Plan at 10-11 (announcing the publicly funded installation of an additional "14 real-time turbidity sensors in the Delta"). That further study is called for does not undermine the record evidence supporting the use of turbidity as an indicator.

Plaintiffs do not address the turbidity trigger in their reply brief. Federal Defendants reliance on turbidity as one of several triggers for Action 1 was not arbitrary and capricious.

(5) <u>Challenges to the Incidental Take Limit/Selective Use of Data.</u>

Plaintiffs maintain Federal Defendants' failed to use the best available scientific data by selectively excluding data from certain parts of the BiOp, while including that data in other sections for different purposes. In particular, Plaintiffs

maintain that such selective use of data tainted: (1) the analysis of the effects of OMR flows on delta smelt; and (2) the formulation of the incidental take statement.[34]

a. FWS's Exclusion of Certain Data Points When Analyzing Entrainment.

On the impact of negative OMR flows on entrainment, the BiOp relies on a plot of the total number of salvaged adult delta smelt against OMR flows for the period from 1984 to 2007, BiOp at 164 (Figure S-8), and uses this plot to support the conclusion that entrainment of adult delta smelt rises with increasingly negative OMR flows, *see* BiOp at 164-65, 348-49. It is also undisputed that FWS eliminated certain data from that plot, excluding data from the years 1987, 1989, 1990, 1991, 1992 and 2007 because "low turbidity conditions" existed in Clifton Court Forebay. BiOp at 164.

This is explained in the graph itself. *Id*. (1987, 1989-92, 1994, and 2007 were excluded because those years exhibited low (<12ntu) average water turbidity during Jan-Feb at Clifton Court Forebay). The BiOp explains that turbidity is a potential indicator of smelt presence or movement. BiOp at 151. The BiOp presents defensible grounds for excluding these data points;

[34] The opening paragraph of the section of Plaintiffs' motion for summary judgment addressing the selective use of data also asserts that this practice tainted the BiOp's justification for monthly flow requirements under RPA Action 4 and examination of the effects to the species of exports of Article 21 water by the SWP. Doc. 551 at 25. However, these two additional arguments were not discussed or supported in the text of Plaintiffs motion. They will not be addressed.

Plaintiffs do not provide any evidence suggesting these exclusions were scientifically improper. There is no independent legal reason why FWS should be precluded from excluding certain data points if scientifically justified.

Under its mandate to utilize the best available science, FWS "cannot ignore available, relevant biological information." *Conner v. Burford*, 848 F.2d 1441, 1454 (9th Cir. 1988); *Kandra v. United States*, 145 F. Supp. 2d 1192, 1208 (D. Or. 2001). Plaintiffs cite *Sierra Club v. EPA*, 346 F.3d 955, 961 (9th Cir. 2003), for the proposition: "[t]he inclusion of data for one purpose and the exclusion of the same data for another, intimately related, purpose is impermissible" and "violates the best available science standard." Doc. 551 at 27. *Sierra Club* does not stand for such a proposition. The *Sierra Club* plaintiffs challenged EPA's conclusion under the Clean Air Act that exceedences of air pollution standards on two particular days in Imperial County, California were caused by transborder emissions from Mexico. 346 F.3d at 959-60. The Ninth Circuit recognized that "where, as here, a court reviews an agency action 'involv[ing] primarily issues of fact,' and where 'analysis of the relevant documents requires a high level of technical expertise,' we must 'defer to the informed discretion of the responsible federal agencies.'" *Id*. at 961 (quoting *Marsh,* 490 U.S. at 377). Such deference was not owed where the agency

decision "is without substantial basis in fact." *Id*. EPA's decision was vacated after plaintiffs presented uncontested evidence, based on wind data, that the pollution at issue was not caused by transborder emissions. *Id*. at 961-62. Nowhere did the Ninth Circuit discuss or find that EPA included data for one purpose while excluding it for some other related purpose, nor did it evaluate or even mention the ESA's best available science standard. Plaintiffs' argument is without legal or factual support.

b. FWS's Use of Data to Examine the Relationship Between OMR Flows and Salvage and Exclusion of that Data from the Incidental Take Limit Analysis.

Plaintiffs next argue that FWS acted unlawfully by selectively using certain data when examining, the relationship between negative OMR flows and entrainment while excluding that same data from the calculation of the incidental take limit.

Where FWS concludes that "an action (or the implementation of any reasonable and prudent alternatives) and the resultant incidental take of listed species will not violate section 7(a)(2) ... the Service will provide with the biological opinion a statement concerning incidental take." 50 C.F.R. § 402.14(i)(1); *see also* 16 U.S.C. § 1536(b)(4); BiOp at 285-93. The Incidental Take Statement ("ITS") provides an exemption from the take prohibitions of ESA section 9 when the agency can demonstrate compliance with its terms and conditions.

Consultation Handbook 4-47. It "specifies the impact, i.e., the amount or extent, of such incidental taking on the species," with an estimate of the number of individuals reasonably likely to be taken with full implementation of the RPA.[35] 50 C.F.R. § 402.14(i)(1)(i); Consultation Handbook 4-50.

The Consultation Handbook enumerates three criteria for ITS take: (1) the take must not be likely to jeopardize the continued existence of listed species or destroy or adversely modify designated critical habitat; (2) it must result from an otherwise lawful activity; and (3) it must be incidental to the purpose of the action. Consultation Handbook 4-48. An agency action can meet the first criterion if the RPA eliminates the likelihood of jeopardy to the species or adverse modification of designated critical habitat. *Id*. If FWS determines that full implementation of the RPA is not likely to result in jeopardy to the species or destruction or adverse modification of critical habitat, the ITS is its estimate of the number of individuals

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[35] Federal Defendants note that there is no requirement that an ITS identify an anticipated number of listed species to be taken. *See Ariz. Cattle Growers,* 273 F.3d at 1249 ("We have never held that a numerical limit is required"); *Pacific Nw. Generating Coop. ("PNGC") v. Brown*, 822 F. Supp. 1479, 1510 (D. Or. 1993), aff'd, 38 F.3d 1058 (9th Cir. 1994). In rejecting such an argument in PNGC, the District of Oregon cited legislative history that "demonstrates that Congress fully anticipated that there would be occasions when impacts would have to be estimated." *Id*. (citing S. Rep. No. 97-418, 97th Cong.2d Sess. 21 (1982), U.S.C.C.A.N. 1982, p. 2807 (take specification not a "quota" requirement)). The court also noted that other legislative history stated, "The Committee ... does not intend that the Secretary will, in every instance, interpret the word 'impact' to be a precise number...For example, it may not be possible to determine the number of eggs of an endangered or threatened fish which will be sucked into a power plant ...." *Id*. (citing H.R. Rep. No. 97-567, 97th Cong., 2d Sess. 27 (1982), U.S.C.C.A.N. 1982, p. 2827)).

which will be taken once the RPA is implemented. If this number is exceeded, the agency must immediately reinitiate consultation with FWS. 50 C.F.R. § 402.14(i)(4).

FWS provided an ITS in the BiOp that sets forth the anticipated level of take that will occur as a result of CVP/SWP operations under the RPA. The BiOp employs an adaptive approach that utilizes a formula to compute the take limit each year using the prior Fall Midwater Trawl Index. BiOp at 287, 383-86. The ITS provides separate estimates of the amount of take anticipated for adult and larval/juvenile life stages of delta smelt upon full implementation of the RPA. *Id*.

BiOp Appendix C explains the methods FWS used to determine adult and juvenile take. To estimate the amount of take, FWS approximated salvage that would be expected under similar conditions, based upon recent historic data from the export salvage facilities.[36] Goude Decl., Doc. 470, at ¶ 14. As Ms. Goude explains, the procedure FWS used yields a discrete value for take as salvage so that the adaptive process can operate

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[36] Ms. Goude explains in her declaration that the actual number of fish "salvaged" -- that is, recovered and counted at the export facility fish screens -- is a small proportion of those actually lost due to CVP/SWP operations. Goude Decl., Doc. 470, at ¶ 16. Pre-screen losses (e.g., those that occur as they enter the structures of the export salvage facilities) can account for additional sources of mortality that remain uncounted, but have been shown to be significant for delta smelt and salmonids. *See* BiOp at 209. Also, delta smelt smaller than 20mm long are not counted in salvage counts, thus significant, uncounted losses of juveniles can occur. Goude Decl., Doc. 470, at ¶ 16. For these reasons, salvage is not a completely accurate measure of actual project take via entrainment. *Id*.

relative to an estimate of the absolute number of fish extant in the system. *Id*. at ¶ 15. The calculation of incidental take varies by year under this methodology, depending on the previous year's FMWT index. This allows take to increase as delta smelt abundance increases. *Id*. Conversely, when the FMWT index is low, the permissible level of take is also reduced. *Id.*

The BiOp sets an incidental take limit for pre-spawning adult delta smelt based on "[t]he average [cumulative salvage index] value for [water years] 2006 to 2008...." BiOp at 287. According to FWS, the years 2006, 2007 and 2008 data were selected because "these years within the historic dataset best approximate expected salvage under RPA Component 1." *Id*. In contrast, FWS relied on a graph that excluded data from 2007 when it analyzed the related "OMR-Salvage relationship for adult delta smelt" which underlies RPA Component 1 and the Project Effects Analysis. BiOp at 348. Plaintiffs argue that "the 2007 data should have been included in the above-described analyses or excluded from both." Doc. 551 at 27. Plaintiffs point out that the inclusion of the 2007 data in calculating the incidental take limit lowered the average cumulative salvage index value and, the take limit ultimately imposed. *See* Deriso Decl., Doc. 396, at ¶ 99 (explaining that exclusion of the 2007 data increased the take coefficient from 7.25 to 10.45). Plaintiffs maintain that FWS unjustifiably included 2005 data in setting the juvenile take

limit, but excluded the data in setting the adult take limit.

The BiOp explains why these years were used. In estimating conditions under which take would occur, FWS initially restricted itself to those years where active adaptive management was used to reduce entrainment and salvage was similar to that expected by RPA operations. *See* BiOp 385-86. Only two years are comparable to this scenario, 2007 and 2008. In order to increase sample size for what FWS knew was a rough estimate, the BiOp utilized the range 2006 to 2008 for adult smelt entrainment, and 2005-2008 for juvenile smelt entrainment. Goude Decl., Doc. 470, at ¶ 14; *see* BiOp at 382-96.

Plaintiffs rejoin that "[i]t was per se unreasonable for FWS to make use of the 2007 salvage data in calculating the ITS because it "best approximate[d] expected salvage under RPA Component 1," after earlier rejecting the same data for Fig. B-13 because it was unrepresentative of salvage trends, and thus could not be used to calculate the OMR flow limits for RPA Component 1." Doc. 697 at 43.

However, such data was used for an entirely different purpose in these two scenarios. Figure B-13 was applied to examine the point at which negative OMR flows posed an unacceptable danger to the smelt. It was premised on a data set of more than 20 years. It was reasonable under those circumstances to exclude data that accounted for confounding

factors, such as turbidity. FWS determined that the best way to calculate the ITS (which seeks to estimate take levels that will occur if the RPA Actions are implemented) was to look at years in which flow restrictions similar to those imposed by the RPA Actions were in place. This data set was far smaller, arguably justifying the inclusion of 2007.

Plaintiffs' argument that 2007 should have been treated as an "outlier" for purposes of the ITS is not accurate. As Federal Defendants explain:

> [D]ata from 2007 [] is, in actuality, data from conditions similar to those under the RPA – where there was salvage under adaptive management to reduce entrainment. Goude Decl. at ¶ 14. The estimates contained in the ITS are intended to reflect operations during a full range of year-types, not just those years when smelt entrainment is highest.

Doc. 660 at 53-54.

Plaintiffs' assertion that the sample size of years was too small presents a scientific dispute. In preparing the ITS, FWS selected years for inclusion to replicate expected operations under the RPA. BiOp at 287. Due to limited data, FWS exercised scientific discretion to select the "most appropriate" years to estimate the level of incidental take.

As to the inclusion of 2005 in the calculation for the juvenile take limit, but not in the adult take limit, the BiOp states:

> The mean values from 2005-2008 were used as an estimate of take under the RPA. The reason for selecting this span of years is that the apparent abundance of delta

> smelt since 2005 as indexed by the 20-mm Survey and the TNS is the lowest on record. It was necessary to separate out this abundance variable, but also to account for other poorly understood factors relating salvage to OMR, distribution, and the extant conditions....

BiOp at 289. Federal Defendants also attempt to provide an explanation based on the record:

> [T]he Service explained the separate treatment of juveniles and adults, noting that "individuals of the larval/juvenile lifestage are less demographically significant than adults." BiOp at 289. Plaintiffs acknowledge – but dismiss – the biological justification that the Service provided for considering 2005 for juveniles: "the apparent abundance of delta smelt since 2005 ... is the lowest on record." BiOp at 289. Based on information from the summer townet survey and the 20mm Survey, it was reasonable for the Service to include the 2005 juvenile data in its computations. BiOp at 392.

Doc. 660 at 53. These justifications do not explain why the approach used to select the years for the adult ITS (years in which conditions mimicked those under the RPA) was abandoned for criteria based upon low smelt abundance. FWS has not provided a rational explanation for this aspect of the ITS.

Plaintiffs argue the 2006 data point should be excluded from the ITS calculation for larval/juvenile smelt, because that year was "one of only three years in the entire multi-decade sample in which OMR flow was positive, resulting in almost zero salvage. *See* BiOp at 254." Doc. 551 at 32 (noting that the juvenile salvage index was 0.4 in 2006, compared with values of 23.4 for 2005, 65.1 for 2007, and 60.9 for 2008). Plaintiffs argue that the use of the 2006 data point to calculate the larval/juvenile

ITS was unreasonable because it was entirely unrepresentative of normal salvage levels. Plaintiffs also point out that removing unrepresentative data points "significantly increases the take level." Deriso Decl., Doc. 396, at ¶ 105. Federal Defendants do not address this potential flaw in the logic underlying the juvenile/larval ITS. Because the juvenile/larval ITS must be remanded on other grounds, FWS should explain why 2006 was included.

c. DWR's Additional Challenges the ITS.

DWR contends the ITS is flawed because it depends on the average cumulative salvage index of the years selected. Because the incidental take estimate is based on an average, there is theoretically a 50% chance each year that the estimate will be exceeded, and a corresponding 50% chance that the agency will have to reinitiate the consultation. Doc. 548 at 11-12. The estimate would have been exceeded in two of the three years used to calculate it.

The record does not explain why an "averaging" approach was used. As part of the process of formulating the ITS, FWS generated a "Concern Level" estimate, "meant to indicate salvage levels approaching the take threshold." BiOp at 387. FWS expressed its "belief" that the "Concern Level" should "trigger at 75 percent of the adult incidental take, as an indicator that operations need to be more constrained to avoid exceeding the

incidental take." *Id*. This means the ITS is not only a threshold used to trigger reconsultation; it also functions as an action that influences operations under the RPA.

Based on known adverse water supply consequences of operating the Projects in a "constrained" manner, it is inexplicable that FWS did not provide a clear and rational explanation of how the ITS is set. A court, "cannot infer an agency's reasoning from mere silence," and "an agency's action must be upheld, if at all, on the basis articulated by the agency." *See PCFFA*, 426 F.3d at 1091. Because no such explanation or basis is provided, the entire ITS must be remanded for the required justifying explanation.

DWR further maintains that the BiOp incorrectly calculated the number of years in which the incidental take limit was historically violated. The BiOp states that the take estimate would be exceeded only five out of the fifteen years between 1993 and 2008. BiOp at 386. This conclusion results from an error. BiOp Table C-1, calculating the number of years the take estimate was exceeded, actually shows that this threshold would be exceeded not only in the five identified years, but in six more years, including two of the years (2006 and 2008) that FWS believes best approximate the future with the RPA fully implemented, a total of eleven out of the sixteen years. *Id*. FWS must correct these errors on remand.

(6) Challenges to the BiOp's Analysis of the Hydrodynamic Effects of the Projects.

Plaintiffs next challenge the BiOp's Project Effects Analysis as unlawful, because it: (1) bases the analysis of effects of Project Operations on the improper assumption that such operations "control" or "drive" hydrodynamic conditions in the Delta, and (2) then determines, relying on this assumption, that because CVP and SWP operations drive the hydrodynamic conditions in the Delta, those operations are the indirect cause of harm to delta smelt; when in truth a multitude of other causes ranging from predation to the adverse effects associated with invasive species contribute to the delta smelt's currently low population levels.

The BiOp explains:

> [There are a] multitude of factors that affect delta smelt population dynamics including predation, contaminants, introduced species, entrainment, habitat suitability, food supply, aquatic macrophytes, and microcystis. The extent to which these factors adversely affect delta smelt is related to hydrodynamic conditions in the Delta, which in turn are controlled to a large extent by CVP and SWP operations. . . . So while many of the other stressors that have been identified as adversely affecting delta smelt were not caused by CVP and SWP operations, the likelihood and extent to which they adversely affect delta smelt is highly influenced by how the CVP/SWP are operated in the context of annual and seasonal hydrologic conditions. While research indicates that there is no single primary driver of delta smelt population dynamics, hydrodynamic conditions driven or influenced by CVP/SWP operations in turn influence the dynamics of delta smelt interaction with these other stressors (Bennett and Moyle 1996).

BiOp at 202. Plaintiffs take issue with the logic and science of this opinion, asserting: (1) in reality, Project Operations do not "control" or "drive" hydrodynamic conditions in the Delta; and (2) hydrodynamic conditions in the Delta do not exert a "high degree of influence" over the other stressors on delta smelt and its habitat, which operate independently.

a. Project Operations as a Driver of Hydrodynamic Conditions in the Delta.

Plaintiffs complain that the BiOp "simply assumed that Project Operations drive hydrodynamics thereby exacerbating the effects of other causes of harm on the delta smelt," although the contrary is established by the record. Doc. 551 at 53. Plaintiffs maintain that Project Operations do not control precipitation patterns, which are the real drivers of inflow to the Delta watershed. *Id.*[37]

CALFED scientists concluded in a 2008 Report:

> Despite California's extensive system of water storage

[37] In a related argument, Plaintiffs challenge the BiOp's conclusion that the long-term upstream shift in the position of X2 was driven by Project Operations. Plaintiffs insist that the premise that Project operations drive hydrodynamic conditions in the Delta is unsupported by the record and best available science. Rather, they insist historic change in X2 was primarily driven by non-Project causes. Doc. 697 at 38. The majority of evidence provided by Plaintiffs in support of this argument, cited in their Reply brief, is inadmissible on summary judgment. For example, Plaintiff's cite paragraph 5 of the Reply Declaration of Dr. Charles Hanson, Doc. 598, which was stricken from the record, *see* Doc. 750 at ¶ 10. Plaintiffs also cite extensively to the transcript from the evidentiary hearing on the motion for preliminary injunction. Plaintiffs have provided no authority that the testimony of witnesses at a post-record hearing is admissible under any of the exceptions to the general rule prohibiting consideration of extra-record evidence, except to explain scientific matter and to determine if the information was considered by the agency.

> and flow management, there is growing evidence that our capacity to manage water supply and water quality is limited. For example, there is no getting around the fact that natural patterns of precipitation and runoff drive Central Valley hydrology, and that the salinities found in the Bay- Delta are driven as much by natural climate variability as they are by freshwater management (Knowles 2002).

CALFED Science Program, The State of Bay-Delta Science 2008 42-43 (2008), Doc. 199 ("State of Bay-Delta Science").[38] Similarly, Dr. Kimmerer has stated:

> Freshwater supply to the San Francisco Estuary depends on highly variable precipitation patterns and the effects of extensive water development projects upstream and within the Delta....
>
> ***
>
> Given the extent and magnitude of the water projects, it may seem paradoxical that most of the interannual variability in flow patterns in the estuary is due to variability in precipitation.

Wim J. Kimmerer, Open Water Processes of the San Francisco Estuary: From Physical Forcing to Biological Responses, 2(1) San Francisco Estuary & Watershed Science 15 (2004), AR 18717-18718. Indeed, precipitation patterns are highly variable. *See* State of Bay-Delta Science at 40-42 ("precipitation patterns are highly variable from year to year (inter-annually) and within years (seasonally)"). As a result, "[f]reshwater input to the estuary is highly variable on all time scales." Wim J. Kimmerer et al.,

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[38] Plaintiffs motion to supplement the record with this document was granted in part, allowing Plaintiffs to reference the document and the Court to consider the document under the relevant factors exception to the administrative record doctrine. Doc. 406 at 4.

Variation of Physical Habitat for Estuarine Nekton with Freshwater Flow in the San Francisco Estuary (May 15, 2008), AR 019016; *see also* Public Policy Institute of California, Envisioning Futures for the Sacramento-San Joaquin Delta 102 (2007) (stating that inflows to the Delta "vary greatly across seasons and years"), AR 019343.

The first paragraph of the Effects analysis states that "hydrodynamic conditions in the Delta... are controlled to a large extent by CVP and SWP [pumping] operations," and that other sources of water diversion "when taken together do not control hydrodynamic conditions throughout the Delta to any degree that approaches the influence of the Banks and Jones export facilities." BiOp at 202. This apparent inconsistency with the science must be considered in light of the BiOp's next page, which explains that "every day the system <u>is in balanced conditions</u>, the CVP and SWP are [] primary driver[s] of delta smelt abiotic and biotic habitat suitability, health, and mortality." BiOp at 203. The BiOp does not assume that pumping operations continuously drive hydrodynamic conditions; rather, Project operations primarily drive hydrodynamic conditions when the system is in balance.[39] With this qualification, the studies

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[39] The BiOp explains: "Balanced water conditions are defined in the COA as periods when it is mutually agreed that releases from upstream reservoirs plus unregulated flows approximately equal[] the water supply needed to meet Sacramento Valley in-basin uses plus exports. Excess water conditions are periods when it is mutually agreed that releases from upstream reservoirs plus

cited by Plaintiffs do not conflict with the BiOp.

The scientific literature does a side-by-side analysis. Kimmerer (2004) finds that "most of the interannual variability in flow patterns in the estuary is due to variability in precipitation ... due to the overwhelming effect of high flow events." AR 18718. He describes the following impacts of the CVP-SWP:

> The water projects have clearly affected the seasonal patterns of flow into the estuary (Kimmerer 2002b). Springtime flow has decreased significantly relative to unimpaired flow because of shifts in water project operations each year from flood management in winter, during which reservoirs are kept at relatively low levels, to water storage in spring, when much of the flow is captured for subsequent irrigation. In addition, flow in summer and early fall is higher than unimpaired flow to support demand for irrigation and urban use, much of which is met by releases from reservoirs into the rivers and subsequent recapture and export from the Delta (Arthur et al. 1996).

Id. While the CALFED report observes that "natural patterns of precipitation and runoff drive Central Valley hydrology," it also finds that "[r]ecent examination of the impacts of water project development in the state has documented species population losses

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unregulated flow exceed Sacramento Valley in-basin uses plus exports. Reclamation's Central Valley Operations Office (CVOO) and DWR's SWP Operations Control Office jointly decide when balanced or excess water conditions exist." BiOp at 19.

"The duration of balanced water conditions varies from year to year. Some very wet years have had no periods of balanced conditions, while very dry years may have had long continuous periods of balanced conditions, and still other years may have had several periods of balanced conditions interspersed with excess water conditions. Account balances continue from one balanced water condition through the excess water condition and into the next balanced water condition. When the project that is owed water enters into flood control operations, at Shasta or Oroville, the accounting is zeroed out for that respective project. The biological assessment provides a detailed description of the changes in the COA." BiOp at 20-21.

due to destruction of habitat, alteration of flow timing and changes in water chemistry, water velocities and runoff quantities." Doc. 199-4 at 15.

The BiOp recognizes that "delta smelt abundance trends have been driven by multiple factors, some of which are affected or controlled by CVP/SWP operations and others that are not. Notably, the BiOp acknowledges the decline of delta smelt cannot be explained solely by the effects of CVP/SWP operations." BiOp at 203. The BiOp's conclusions about the cause and effect of other stressors are ambiguous. Plaintiffs' quest for precision in delinking Project operations as the primary driver of smelt decline is understandable in view of the ambiguity of the BiOp.

b. Treatment of Other Stressors.

Plaintiffs complain that the BiOp attributes a wide variety of causes of harm to delta smelt and its habitat—such as aquatic macrophytes, predators, competition, toxic blue-green algae, and contaminants—to continued Project Operations, without any meaningful explanation. *See* BiOp at 182-188, 202-203.

The BiOp concludes:

> Other baseline stressors will continue to adversely affect the delta smelt, such as contaminants, microcystis, aquatic macrophytes, and invasive species. Available information is inconclusive regarding the extent, magnitude and pathways by which delta smelt may be affected by these stressors independent of CVP/SWP operations. However, the operation of the CVP/SWP, as proposed, is likely to reduce or preclude seasonal flushing flows, substantially reduce the natural frequency of upstream and downstream movement of the

> LSZ, and lengthen upstream shifts of the LSZ to an extent that may increase the magnitude and frequency of adverse effects to the delta smelt from these stressors.

BiOp at 277.

Plaintiffs argue that the BiOp makes no rational connection between the other causes of harm to the smelt and their habitat and continued Project Operations.[40] Plaintiffs acknowledge that the BiOp contains some discussion of various causes of harm to delta smelt and their habitat other than from Project Operations, BiOp at 182-188, but complain that the BiOp "does not quantitatively (or even qualitatively) explain the [independent] impact that these causes of harm to the species and its habitat have on the size of the delta smelt population, nor to the ostensible ecological pathways by which these environmental stressors affect the fish." Doc. 551 at 56-57.

Plaintiffs argue that the BiOp's treatment of other stressors conflicts with a "consensus that has emerged over the last several years in the scientific community that there are a host of causes of harm to the species that collectively have

[40] Specifically, Plaintiffs maintain that, to comply with the law, FWS must "(1) analyze the effect that other causes of harm have on the delta smelt and its habitat; (2) analyze the extent to which hydrodynamics contribute to each of those other causes of harm to the species and its habitat; (3) analyze the extent to which Project Operations—as distinguished from the other operations that result in the diversion of most of the water from the Delta's watershed—influence hydrodynamics in the Delta watershed; and (4) assess the extent of harm attributable to other causes that can be traced to Project Operations in light of such an analysis." Doc. 551 at 56. Plaintiffs point to no statute, regulation, or caselaw that imposes such specific requirements. Nonetheless, the BiOp must establish a rational connection between the facts and its conclusion that Project Operations exacerbate the impacts of other stressors.

contributed to its decline." *Id*. at 57. Plaintiffs point to a 2007 Public Policy Institute of California Report entitled "Envisioning Futures for the Sacramento-San Joaquin Delta" by Jay Lund, et al., which discusses how "[s]everal basic assumptions on how the [Sacramento-San Joaquin] estuary operates have proven to be incorrect or only partially correct." AR 19303. The PPIC report describes these revised understandings as a set of "paradigm shifts" in Table 4.1, reproduced in substance below:

Table 4.1
New Understanding of the Delta Ecosystem

New Paradigm	Old Paradigm
1. **Uniqueness of the San Francisco Estuary** The San Francisco Estuary has complex tidal hydrodynamics and hydrology. Daily tidal mixing has more influence on the ecology of the estuary than riverine outflows, especially in the western and central Delta. Conditions that benefit striped bass (an East Coast species) do not necessarily benefit native organisms.	The San Francisco Estuary works on the predictable model of East Coast estuaries with gradients of temperature and salinity controlled by outflow. Freshwater outflow is the most important hydrodynamic force. If the estuary is managed for striped bass, all other organisms, and especially other fish, will benefit.
2. **Invasive Species** Alien species are a major and growing problem that significantly inhibits our ability to manage in support of desirable species.	Alien (nonnative) species are a minor problem or provide more benefits than problems.
3. **Interdependence** Changes in management of one part of the system affect other parts. All are part of the estuary and can change states in response to outflow and climatic conditions. Floodplains are of major ecological importance and affect estuarine function. Suisun Marsh is an integral part of the estuary ecosystem and its future is closely tied to that of the Delta.	The major parts of San Francisco Estuary can be managed independently of one another. The Delta is a freshwater system, Suisun Bay and Marsh are a brackish water system, and San Francisco Bay is a marine system. Floodplains such as the Yolo Bypass have little ecological importance. Suisun Marsh is independent of the rest of the estuary

4. **Stability** The Delta will undergo dramatic changes in the next 50 years as its levees fail because of natural and human-caused forces such as sea level rise, flooding, climate, and subsidence. A Delta ecosystem will still exist, with some changes benefiting native species. Agriculture is unsustainable in some parts of the Delta.	The Delta is a stable geographic entity in its present configuration. Levees can maintain the Delta as it is. Any change in the Delta will destroy its ecosystem. Agriculture is the best use for most Delta lands.
5. **Effects of Human Activities** Pumping in the Delta is an important source of fish mortality but only one of several causes of fish declines. Entrainment of fish at the power plants is potentially a major source of mortality. Changes in ocean conditions (El Niño events, Pacific Decadal Oscillation, ocean fishing, etc.) have major effects on the Delta. Hatcheries harm wild salmon and steelhead. Chronic toxicants continue to be a problem, and episodic toxic events from urban and agricultural applications are also a major problem.	Pumping in the southern Delta is the biggest cause of fish declines in the estuary. Fish entrainment at power plants is a minor problem. Changes in ocean conditions have no effect on the Delta. Hatcheries have a positive or no effect on wild populations of salmon and steelhead. Chronic toxicants (e.g., heavy metals, persistent pesticides) are the major problems with toxic compounds in the estuary.

AR 19305-306. The fifth paradigm shift finds that Delta Pumping is an "important source of fish mortality but only one of several causes of fish declines." AR 019306. This finding is further supported by the Interagency Ecological Program's conceptual model that describes observed pelagic fish declines in the Delta and recognizes numerous sources of harm to the species including contaminants, disease, toxic algal blooms, climate change, predation, entrainment in diversions, and limited food availability, limited food co-occurrence with the species, and poor food quality. *See* Randall Baxter et al., Pelagic Organism Decline Progress Report: 2007 Synthesis of Results (2008) AR 16935-53. In light of this general, undisputed consensus that many factors contribute to delta smelt mortality, Plaintiffs challenge the BiOp's attribution to the Projects of the effects

of: (1) predation; (2) aquatic macrophytes; and (3) microcystis.

(1) Predation Analysis.

Plaintiffs describe the BiOp's predation as a purportedly flawed attribution of another stressor to Project Operations. The BiOp generally acknowledges that striped bass prey on the delta smelt but concludes that "[i]t is unknown whether incidental predation by striped bass (and other lesser predators) represents a substantial source of mortality for delta smelt." BiOp at 183. The BiOp does not include any estimates of the effect of predation on the delta smelt population. Such information was available. The Conservation Plan for DFG's Striped Bass Management Program ("Conservation Plan"), which was submitted to FWS as part of an application for an incidental take permit, states: "[d]espite the low incidence of delta smelt in striped bass stomachs, the year-round overlap in distribution of delta smelt and striped bass results in an estimated annual consumption of about 5.3% of the delta smelt population by a striped bass population of approximately 765,000 adults." Doc. 181-1 at 32 (emphasis added).) The Conservation Plan explains that FWS and DFG "have agreed that a predation rate of 5.3% of the annual delta smelt population is a reasonable estimate." *Id.* at 33. FWS issued an incidental take permit to DFG on the basis of this striped bass predation estimate. There is question whether this underestimates the effect on delta smelt of bass

predation. *See* First Amended Complaint, *Coalition v. McCamman*, 1:08-cv-00397 OWW GSA, Doc. 46.

FWS need not include every piece of available information regarding other stressors in the BiOp. *Kempthorne*, 506 F. Supp. 2d at 367 ("If FWS was required to consider and address every new piece of information it received prior to publication of its decision, it would be effectively impossible for the agency to complete a biological opinion."). However, FWS cannot ignore relevant information pertaining to a major source of mortality to the species, particularly when that information is decidedly contrary to BiOp findings. It is not clear from the record whether 5.6% mortality should be considered significant. In related contexts, mortality of 1% has been used as an incidental take limit, *see* Findings of Fact and Conclusions of Law Re Existence of Irreparable Harm, *PCFFA v. Gutierrez*, 1:06-cv-00245 OWW GSA, Doc. 367 at 48:5-9 (noting that incidental take limit for winter-run Chinook salmon is set at two percent of the estimated number of juveniles produced each year), suggesting that such small percentages may be significant enough to merit discussion. The 5.3% figure may be partially attributable to Project operations. As the BiOp explains, there are high rates of predation in Clifton Court Forebay, BiOp 160-161, 209, but the contribution of striped bass predation to this mortality is not articulated. The BiOp erroneously failed to consider available

information regarding the magnitude of striped bass predation on delta smelt, with the likely result of erroneously attributing to the Projects, impacts independent of Project Operations.

(2) Aquatic Macrophytes.

The BiOp discusses aquatic macrophytes:

> In the last two decades, the interior Delta has been extensively colonized by submerged aquatic vegetation. The dominant submerged aquatic vegetation is Egeria densa, a nonnative from South America that thrives under warm water conditions. Research suggests that *Egeria densa* has altered fish community dynamics in the Delta, including increasing habitat for centrarchid fishes including largemouth bass (Nobriga et al. 2005; Brown and Michniuk 2007), reducing habitat for native fishes (Brown 2003; Nobriga et al. 2005; Brown and Michniuk 2007), and supporting a food web pathway for centrarchids and other littoral fishes (Grimaldo et al in review). *Egeria densa* has increased its surface area coverage by up to 10 percent per year depending on hydrologic conditions and water temperature (Erin Hestir personal communication University of California Davis).
>
> *Egeria densa* and other non-native submerged aquatic vegetation (e.g., *Myriophyllum spicatum*) can affect delta smelt in direct and indirect ways. Directly, submerged aquatic vegetation can overwhelm littoral habitats (inter-tidal shoals and beaches) where delta smelt may spawn making them unsuitable for spawning. Indirectly, submerged aquatic vegetation decreases turbidity (by trapping suspended sediment) which has contributed to a decrease in both juvenile and adult smelt habitat. Increased water transparency may delay feeding and may also make delta smelt more susceptible to predation pressure.

BiOp at 182-183. General discussions of *Egeria densa* are included in the Critical Habitat section of the BiOp. BiOp at 196, 198, 201. Discussion of PCE # 2 explains:

> As stated in the Status and Baseline Section, research

> suggests that the nonnative South American aquatic plant *Egeria densa* has altered fish community dynamics in the Delta. In addition to the above-mentioned effect of overwhelming spawning habitat (PCE #1), *Egeria* and other submerged aquatic vegetation decreases turbidity by trapping suspended sediment, thereby decreasing juvenile and adult smelt habitat (Feyrer et al. 2007; Nobriga et al. 2008). Increased water transparency may also make delta smelt more susceptible to predation. It appears that aquatic macrophytes may have a role in degrading pelagic habitat to the extent that the Delta's ability to fulfill its intended conservation purpose continues to diminish. *Egeria* has the additional effect of decreasing turbidity, described above as important to successful feeding of newly-hatched larval delta smelt. However, there is still enough turbidity in the Central and South Delta to initiate larval feeding responses because larvae collected in the South Delta have comparatively high growth rates. So while *Egeria* may reduce or eliminate the extent and quality of spawning habitat for delta smelt, it is not at this considered to have detectable effects on spawning or early feeding success.

BiOp at 198.

The BiOp concludes:

> Available information is inconclusive regarding the extent, magnitude and pathways by which delta smelt may be affected by these stressors independent of CVP/SWP operations. However, the operation of the CVP/SWP, as proposed, is likely to reduce or preclude seasonal flushing flows, substantially reduce the natural frequency of upstream and downstream movement of the LSZ, and lengthen upstream shifts of the LSZ to an extent that may increase the magnitude and frequency of adverse effects to the delta smelt from these stressors.

BiOp at 277. Although a connection may exist, the record does not reflect any discussion, nor have the parties pointed to any study, connecting "seasonal flushing flows ... the natural frequency of upstream and downstream movement of the LSZ, and

lengthen[ed] upstream shifts of the LSZ" to the presence of any aquatic macrophyte. FWS has failed to make a rational connection between the facts in the record and its conclusions, particularly when the science indicates the contrary is likely true.

(3) Microcystis

FWS makes no connection whatsoever between microcystis, large blooms of toxic blue-green algae, and continued CVP and SWP operations. *See* BiOp at 186. In a discussion regarding the Vernalis Adaptive Management Plan (VAMP) period,[41] FWS stated:

> Without the flow component, the larval and juvenile delta smelt would remain in the Central and South Delta, where they could be exposed to lethal water temperatures, entrainment at Banks and Jones after the VAMP export curtailment period, or succumb to predation or microcystis blooms.

BiOp at 224. The BiOp does not analyze the effect that this asserted increased exposure to other stressors has on the delta smelt, or how it is caused by Project Operations; rather, FWS simply concludes without support that this effect buttresses a determination that the proposed action will jeopardize the delta smelt.

It is undisputed that numerous stressors, including ammonia

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[41] "Adopted by the SWRCB in D-1641, the San Joaquin River Agreement (SJRA) includes a 12-year program providing for flows and exports in the lower San Joaquin River during a 31-day pulse flow period during April and May. It also provides for the collection of experimental data during that time to further the understanding of the effects of flows, exports, and the barrier at the head of Old River on salmon survival. This experimental program is commonly referred to as the VAMP (Vernalis Adaptive Management Plan)." BiOp at 78.

and other toxics, food limitation, predation, the introduction of non-native species and other factors, all have adverse impacts to delta smelt. *See e.g.*, BiOp at 182-84 (discussing other stressors). Yet, the BiOp concludes that Project Operations are "a primary factor influencing delta smelt abiotic and biotic habitat suitability, health, and mortality." BiOp at 189 (emphasis added). FWS rationalizes this conclusion, at least in part, by attributing the impacts of many of the "other stressors" to the Projects. This attribution has not been justified, nor is it logical or explained by any science. Given that the impacts of regulating Project Operations are so consequential, such unsupported attributions (a result in search of a rationale) are unconscionable.

(7) Indirect Effects Analysis.

Plaintiffs assert that the BiOp inappropriately categorizes adverse effects on delta smelt from limited food supply, invasive species, and contaminants as "indirect effects" caused by Project Operations. The Joint Consultation Regulations promulgated by FWS and NMFS define: "[i]ndirect effects are those that are caused by the proposed action and are later in time, but still are reasonably certain to occur." 50 C.F.R. § 402.02 (emphasis added). The ESA's definition differs from NEPA's definition of indirect effects of an action: "[i]ndirect effects, which are caused by the action and are later in time or farther removed in

distance, but are still reasonably foreseeable." 40 C.F.R. § 1508.8(b). In the preamble of the Final Rule adopting the ESA regulations, FWS explained that it intended a narrower regulatory definition of indirect effects under the ESA than applied in the NEPA context (i.e., compare "reasonably certain to occur" with "reasonably foreseeable"). 51 Fed. Reg. 19,926 (June 3, 1986). NMFS and FWS contrasted the ESA with NEPA and expressly explained the intent and rationale for adopting the more narrow "reasonably certain to occur" standard for indirect and cumulative effects under ESA:

> If the jeopardy standard is exceeded, the proposed Federal action cannot proceed without an exemption. This is a substantive prohibition that applies to the Federal action involved in consultation. In contrast, NEPA is procedural in nature, rather than substantive, which would warrant a more expanded review of cumulative effects. Otherwise, in a particular situation, the jeopardy prohibition could operate to block "nonjeopardy" actions because future, speculative effects occurring after the Federal action is over might, on a cumulative basis, jeopardize a listed species. Congress did not intend that Federal actions be precluded by such speculative actions.

51 Fed. Reg. at 19,933.

Shortly after adoption of the ESA regulations, the Ninth Circuit confirmed "'[t]he reasonably certain to occur' standard applies to 'indirect effects ... caused by the proposed action." *Sierra Club v. Marsh*, 816 F.2d 1376, 1388 (9th Cir. 1987); *see also Ariz. Cattle Growers Ass'n v. FWS*, 273 F.3d 1229, 1243 (9th Cir. 2001) (invalidating several incidental take statements

regarding grazing and effects on fish because "it would be unreasonable for [FWS] ... to impose conditions on otherwise lawful land use if a take were not reasonably certain to occur as a result of that activity"); *Ctr. for Biological Diversity v. U.S. Dept. of Hous. & Urban Dev.*, 541 F. Supp. 2d 1091, 1100-01 (D. Ariz. 2008) (dismissing a suit alleging federal agencies had violated the ESA by failing to analyze the indirect effects of providing federal funding to local development projects, concluding that the link between such financial assistance and groundwater depletion that could harm listed species was "too attenuated" to meet the standards of 50 C.F.R. § 402.02). "[T]he mere potential for harm ... is insufficient" to meet the "reasonably certain to occur" standard. *Ariz. Cattle Growers Ass'n*, 273 F.3d at 1246. Other causes must be addressed applying this standard.

a. <u>Effect of Project Operations on Delta Smelt Food Supplies.</u>

The BiOp claims that one of "three major seasonally occurring categories of effects" on delta smelt is "entrainment of *Pseudodiaptomus forbesi*[42], the primary prey of delta smelt during summer-fall." BiOp at 203. The BiOp categorizes this as an "indirect effect." *id.*, and justifies RPA Component 4 (Action

[42] *Pseudodiaptomus forbesi* is a small aquatic copepod introduced into the Delta in 1988, and has since become an important source of prey for delta smelt. BiOp at 184.

6)[43] in part by the statement that "[t]he Effects Section indicates that [*P. forbesi*] distribution may be vulnerable to effects of exports facilities operations and, therefore, the projects have a likely effect on the food supply available to delta smelt." BiOp at 380-81.

The relevant section of the effects analysis provides:

> Entrainment of *Pseudodiaptomus forbesi* (June-September)
>
> Historically, the diet of juvenile delta smelt during summer was dominated by the copepod *Eurytemora affinis* and the mysid shrimp *Neomysis mercedis* (Moyle et al. 1992; Feyrer et al. 2003). These prey bloomed from within the estuary's LSZ and were decimated by the overbite clam *Corbula amurensis* (Kimmerer and Orsi 1996), so delta smelt switched their diet to other prey. *Pseudodiaptomus forbesi* has been the dominant summertime prey for delta smelt since it was introduced into the estuary in 1988 (Lott 1998; Nobriga 2002; Hobbs et al. 2006). Unlike *Eurytemora* and *Neomysis*, *Pseudodiaptomus* blooms originate in the freshwater Delta (John Durand San Francisco State University, oral presentation at 2006 CALFED Science Conference). This freshwater reproductive strategy provides a refuge from overbite clam grazing, but *Pseudodiaptomus* has to be transported to the LSZ during summer to co-occur with most of the delta smelt population. This might make *Pseudodiaptomus* more vulnerable to pumping effects from the export facilities than *Eurytemora* and *Neomysis* were. By extension, the projects might have more effect on the food supply available to delta smelt than they did before the overbite clam changed the LSZ food web. As evidence for this hypothesis, the IEP Environmental Monitoring Program zooplankton data show the summertime density of *Pseudodiaptomus* is generally higher in the South Delta than in Suisun Bay. The ratio of South Delta *Pseudodiaptomus* density to Suisun Bay *Pseudodiaptomus* density was greater than one in 73 percent of the collections from June- September 1988-2006. The average value of this ratio is 22, meaning

[43] Action 6 requires the creation or restoration of 8,000 acres (12.5 square miles) of habitat. BiOp at 379.

> that on average summer *Pseudodiaptomus* density has been 22 times higher in the South Delta than Suisun Bay. Densities in the two regions are not correlated (P > 0.30). This demonstrates that the presence of high copepod densities in the South Delta which delta smelt do not occupy during summer months, do not necessarily occur simultaneously in the LSZ where delta smelt rear.
>
> There is statistical evidence suggesting that the co-occurrence of delta smelt and *Pseudodiaptomus forbesi* has a strong statistical influence on the survival of young delta smelt from summer to fall (Miller 2007). In addition, recent histopathological evaluations of delta smelt have shown possible evidence of food limitation in delta smelt during the summer (Bennett 2005; Bennett et al. 2008). However, the glycogen depletion of the delta smelt livers reported in these studies can also arise from thermal stress due to high summer water temperatures (Bennett et al. 2008).

BiOp at 228. These observations show that *P. forbesi* from the southern Delta are an important source of summer food supply to delta smelt in the lower salinity zone ("LSZ"), and that Project Operations (i.e., export pumping) prevent *P. forbesi* in the South Delta from flowing to the LSZ during that time, causing a reduction in the density of *P. forbesi* that subsequently causes deleterious effects to delta smelt.

Federal Defendants are correct that nothing in the ESA requires FWS to rule out all other potential factors that may or may not play a role in the ecosystem under analysis. *See* Doc. 660 at 58. However, the ESA does require the agency to evaluate the impacts of the proposed action, and make a determination whether the proposed action is likely to have direct and indirect effects on the species. 50 C.F.R. § 402.02 (defining "jeopardize

the continued existence of" to means "to engage in an action that reasonably would be expected, directly or indirectly, to reduce appreciably the likelihood of both the survival and recovery of a listed species in the wild by reducing the reproduction, numbers, or distribution of that species."). Plaintiffs argument is simply that "there was no data or analysis in the BiOp (or elsewhere in the record) to support the BiOp's finding that export pumping causes reduced availability of [*P. forbesi]* for consumption by delta smelt in the Low Salinity Zone and that this reduced availability is reasonably certain to occur." Doc. 695 at 55.

Plaintiffs' central complaint is that in evaluating the indirect effect of Project operations on *P. forbesi*, FWS used data from a few Suisun Bay sampling stations to represent the entire lower salinity zone, even though the low salinity zone occurs outside Suisun Bay as well.[44] The peer review found a

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[44] Plaintiffs also summarily argue that this conclusion is unjustified because:

- FWS did not consider or rule out the fact that grazing by exotic clam species causes the observed reduced *P. forbesi* density in Suisun Bay.
- FWS did not consider or rule out the fact that higher densities of *P. forbesi* in the South Delta are caused by differences in spatial distribution between juvenile and adult *P. forbesi* because juveniles are more dense in the South Delta.
- FWS did not consider or account for the fact that Plaintiffs provided FWS with results of regression analyses of the best scientific data available that showed "[*P. forbesi*] densities in Suisun Bay are not correlated with exports ...," but that there is "a highly significant correlation between [*P. forbesi*] densities in Suisun Bay and those in Suisun Marsh, suggesting (unsurprisingly) that if Suisun Bay densities are being subsidized, the most likely source is Suisun Marsh." AR 006369; 006377-006378.

"relationship between outflow and abundance of *P. forbesi* in the [lower salinity zone] ... can be detected only by comparing the distribution of copepods in salinity space rather than relying on sampling station locations." AR 008821. FWS did nothing to correct this problem in the final Effects Analysis.

Plaintiffs also complain that the BiOp contains no quantitative analysis of the impact of exports on *P. forbesi*. Federal Defendants' only response to this criticism is to point out that the draft BiOp did contain a quantitative analysis. This draft was presented to the Peer Review panel, which responded that it "agree[d] with the conceptual model and with the justification of its elements" as "well-supported," but had concerns about parts of that analysis, and recommended that it be revised. Goude Decl., Doc. 470, ¶ 5. The Panel concluded that if a "revised analysis does not show a substantial (not necessarily statistically significant) pattern, the analysis should be mentioned but the results dropped as a quantitative metric from the [Effects Analysis]." *Id*. After considering the Panel's recommendation, FWS decided not to use the analysis as a quantitative metric, instead concluding that a qualitative

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Doc. 551 at 48-49. The support for these arguments were incorporated by reference from the extensive argument concerning the BiOp's food analysis contained in Plaintiffs' motion for Preliminary Injunction. Given the prolixity of briefing and the highly contentious process by which page limits for the motions for summary judgment were set in this case, it would be highly prejudicial to Defendants to permit such extensive incorporation by reference into the summary judgment proceedings. These arguments will not be addressed.

analysis and discussion was sufficient and appropriate for the final 2008 Biological Opinion. *Id*. The BiOp does contain a qualitative discussion of the impacts of the Delta Food Web, acknowledging the effects that the overbite clam has had on the pelagic food web, including upon the delta smelt, BiOp at 184-85, but noting "it is uncertain whether this is a direct consequence of the overbite clam." BiOp at 184.

Although nothing in the ESA mandates the use of quantitative analyses *per se*, the Peer Review's critique of the *P. forbesi* analysis cannot be separated from FWS's abandonment of its quantitative analysis. The Peer Review specifically criticized the use of fixed-location monitoring sites as part of the quantitative analysis. Rather than correct this problem, FWS's response was to abandon the quantitative analysis, choosing to advance the same, potentially flawed conclusion in a more subjective, qualitative analysis. This conduct suggests another unlawful, results-driven choice, ignoring best available science.

b. <u>Pollution and Contaminants</u>

The BiOp claims "[r]earing habitat in the South Delta may also be impacted indirectly through increases in contaminant concentrations." BiOp at 242. In assessing Project effects to critical habitat, the BiOp states "[t]he contaminant effects may be generated or diluted by flow depending on the amount of flow, the type of contaminant, the time of year, and relative

concentrations." BiOp at 240.

Plaintiffs argue "[g]eneral statements like this do not comport with ESA's requirements for attributing indirect effects to an action." Doc. 661 at 50. Plaintiffs contend: "[t]o meet ESA's regulatory standard for indirect effects," requiring such indirect effects be "reasonably certain to occur" FWS must "support these general hypotheses with discussion and use of scientific data showing":

> (1) how a specific individual contaminant concentration (e.g., ammonia, mercury, pyrethroids, etc.) would be increased by a particular flow modification caused by Project Operations;
>
> (2) at what time of year or month such flow modifications and contaminant concentration increases would occur; and
>
> (3) how and to what extent this alleged contaminant increase would affect the abundance of delta smelt.

Id. Plaintiffs do not cite any specific statute, regulation, or case that requires such specific findings before an impact is a sufficient indirect effect. The record must reflect that contaminant-related impacts indirectly caused by Project Operations are "reasonably certain" to occur. It is undisputed that contaminants are not introduced by the Projects, rather by others conducting municipal, industrial, and agricultural (runoff) activities.

FWS provided a qualitative discussion of the impacts of pollutants and changed Delta hydrodynamics resulting from Project

operations upon the smelt:

Contaminants

Contaminants can change ecosystem functions and productivity through numerous pathways. However, contaminant loading and its ecosystem effects within the Delta are not well understood. Although a number of contaminant issues were first investigated during the POD years, concern over contaminants in the Delta is not new. There are long-standing concerns related to mercury and selenium levels in the watershed, Delta, and San Francisco Bay (Linville et al. 2002; Davis et al. 2003). Phytoplankton growth rate may, at times, be inhibited by high concentrations of herbicides (Edmunds et al. 1999). New evidence indicates that phytoplankton growth rate is chronically inhibited by ammonium concentrations in and upstream of Suisun Bay (Wilkerson et al. 2006, Dugdale et al. 2007). Contaminant-related toxicity to invertebrates has been noted in water and sediments from the Delta and associated watersheds (e.g., Kuivila and Foe 1995, Giddings 2000, Werner et al. 2000, Weston et al. 2004). Undiluted drainwater from agricultural drains in the San Joaquin River watershed can be acutely toxic (quickly lethal) to fish and have chronic effects on growth (Saiki et al. 1992). Evidence for mortality of young striped bass due to discharge of agricultural drainage water containing rice herbicides into the Sacramento River (Bailey et al. 1994) led to new regulations for water discharges. Bioassays using caged Sacramento sucker (Catostomus occidentalis) have revealed deoxyribonucleic acid strand breakage associated with runoff events in the watershed and Delta (Whitehead et al. 2004). Kuivila and Moon (2004) found that peak densities of larval and juvenile delta smelt sometimes coincided in time and space with elevated concentrations of dissolved pesticides in the spring. These periods of cooccurrence lasted for up to 2-3 weeks, but concentrations of individual pesticides were low and much less than would be expected to cause acute mortality. However, the effects of exposure to the complex mixtures of pesticides actually present are unknown.

The POD investigators initiated several studies beginning in 2005 to address the possible role of contaminants and disease in the declines of Delta fish and other aquatic species. Their primary study consists of twice-monthly monitoring of ambient water toxicity at fifteen sites in the Delta and Suisun Bay. In 2005 and 2006, standard bioassays using the amphipod Hyalella azteca had low (<5 percent) frequency of occurrence of toxicity (Werner et al. 2008). However, preliminary results from 2007, a dry year, suggest the

incidence of toxic events was higher than in the previous (wetter) years. Parallel testing with the addition of piperonyl butoxide, an enzyme inhibitor, indicated that both organophosphate and pyrethroid pesticides may have contributed to the pulses of toxicity. Most of the tests that were positive for H. azteca toxicity have come from water samples from the lower Sacramento River. Pyrethroids are of particular interest because use of these insecticides has increased within the Delta watershed (Ameg et al. 2005, Oros and Werner 2005) as use of some organophosphate insecticides has declined. Toxicity of sediment-bound pyrethroids to macroinvertebrates has also been observed in small, agriculture-dominated watersheds tributary to the Delta (Weston et al. 2004, 2005). The association of delta smelt spawning with turbid winter runoff and the association of pesticides including pyrethroids with sediment is of potential concern.

In conjunction with the POD investigation, larval delta smelt bioassays were conducted simultaneously with a subset of the invertebrate bioassays. The water samples for these tests were collected from six sites within the Delta during May-August of 2006 and 2007. Results from 2006 indicate that delta smelt are highly sensitive to high levels of ammonia, low turbidity, and low salinity. There is some preliminary indication that reduced survival may be due to disease organisms (Werner et al. 2008). No significant mortality of larval delta smelt was found in the 2006 bioassays, but there were two samples [] collected from sites along the Sacramento River and had relatively low turbidity and salinity levels and moderate levels of ammonia. It is also important to note that no significant H. azteca mortality was detected in these water samples. While the H. azteca tests are very useful for detecting biologically relevant levels of water column toxicity for zooplankton, interpretation of the H. azteca test results with respect to fish should proceed with great caution. The relevance of the bioassay results to field conditions remains to be determined.

The POD investigations into potential contaminant effects also include the use of biomarkers that have been used previously to evaluate toxic effects on POD fishes (Bennett et al. 1995, Bennett 2005). The results to date have been mixed. Histopathological and viral evaluation of young longfin smelt collected in 2006 indicated no histological abnormalities associated with exposure to toxics or disease (Foott et al. 2006). There was also no evidence of viral infections or high parasite loads. Similarly, young threadfin shad showed no histological evidence of contaminant effects or of viral infections (Foott et al. 2006). Parasites were noted in threadfin shad gills at a high frequency but

> the infections were not considered severe. Both longfin smelt and threadfin shad were considered healthy in 2006. Adult delta smelt collected from the Delta during the winter of 2005 also were considered healthy, showing little histopathological evidence for starvation or disease (Teh et al., unpublished data). However, there was some evidence of low frequency endocrine disruption. In 2005, 9 of 144 (6 percent) of adult delta smelt males sampled were intersex, having immature oocytes in their testes (Teh et al., unpublished data).
>
> In contrast, preliminary histopathological analyses have found evidence of significant disease in other species and for POD species collected from other areas of the estuary. Massive intestinal infections with an unidentified myxosporean were found in yellowfin goby *Acanthogobius flavimanus* collected from Suisun Marsh. Severe viral infection was also found in inland silverside and juvenile delta smelt collected from Suisun Bay during summer 2005. Lastly, preliminary evidence suggests that contaminants and disease may impair survival of age-0 striped bass. Baxter et al. 2008 found high occurrence and severity of parasitic infections, inflammatory conditions, and muscle degeneration in young striped bass collected in 2005; levels were lower in 2006. Several biomarkers of contaminant exposure including P450 activity (i.e., detoxification enzymes in liver), acetylcholinesterase activity (i.e., enzyme activity in brain), and vitellogenin induction (i.e., presence of egg yolk protein in blood of males) were also reported from striped bass collected in 2006 (Ostrach 2008).

BiOp at 186-188.

It is not clear how the BiOp or any other document in the record links the impacts of contaminants to Project Operations. The BiOp does link the position of X2 to the extent of available delta smelt habitat, suggesting that a more confined habitat "may increase" the effects of contaminants:

> During the fall, when delta smelt are nearing adulthood, the amount of suitable abiotic habitat for delta smelt is positively associated with X2. This results from the effects of Delta outflow on salinity distribution throughout the Estuary. Fall X2 also has a measurable effect on recruitment of juveniles the

> following summer in that it has been a significant covariate in delta smelt's stock-recruit relationship since the invasion of the overbite clam. Potential mechanisms for the observed effect are two-fold. First, positioning X2 seaward during fall provides a larger habitat area which presumably lessens the likelihood of density-dependent effects (e.g., food availability) on the delta smelt population. Second, a more confined distribution may increase the impact of stochastic events that increase mortality rates of delta smelt. For delta smelt, this includes predation and anthropogenic effects such as contaminants and entrainment (Sommer et al. 2007).

BiOp at 234. The Effects on Critical Habitat section states:

> [T]hrough upstream depletions and alteration of river flows, the CVP/SWP has played a role in altering the environment of the Delta. This has resulted in adverse effects to delta smelt spawning habitat availability and may mobilize contaminants. The contaminant effects may be generated or diluted by flow depending on the amount of flow, the type of contaminant, the time of the year, and relative concentrations.

BiOp at 240.

FWS may only count indirect effects as effects of the action if they are "reasonably certain to occur." FWS's contaminants analysis does not demonstrate it has complied with this requirement. It must be done.

(8) <u>Critical Habitat as Independent Basis for RPA.</u>

Federal Defendants argue that, even if Plaintiffs demonstrate that the BiOp's "jeopardy" findings were arbitrary and capricious, the Court should nevertheless deny Plaintiffs' motion because the RPA is necessary to avoid adverse modification of the delta smelt's critical habitat. Doc. 660 at 55-58. The ESA requires, once FWS finds the proposed agency action will

result in "jeopardy or adverse modification [of critical habitat] ... the Secretary shall suggest those reasonable and prudent alternatives which [it] believes would not violate [Section 7(a)(2)] and can be taken by the Federal agency or applicant in implementing the agency action." 16 U.S.C. § 1536(b)(3)(A). Avoiding adverse modification of critical habitat is an independent statutory basis for promulgation of an RPA. Federal Defendants maintain that, in light of the statutory mandate to avoid both jeopardy and adverse modification, Plaintiffs must make a separate showing, independent of or in addition to their jeopardy arguments, that the BiOp's findings on critical habitat are also arbitrary and capricious. This is true in part. To support a finding that the adverse modification conclusion is arbitrary and capricious, Plaintiffs must demonstrate either that the underlying critical habitat analysis was independently flawed or that the critical habitat analysis was entirely dependent on flawed aspects of the jeopardy analysis. Whether or not the RPA and its constituent Actions are erroneous is a separate question.

The BiOp makes findings concerning the impact of export pumping on delta smelt critical habitat, *see* BiOp at 190-202; 239-244, and concludes:

> After reviewing the current status of delta smelt critical habitat, the effects of the proposed action and the cumulative effects, it is the Service's biological opinion that the coordinated operations of the CVP and SWP, as proposed, are likely to adversely modify delta smelt critical habitat. The Service

> reached this conclusion based on the following findings, the basis for which is presented in the preceding Status of Critical Habitat/Environmental Baseline, Effects of the Action, and Cumulative Effects sections of this document.
>
> 1. The conservation role of delta smelt critical habitat is to provide migration, spawning and rearing habitat conditions necessary for successful delta smelt recruitment at levels that will provide for the conservation of the species. Appropriate physical habitat (PCE 1), water (PCE 2), river flows (PCE 3), and salinity (PCE 4) are essential for successful delta smelt spawning and survival.
>
> 2. The past and present operations of the CVP/SWP have degraded these habitat elements (particularly PCEs 2-4) to the extent that their co-occurrence at the appropriate places and times is insufficient to support successful delta smelt recruitment at levels that will provide for the species' conservation.
>
> 3. Implementation of the proposed action is expected to perpetuate the very limited cooccurrence of PCEs at appropriate places and times by: (a) altering hydrologic conditions in a manner that adversely affects the distribution of abiotic factors such as turbidity and contaminants; (b) altering river flows to an extent that increases delta smelt entrainment at Banks and Jones, as well as reduces habitat suitability in the Central and South Delta; and (c) altering the natural pattern of seasonal upstream movement of the LSZ to an extent that is likely to reduce available habitat for the delta smelt within areas designated as critical habitat.
>
> The proposed action does include a provision for VAMP to address augmentation of river flow but future implementation of this provision is not well defined, making its beneficial effects on the PCEs of delta smelt critical habitat uncertain.
>
> 4. On the basis of findings (1)-(3) above, the Service concludes that implementation of the proposed action is likely to prevent delta smelt critical habitat from serving its intended conservation role.

BiOp 278-79.

Plaintiffs respond to Federal Defendants' argument that the critical habitat analysis is actually flawed in a number of ways:

(1) FWS failed to identify the threshold for adverse modification, or to assess and explain whether the magnitude and extent of any claimed effects to critical habitat rise to that threshold level;

(2) in making finding 3(a), the BiOp did not provide analysis or explanation showing how alleged indirect effects to critical habitat will be caused by Project operations and will be reasonably certain to occur; and

(3) in making findings 3(b) and 3(c), FWS expressly relied on the flawed analyses of entrainment and X2.

Doc. 697 at 64-71:[45]

a. Identification of a Threshold For Adverse Modification/ Explanation of How Any Alleged Alteration To Critical Habitat Would Exceed that Threshold.

The BiOp's critical habitat findings 1 and 2 state that "appropriate" habitat elements are "essential" and have been "degraded ... to the extent that their co-occurrence at the appropriate places and times is insufficient to support successful delta smelt recruitment at levels that will provide for the species' conservation." BiOp at 278. However,

[45] Federal Defendants' motion to strike these arguments on the ground that they were raised for the first time in Plaintiffs' reply brief was denied. Federal Defendants were afforded the opportunity to respond, *see* Doc. 745 at 2, which they did, *see* Doc. 746 at 2-7.

Plaintiffs complain that the BiOp does not explain the extent of co-occurrence of habitat elements that is necessary for conservation of delta smelt; the magnitude of the claimed degradation of this co-occurrence that is attributable to Project operations; or why that effect renders the habitat elements "insufficient" to support the species' recovery. Plaintiffs argue, without such analysis there is no basis for FWS to conclude that habitat changes caused by Project operations will result in adverse modification of critical habitat.

Destruction or adverse modification means "a direct or indirect alteration that appreciably diminishes the value of critical habitat for both the survival and recovery of a listed species." 50 C.F.R. § 402.02. Previous rulings in related cases have held "that NMFS and FWS have interpreted the term 'appreciably diminish' to mean 'considerably reduce.'" Findings of Fact and Conclusions of Law Re the Existence of Irreparable Harm, *PCFFA v. Gutierrez*, 1:06-cv-245 OWW GSA, Doc. 367 at 24:6-9 (citing Consultation Handbook at 4-34).

Plaintiffs cite *Gifford Pinchot*, 378 F.3d at 1074, and *NWF v. NMFS II*, 524 F.3d at 932 & n.10, for the principle that FWS must identify a threshold for adverse modification and assess and explain whether the magnitude and extent of any claimed effects to critical habitat reach that threshold. These cases do not support Plaintiff's argument. *Gifford Pinchot* rejected FWS's

interpretation of "adverse modification" in a manner that only triggered an adverse modification finding where there is "an appreciable diminishment of the value of critical habitat for both survival and recovery." *Id*. at 1069. After rejecting FWS's rationale for applying the regulation, the Ninth Circuit reasoned that the various biological opinions at issue could nevertheless be found valid if they actually evaluated the impact to recovery. The *Gifford Pinchot* plaintiffs raised concerns about FWS's complete failure to address the issue of recovery in that biological opinion's critical habitat analysis. The Appeals Court specifically found that FWS detailed the percentage loss of critical habitat but did not discuss the specific impact of that loss on recovery, rendering the BiOp insufficient. 378 F.3d at 1074.

Following *Gifford Pinchot*, *NWF v. NMFS II* held that NMFS acted arbitrarily and capriciously by failing to analyze the impacts of dam operations on the recovery value of critical habitat. 524 F.3d at 932. NMFS' argument "that it 'implicitly' analyzed recovery in its survival analysis" was rejected as a "post hoc justification," because a court cannot consider "an analysis that is not shown in the record." *Id*. at 932 n.10 (internal citations and quotations omitted). Plaintiffs do not directly challenge the BiOp's recovery analysis; rather, they argue that the BiOp should have set a "threshold" for adverse

modification. Nothing in *Gifford Pinchot* or *NWF v. NMFS II* requires FWS to set a "threshold" for adverse modification.

Butte Environmental Council v. U.S. Army Corps of Engineers, 607 F.3d 570, 582-83 (9th Cir. 2010), suggests exactly the opposite. *Butte* upheld FWS's determination that destruction of a very small percentage (less than 1%) of designated critical habitat would not adversely modify the species' critical habitat. Relevant here is the Ninth Circuit's rejection of a demand that FWS address the rate of loss of critical habitat, finding that nothing in the statute or regulations requires FWS to perform such a calculation. *Id*.

Plaintiffs extensively discuss the BiOp's critical habitat analysis to attempt to demonstrate the BiOp does not identify a threshold for adverse modification or what standard for adverse modification FWS applied. *See* Doc. 697 at 66-69. Plaintiffs criticize the individual critical habitat findings for failing to clearly describe the effects of project operations on the quantity or quality of the individual habitat elements.

This disassembly, focusing on the critical habitat conclusion, does not consider the BiOp as a whole. The BiOp's adverse modification determination relies on four components: "(1) the Status of Critical Habitat... ; (2) the Environmental Baseline... ; (3) the Effects of the Action... ; and (4) Cumulative Effects...." BiOp at 139. The Status of the

Species/Environmental Baseline sections analyze how project operations have degraded the PCEs up to the present time, while the Effects Analysis analyzes how these ongoing operations will continue to adversely modify critical habitat in the future. *See id*. at 202-203. Most of the impacts analysis is found in the Status of the Species / Environmental Baseline section. The Effects Analysis explains that these well-documented prior effects will continue due to ongoing Project operations. *Id*.

In the discussion of PCE # 2 (water quality, including abiotic elements), the BiOp explains how this PCE's condition is substantially degraded by Project operations. FWS found that project operations cause "[p]ersistent confinement of the effective spawning population" and otherwise "adversely affect" turbidity, "reproductive success," the availability of prey, and the exposure of delta smelt to contaminants and to localized catastrophic events. *Id*. at 197. Plaintiffs' omnibus complaint that the critical habitat section entirely lacks analytical structure is overbroad.

b. <u>Reliance On Assumptions Of Indirect Effects Without Providing Evidence That These Indirect Effects Are Reasonably Certain To Occur.</u>

Plaintiffs argue BiOp critical habitat finding 3(a), BiOp at 278, is flawed as unsupported by any analysis verifying that Project-induced changes to Delta hydrodynamics interact with other abiotic factors to exacerbate the effects of those factors

on the delta smelt's critical habitat. Plaintiffs assert the BiOp's conclusory assertions do not explain how described indirect effects to critical habitat are reasonably certain to occur. *See* 50 C.F.R. § 402.02 (requiring that indirect effects be reasonably certain to occur).

The BiOp concludes the impact of Project Operations on PCE 2 (Water), "[a]s described in the Effects Section, the CVP/SWP alter the hydrologic conditions within spawning habitat throughout the spawning period for delta smelt by impacting various abiotic factors including the distributions of turbidity, food, and contaminants." BiOp at 239; *see also* BiOp at 241 ("In addition, pumping at Banks and Jones can alter flows within the Delta. This results in a corresponding alteration of larval and juvenile transport."); BiOp at 242 ("As described in the Effects Section, the CVP/SWP alter the hydrologic conditions within rearing habitat throughout the spawning period for delta smelt by impacting various abiotic factors including distributions of turbidity, food, and contaminants."); *id.* ("Pumping at Banks and Jones alters flows within the Delta. As described in the Effects Section, negative flows can result in an increased risk of entrainment when rearing habitat includes the South Delta."); BiOp at 243 ("As stated previously, the CVP/SWP alters the extent and location of the LSZ by modifying both the Sacramento and San Joaquin river flows which reduces habitat quality and

quantity).).

The BiOp links export pumping and contaminant effects:

> The CVP and SWP, as analyzed in the Effects Section, directly influence the location and the amount of suitable spawning habitat, especially in drier WYs. Further, through upstream depletions and alteration of river flows, the CVP/SWP has played a role in altering the environment of the Delta. This has resulted in adverse effects to delta smelt spawning habitat availability and may mobilize contaminants. The contaminant effects may be generated or diluted by flow depending on the amount of flow, the type of contaminant, the time of the year, and relative concentrations.

BiOp at 239. Although, the BiOp supports the conclusion that the Projects drive hydrodynamics during times of balanced conditions, nowhere in the BiOp or in any record citation provided by any party is there any support for the conclusion that Project operations are reasonably certain to exacerbate contaminant impacts. It is logical that changes in hydrodynamics could impact exposure to contaminants in the water, but the extent of this influence is unknown and unsupported by any analysis or record citation.

c. Reliance on Analysis Of Entrainment and X2 in Support of the Adverse Modification Determination.

Plaintiffs opening brief argued: "the BiOp's determination that proposed Project Operations will adversely modify critical habitat rests upon the same defective Project Effects Analysis that led FWS to its determination that Project Operations would jeopardize the delta smelt." Doc. 551 at 63. The critical

habitat conclusion section does explicitly rely on conclusions reached in the effects analysis' regarding entrainment and the movement of X2. For example, Critical Habitat conclusion #3 provides:

> 3. Implementation of the proposed action is expected to perpetuate the very limited co-occurrence of PCEs at appropriate places and times by: (a) altering hydrologic conditions in a manner that adversely affects the distribution of abiotic factors such as turbidity and contaminants; (b) altering river flows to an extent that increases delta smelt entrainment at Banks and Jones, as well as reduces habitat suitability in the Central and South Delta; and (c) altering the natural pattern of seasonal upstream movement of the [Low Salinity Zone ("LSZ")] to an extent that is likely to reduce available habitat for the delta smelt within areas designated as critical habitat.

BiOp at 278.

The BiOp's general conclusion that Project Operations increase delta smelt entrainment with resulting population-level impacts within year classes is valid. It is, rather, the BiOp's quantitative conclusions regarding the exact negative OMR flow ranges that are unfounded. FWS did not err by incorporating this general conclusion in its Critical Habitat conclusion.

As for the inclusion of the finding that Project Operations alter the natural pattern of seasonal movement of the Low Salinity Zone ("LSZ"), this underlying conclusion from the Effects section is not supported by the record, because it is based at least in part on the invalid quantitative analysis using the Calsim II to Dayflow comparison. This aspect of the critical

habitat analysis is without record support. These areas must be addressed on remand.

(9) Discretionary v. Nondiscretionary Actions.

Plaintiffs complain that the BiOp's Project Effects analysis was "tainted" because it does not distinguish between discretionary and non-discretionary actions. Doc. 551 at 61-63. *National Association of Home Builders v. Defenders of Wildlife*, 551 U.S. 644 (2008), held that ESA § 7's consultation requirements do not apply to non-discretionary actions. Where an agency is required by law to perform an action, it lacks the power to insure that the action will not jeopardize the species. *Id*. at 667. Plaintiffs' cite the Coordinated Operations Agreement, the Central Valley Project Improvement Act's ("CVPIA") requirements to deliver water for Central Valley wildlife refuge areas, and D-1641 as examples of mandatory aspects of Project operations that, they claim, should have been segregated from other Project Operations in the Project Effects Analysis.

However, *Home Builders* does not address whether, once section 7 consultation is triggered, the jeopardy analysis must separately identify and segregate discretionary from non-discretionary actions, relegating the non-discretionary actions to the environmental baseline. *Home Builders* addressed whether the section 7 consultation obligation attaches to a particular agency action at all. *See Home Builders*, 551 U.S. at 669-70

(holding that consultation "duty does not attach to actions... that an agency is required by statute to undertake....") (emphasis added). Plaintiffs do not suggest that section 7 does not apply to the coordinated operations of the Projects. Rather, Plaintiffs contend that the section 7 consultation process requires distinguishing between discretionary and non-discretionary Project operations to identify the actions not subject to Section 7. Neither *Home Builders* nor the regulation interpreted in *Home Builders*, 50 C.F.R. § 402.03, includes any such requirement. Plaintiffs' motion for summary judgment that the BiOp unlawfully failed to distinguish between discretionary and non-discretionary actions is DENIED. This does not mean non-discretionary actions required by law must not be considered in the consultation process. Federal Defendants and Defendant-Intervenors' cross-motion on identification of non-discretionary actions is GRANTED.

B. Application of the RPA Regulations.

Plaintiffs next argue that, in adopting the RPA, Federal Defendants did not undertake the analysis required by Section 7 and its Joint Consultation Regulations. Doc. 551 at 65-79. Under the ESA, if a biological opinion concludes that a proposed agency action will cause jeopardy to a listed species or result in the destruction or adverse modification of its critical habitat, "the Secretary shall suggest those reasonable and

prudent alternatives which he believes would not violate subsection (a)(2) and can be taken by the Federal agency or applicant in implementing the agency action." 16 U.S.C. § 1536(b)(3)(A); 50 C.F.R. § 402.14(h)(3). The Joint Consultation Regulations define such reasonable and prudent alternatives as follows:

> Reasonable and prudent alternatives refer to alternative actions identified during formal consultation that can be implemented in a manner consistent with the intended purpose of the action, that can be implemented consistent with the scope of the Federal agency's legal authority and jurisdiction, that is [sic] economically and technologically feasible, and that the Director believes would avoid the likelihood of jeopardizing the continued existence of listed species or resulting in the destruction or adverse modification of critical habitat.

50 C.F.R. § 402.02; *see also* 51 Fed. Reg. at 19,958; 50 C.F.R. § 402.14(g)(5); *Home Builders*, 551 U.S. at 652 (Section 402.02 defines what qualifies as an RPA). Under this definition, an RPA must: (1) be consistent with the purpose of the underlying action; (2) be consistent with the action agency's authority; (3) be economically and technologically feasible; and (4) avoid the likelihood of jeopardy to the species or adverse modification of its critical habitat. 50 C.F.R. § 402.02; *see also* 16 U.S.C. § 1536(b)(3)(A); *Greenpeace v. Nat'l Marine Fisheries Serv.*, 55 F. Supp. 2d 1248, 1264 (W.D. Wash. 1999).

(1) <u>FWS Did Not Explicitly Analyze Any of the Four Factors in the BiOp.</u>

It has already been determined that "the BiOp does not

explicitly discuss the first three factors -- consistency with the purpose of the action; consistency with the legal authority and jurisdiction of the action agency; and economic and technological feasibility -- at all." Memorandum Decision Re Cross Motions for Summary Judgment Re Reasonable and Prudent Alternative Claims, Doc. 354 at 16 ("None of the terms 'consistent with the intended purpose of the action,' 'jurisdiction,' 'legal authority,' or 'economically and technologically feasible,' are used in the RPA section of the BiOp."). "[I]t is undisputed that the BiOp's language contains no such discussion." *Id*. at 21.

An October 15, 2009 Decision rejected Plaintiffs' earlier argument that this analysis must be included "on the face" of the BiOp. *See* Doc. 354 at 38. However, the question of whether FWS properly promulgated the RPA was left to be "decided on the basis of the entire record." *Id*. at 51. Of the four requirements, "[j]eopardy has been found to be the 'guiding standard' for determination of RPAs." *Id*. at 27 (citing *Greenpeace* 55 F. Supp. 2d at 1268). Whether and how the record must demonstrate compliance with § 402.02 is a separate question.

(2) <u>Compliance with § 402.02.</u>

Plaintiffs allege that FWS violated the APA because the administrative record contains <u>no meaningful analysis</u> related to the first three requirements of § 402.02, and that, while FWS

undertook some analysis regarding whether its RPA would avoid jeopardizing delta smelt (the fourth factor described in § 402.02), that analysis is flawed because it was not based upon the best available science.

a. Jeopardy Factor (Fourth Factor).

Plaintiffs maintain that FWS violated the ESA by adopting its RPA without providing a reasoned analysis regarding how the various RPA actions will avoid the likelihood of jeopardizing the delta smelt or adversely modifying its critical habitat. The Consultation Handbook directs that "[w]hen a reasonable and prudent alternative consists of multiple activities, it is imperative that the opinion contain a thorough explanation of how each component of the alternative is essential to avoid jeopardy." Consultation Handbook at 4-43. Plaintiffs do not dispute that the BiOp contains extensive discussion of the need for the RPA components. Rather, Plaintiffs contend that the RPA violates § 402.2 because that discussion is not based on the best available science.

The § 402.02 requirements and the best available science requirement are separate. It is undisputed that both the BiOp and its RPA must be based on the best available science, but a violation of that requirement does not necessarily violate § 402.02. Whether each part of the jeopardy analysis relies on the best available science is discussed above. Section 402.02

does not provide an independent statutory basis for imposing liability upon FWS for failing to comply with the best available science requirement. Plaintiffs' motion for summary judgment on this ground is DENIED; Federal Defendants' and Defendant-Intervenors' is GRANTED.

b. Non-Jeopardy Factors (Factors One Through Three).

It is undisputed that the BiOp contains no explicit discussion of the first three factors: (1) consistency with the purpose of the underlying action; (2) consistency with the action agency's authority; and (3) economic and technological feasibility. Plaintiffs insist that the ESA and its implementing regulations require that the record contain explicit "analyses" of each of the four factors. As authority, Plaintiffs invoke general principles of Administrative Law, including the rule that a court "cannot infer an agency's reasoning from mere silence." *See PCFFA,* 426 F.3d at 1091.

It is undisputed that there is no explicit analysis anywhere in the record of the three non-jeopardy factors. Federal Defendants and Defendant-Intervenors dismiss this fact, arguing (1) that no such explicit analysis is required by law and (2) that satisfaction of all three factors is so obvious that explicit analysis is unnecessary. *See* Doc. 660 at 70-72; Doc. 661-3 at 35-38.

Many of the cases upon which the parties now rely were

discussed in the October 15, 2009 Decision:

> Plaintiffs and DWR rely on caselaw to support their contention that, despite the lack of an explicit requirement, the BiOp must include findings treating the first three RPA requirements. It is undisputed that an agency acts arbitrarily and/or capriciously when it fails to consider an important aspect of a problem before it. *Pac. Coast Fed'n of Fishermen's Ass'ns v. NMFS*, 265 F.3d 1028, 1034 (9th Cir. 2001) ("*PCFFA I*"). But, whether an agency must expressly consider any particular issue on the face of its decisional document, as opposed to elsewhere in the administrative record, is a different question. On the one hand, an agency action may be upheld even if it is of "less than ideal clarity" as long as "the agency's path may reasonably be discerned." *Bowman Transp., Inc. v. Arkansas-Best Freight System, Inc.*, 419 U.S. 281, 285-86 (1974). However, a court "cannot infer an agency's reasoning from mere silence..." but must "rely only on what the agency actually said...." *Compare Gifford Pinchot Task Force v. U.S. Fish and Wildlife Serv.*, 378 F.3d 1059, 1072 n.9 (9th Cir. 2004) (holding that the court "may only rely on what the agency said in the record to determine what the agency decided and why"); *Pac. Coast Fed'n of Fishermen's Ass'ns v. NMFS*, 426 F.3d 1082, 1092 (9th Cir. 2005) ("*PCFFA II*") (citing *Gifford Pinchot* for the proposition that a court must "rely only on what the agency actually said in the biological opinion"). Does the caselaw require that the RPA requirements be discussed on the face of the BiOp?
>
> Plaintiffs place great weight on the Ninth Circuit's decision in *Southwest Center for Biological Diversity v. U.S. Bureau of Reclamation*, 143 F.3d 515, 518 (9th Cir. 1998), upholding a FWS biological opinion concluding that Reclamation's operations on Lake Mead and the Lower Colorado River would jeopardize an endangered bird species, the Southwestern Willow Flycatcher. Before the BiOp was finalized, FWS sent Reclamation a draft RPA comprised of a number of short and long-term components. *Id*. Some of the short-term measures would have required Reclamation to lower the level of Lake Mead. Reclamation advised FWS that it lacked discretion to do so. *Id*. FWS's final BiOp confirmed that project operations would jeopardize the species, but proposed a new RPA which no longer

required Reclamation to take the originally-proposed short term actions, replacing them with other short term measures. *Id*.

Environmental plaintiffs argued that FWS improperly rejected the draft RPA in favor of the final RPA, which does less to preserve habitat near Lake Mead, "based on Reclamation's alleged lack of discretion to lower the level of Lake Mead." *Id*. at 523. Specifically, Plaintiffs complained "that the secretary never independently reviewed Reclamation's representation that it lacked such discretion." *Id*.

The Ninth Circuit rejected this argument on several grounds. First, "under the ESA, the Secretary was not required to pick the first reasonable alternative the FWS came up with in formulating the RPA. The Secretary was not even required to pick the best alternative or the one that would most effectively protect the Flycatcher from jeopardy.... <u>The Secretary need only have adopted a final RPA which complied with the jeopardy standard and which could be implemented by the agency</u>." *Id*. at 523 (emphasis added).

Second, "under the ESA, the Secretary was not required to explain why he chose one RPA over another, or to justify his decision based solely on apolitical factors.[FN5]" *Id*. Footnote 5 further explains:

> The Secretary must rely on "the best scientific and commercial data available" in formulating an RPA, 16 U.S.C. § 1536(a)(2). However, the ESA does not explicitly limit the Secretary's analysis to apolitical considerations. <u>If two proposed RPAs would avoid jeopardy to the Flycatcher, the Secretary must be permitted to choose the one that best suits all of its interests, including political or business interests</u>.

Id.
The Ninth Circuit then articulated the governing standard: "The only relevant question before [the court] for review was whether the Secretary acted arbitrarily and capriciously or abused his discretion in adopting the final RPA." *Id*. "In answering this question, the court had only to determine if the final RPA met the standards and requirements of the ESA. The court was not in a position to determine if the draft

RPA should have been adopted or if it would have afforded the Flycatcher better protection." *Id*.

The Ninth Circuit reviewed the evidence and found no APA violation:

> Upon careful review of the evidence, we cannot say the district court erred in finding that the final RPA met the standards and requirements of the ESA. The district court determined that the FWS considered the relevant factors and reasonably found that the Flycatcher could survive the loss of habitat at Lake Mead for eighteen months until 500 acres could be protected, then survive an additional two years until an additional 500 acres could be protected, and finally survive through the MSCP process until compensation could be made for the historical habitat lost on the Lower Colorado River and until an extensive ecological restoration could be undertaken. Southwest failed to present any convincing evidence to contradict the FWS' findings. Southwest merely relied upon the discarded draft RPA which had indicated that preservation of the Lake Mead habitat was necessary to the survival of the Flycatcher. However, upon further consideration of the matter, the FWS was entitled to, and did, in fact, change its mind. The FWS concluded in the final BO that the proposed short-term and long-term provisions of the final RPA would avoid jeopardy to the Flycatcher, notwithstanding the failure to modify Reclamation's operation of Hoover Dam at Lake Mead. <u>Because there was a rational connection between the facts found in the BO and the choice made to adopt the final RPA, and because we must defer to the special expertise of the FWS in drafting RPAs that will sufficiently protect endangered species, we cannot conclude that the Secretary violated the APA</u>.

Id. (emphasis added).

Plaintiffs argue the emphasized text, approving FWS's RPA because there was a rational connection between the facts "found in the BiOp" and that decision, establishes that the FWS must make findings on all four RPA requirements on the face of the BiOp. This overstates the Ninth Circuit's holding. First,

Southwest Center says nothing about requiring findings on the face of the BiOp. The requisite findings were, unsurprisingly, in the BiOp in that case, because those findings concerning how each component of the final RPA would avoid jeopardy, were explicitly required by the Consultation Handbook. Consultation Handbook 4-41 ("When a reasonable and prudent alternative consists of multiple activities, it is imperative that the opinion contain a thorough explanation of how each component of the alternative is essential to avoid jeopardy and/or adverse modification.")(emphasis added). Neither the Handbook, the ESA, nor any of its implementing regulations explicitly require that the BiOp contain an analysis of any of the other three RPA requirements.

Plaintiffs suggest the second sentence from the *Southwest Center* language delineates that findings are required for all four RPA requirements. Plaintiffs quote that sentence as authority to claim the "'FWS considered the relevant factors and reasonably found'[] the Joint Consultation Regulations requirements were satisfied with respect to an RPA issued in a biological opinion for the Southwest Willow Flycatcher...." Doc. 237 at 10. This is misleading, because the entire sentence makes clear that the only "findings" discussed in *Southwest Center* were findings concerning the capacity of the Flycatcher to survive in the short term while the RPA was being implemented. 143 F.3d at 523. *Southwest Center* only stands for the proposition that FWS must justify its conclusion that the RPA would prevent jeopardy and/or adverse modification in the BiOp. *See Greenpeace*, 55 F. Supp. 2d at 1268 (finding the jeopardy determination to be the "guiding standard" for determination of RPAs). *Southwest Center* does not create the discussion requirement Plaintiffs suggest.

PCFFA II, on which Plaintiffs also rely, is not contrary. 426 F.3d 1082. There, the Ninth Circuit overturned an RPA adopted for coho salmon because NMFS failed to articulate the bases for its assumptions underlying the RPA. *Id*. at 1090-95. The district court concluded that the agency had "implicitly considered" whether all three phases of the RPA would ensure against jeopardy. *Id*. at 1091. The Ninth Circuit emphasized that "it is a basic principle of administrative law that the agency must articulate the reason or reasons for its decision." *Id*.

The Ninth Circuit found "little substance to the discussions of Phases I and II" in the BiOp. *Id*. at 1093. Although some language suggested that "the agency believed that the RPA would avoid jeopardy to the coho, this assertion alone is insufficient to sustain the BiOp and the RPA." *Id*. The Ninth Circuit refused to "take [the agency's] word that the species will be protected if its plans are followed." *Id*. As in *Southwest Center*, *PCFFA II* only discussed whether the RPA would avoid jeopardy, the analysis of which is explicitly required in the BiOp. Here, Plaintiffs seek to extend this logic to mandate that FWS include specific findings concerning the three other RPA requirements in the BiOp. *PCFFA II* does not require this.

Plaintiffs also cite *NRDC v. Kempthorne*, 506 F. Supp. 2d 322 (E.D. Cal. 2007), which held that, although certain, potentially critical data was part of the administrative record, its significance, or lack thereof, was not discussed in the BiOp. *Id*. at 362-363. The government's post hoc reasoning was rejected, that, even if the data had been addressed in the BiOp, the ultimate opinion reached by the Service would not have been different. "Although a decision of less than ideal clarity may be upheld if the agency's path may reasonably be discerned, [a court] cannot infer an agency's reasoning from mere silence. Rather, an agency's action must be upheld, if at all, on the basis articulated by the agency itself." *Id*. at 366 (citing *PCFFA*, 426 F.3d at 1091). The district court further reasoned "[h]ad FWS examined the FMWT 2004 data in the BiOp, the weight it gave to that data would have been entitled to deference. The agency's silence cannot be afforded deference." *Kempthorne*, 506 F. Supp. 2d at 366.

Plaintiffs argue that this language reflects a requirement that analysis of the data must be included <u>in the BiOp</u>, suggesting that if such analysis was instead found elsewhere in the administrative record it would be insufficient. This reads too much into *Kempthorne*, where the necessary reasoning was found in <u>neither</u> the BiOp <u>nor</u> the administrative record. *Id*. at 380 (district court searched for, but did not find, certain analyses in the BiOp or "elsewhere in the administrative record). *Kempthorne* found the content of the BiOp lacking in light of the entire AR, both of

which entirely failed to competently perform the required ESA jeopardy and habitat modification analyses. The practical fact is that a BiOp is much more accessible than the administrative record, which can be tens of thousands of pages long. *Kempthorne* did not address or decide the issue presented here.

In APA review cases, it is well established that, in determining whether agency action was "arbitrary, capricious, an abuse of discretion, or otherwise not in accordance with law.... the court shall review the whole record or those parts of it cited by a party, and due account shall be taken of the rule of prejudicial error." 5 U.S.C. § 706. The "whole record," includes "everything that was before the agency pertaining to the merits of its decision." *Portland Audubon Soc'y v. Endangered Species Committee*, 984 F.2d 1534, 1548 (9th Cir. 1993). *See also Seattle Audubon Soc'y v. Lyons*, 871 F. Supp. 1291, 1308 (W.D. Wash. 1994) (finding declarations properly considered to "explain the agency's actions or to determine whether its course of inquiry was inadequate.").

DWR's cases do not undermine this reasoning. *Motor Vehicle Manufacturers Association of the United States, Inc., v. State Farm Mutual Auto Insurance Company*, 463 U.S. 29 (1983), concerned the National Highway Traffic Safety Administration's ("NHTSA") decision to rescind passive restraint crash safety requirements for new motor vehicles. When NHTSA learned that automakers opted to install automatic seatbelts which users could easily detach, the agency rescinded the order in light of the expense required to implement a program that would have only minimal safety benefits because it could be disengaged by users. *Id*. at 38-39. The Court concluded that this decision was arbitrary and capricious because NHTSA failed to consider modifying the standard to require the installation of airbags. *Id*. at 46. In reaching this conclusion, the Court indicated it must "consider whether the <u>decision</u> was based on a consideration of the relevant factors and whether there has been a clear error of judgment." *Id*. (emphasis added).

Focusing on *State Farm's* use of the word "decision," DWR asserts that all relevant factors must be considered in the text of the agency's decision document, rather than elsewhere in the administrative

record. But, *State Farm* also emphasized that the relevant statue required a "record of the rulemaking proceedings to be compiled," *id*. at 43-44, and indicated that "Congress established a presumption against.... changes in current policy that are not justified by the rulemaking record," *id*. at 43. *State Farm* does not support DWR's position that the "whole record" rule should be ignored in favor of a requirement that any and all analytical reasoning must be included in the decision document (the BiOp).

DWR also relies on *Burlington Truck Lines, Inc. v. United States*, 371 U.S. 156, 168-69 (1962), which criticized the Interstate Commerce Commission's ("ICC") failure to make any findings or include any analysis to justify a particular decision. The Court noted that "expert discretion is the lifeblood of the administrative process, but unless we make the requirements for administrative action strict and demanding, expertise, the strength of modern government, can become a monster which rules with no practical limits on its discretion." *Id*. at 167 (internal citations and quotations omitted). *See also Ry. Labor Executives' Ass'n v. ICC*, 784 F.2d 959, 974 (refusing to "rummage around in the record below to find a plausible rationale to fill the void in the agency order under review"). *Burlington* and *Railway Labor Executives'* insistence upon formal findings is unsurprising given that, under the procedures applicable in that case, where the ICC was required to "make findings that support its decision, and those findings must be supported by substantial evidence." *Id*. No such general findings requirement exists here. Rather, the only findings explicitly required by the Consultation Handbook are those concerning the capacity of any RPA to prevent jeopardy and/or adverse modification.

A statute or regulation may specifically require certain reasoning or findings to be included in the ultimate decision document. The above-mentioned requirement that the BiOp explain why each part of a multi-part RPA ensures against jeopardy or adverse modification is one such example. However, there is no parallel requirement that FWS certify or make findings with respect to the other three RPA requirements on the fac[e] of the record. It is not appropriate for a court to "create[] a requirement not found in any

> relevant statute or regulation." *The Lands Council v. McNair*, 537 F.3d 981, 991 (9th Cir. 2008). Rather, the issue of whether FWS properly promulgated the RPA must be decided on the basis of the entire record.

Doc. 354 at 38-51 (footnotes omitted, emphasis in original). Plaintiffs' argument that the three non-jeopardy factors must be explicitly analyzed on the face of the BiOp was rejected, but the question of how the three non-jeopardy factors must be treated elsewhere in the record was left open. Must an explicit analysis of the three factors be included in the record? Or may evidence in the record itself, even absent explicit analysis, be relied upon to evaluate whether the RPA satisfies the three factors? The October 15, 2009 Decision recognizes a dichotomy in the caselaw:

> On the one hand, an agency action may be upheld even if it is of "less than ideal clarity" as long as "the agency's path may reasonably be discerned." *Bowman Transp., Inc. v. Arkansas-Best Freight System, Inc.*, 419 U.S. 281, 285-86 (1974). However, a court "cannot infer an agency's reasoning from mere silence..." but must "rely only on what the agency actually said...." *Compare Gifford Pinchot Task Force v. U.S. Fish and Wildlife Serv.*, 378 F.3d 1059, 1072 n.9 (9th Cir. 2004) (holding that the court "may only rely on what the agency said in the record to determine what the agency decided and why"); *Pac. Coast Fed'n of Fishermen's Ass'ns v. NMFS*, 426 F.3d 1082, 1092 (9th Cir. 2005) ("*PCFFA II*") (citing *Gifford Pinchot* for the proposition that a court must "rely only on what the agency actually said in the biological opinion").

Id. at 39.

Defendants acknowledge that the agency must explicitly analyze the jeopardy factor, but claim that it is permissible for

the agency not to address the non-jeopardy factors anywhere in the administrative record. To accept Defendants' view would be to abdicate the judicial review function. Even though the jeopardy factor is the "guiding standard" for the adoption of an RPA, *see Greenpeace*, 55 F. Supp. 2d at 1268, this does not eviscerate the other three § 402.02 factors. *Greenpeace* rejected the contention that the "economically and technologically feasible" language required the agency to "balance the benefit to the species against the economic and technical burden on the industry before approving an RPA," because such a conclusion would be inconsistent with the purposes of the ESA under *TVA v Hill*. *Id*. *Greenpeace* confirms that 50 C.F.R. § 402.02 "contains four distinct requirements for any valid RPA," *id*. at 1264, and that FWS "must come up with [RPAs] that are consistent with the purposes of the underlying action and the action agency's authority, that are economically and technologically feasible, and which avoid the likelihood of jeopardy and adverse modification." *Id*.

According to *PCFFA*, a court should "sustain an agency action if the agency has articulated a rational connection between the facts found and the conclusions made." 426 F.3d at 1090 (citing *Motor Vehicle Mfrs. Ass'n,* 463 U.S. at 43).

> "Even when an agency explains its decision with 'less than ideal clarity,' a reviewing court will not upset the decision on that account 'if the agency's path may reasonably be discerned.'" *Alaska Dep't of Envt'l*

> *Conserv. v. EPA*, 540 U.S. 461, 497 (2004) (quoting Bowman *Transp., Inc. v. Arkansas-Best Freight Sys., Inc.*, 419 U.S. 281, 286 (1974))
>
> While our review is deferential, our inquiry must "be searching and careful." *Marsh*, 490 U.S. at 378. We must determine whether the agency's decision was "based on a consideration of the relevant factors and whether there has been a clear error of judgment." *Id*.

Id. Here, the agency has articulated absolutely no connection between the facts in the record and the required conclusion that the RPA is (1) consistent with the purpose of the underlying action; (2) consistent with the action agency's authority; and (3) economically and technologically feasible. The record here is not just an explanation of "less than ideal clarity." There is no explanation at all

Defendants offer a number of post hoc rationalizations for the RPA. Defendant-Intervenors argue that the record demonstrates the RPA can be implemented in a manner consisted "with the intended purpose of the action" and "within the scope of the Federal agency's legal authority and jurisdiction," because, by letter dated December 15, 2008, the Bureau "provisionally accept[ed]" most portions of the RPA and stated that Components 3 and 4 "both need additional review and refinement before Reclamation will be able to determine whether implementation of these actions by the Projects is reasonable and prudent." *NRDC v. Kempthorne*, 1:05-cv-01207 OWW GSA, Doc. 767-1. Defendant-Intervenors conclude that the Bureau has made no

determination that the RPA is inconsistent with the purpose of the action or with its legal authority and jurisdiction. Doc. 661-3 at 38. They suggest as to economic and technological feasibility, that these requirements must have been considered because, based on concerns expressed by the Bureau, the RPA was modified to be more flexible.[46] *Id*. at 37.

But, the record provides none of these explanations.[47] FWS is ultimately responsible to ensure that the record supports the RPA. FWS explained in the preamble to its final rule adopting the Joint Consultation Regulations:

> [I]n those instances where the Service disagrees with a Federal agency's assessment of the reasonableness of its alternatives, the Service must reserve the right to include those alternatives in the biological opinion if it determines that they are "reasonable and prudent" according to the standards set out in the definition in

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[46] For example, OMR flows under Components 1 and 2 are to be calculated based on a 14-day running average, compared to the 7-day average under the interim remedial order. *See* BiOp at 168, 280-82. The turbidity trigger for Action 1 of Component 1 is now based on a 3-day average at three stations in the Delta, compared to one station under the Court's interim remedial order, to "better reflect a Delta-wide change in turbidity than one station which may be prone to localized conditions." BiOp at 281, 347.

[47] The specific requirements of the X2 action are another example of how the record fails to address the "consistentcy with the intended purpose of the action," and is "within the scope of the … agency's authority and jurisdiction." 50 C.F.R. § 402.02. Because of competing demands for water from the Projects, combined with a limited supply, one purpose of the Projects is to ensure that that water use and allocation be carefully managed, and to also ensure that water is put to a beneficial use and not wasted. This purpose is, in fact, required by California law, Cal. Const. art. X, § 2; Cal. Water Code § 275, and imposed upon federal project operations by virtue of Section 8 of the Reclamation act of 1902. 43 U.S.C. § 383. The Projects will have to expend hundreds of thousands of acre feet of water to maintain X2 as far seaward as Component 3 requires. Miller Decl., Doc. 400, at ¶¶ 67-73. Less water would be required if X2 did not need to be pushed so far downstream–water would then be available for other uses. Yet nothing in the BiOp or the record explains why it is essential that X2 be moved seaward to the degree required by Component 3 in order to protect the smelt and its habitat.

> § 402.02; the Service cannot abdicate its ultimate duty to formulate these alternatives by giving Federal agencies control over the content of a biological opinion.

51 Fed. Reg. 19,926, 19,952 (June 3, 1986). Even if, *arguendo*, the RPA is consistent with the multiple purposes of the action and the agency's statutory authority, and is economically and technologically feasible to implement, the APA requires, and the public is entitled under the law to receive, some exposition in the record of why the agency concluded (if it did so at all) that all four regulatory requirements for a valid RPA were satisfied. The RPA Actions manifestly interdict the water supply for domestic human consumption and agricultural use for over twenty million people who depend on the Projects for their water supply. "Trust us" is not acceptable. FWS has shown no inclination to fully and honestly address water supply needs beyond the species, despite the fact that its own regulation requires such consideration.

How the appropriation of water for the RPA Actions, to the exclusion of implementing less harmful alternatives, is required for species survival is not explained. The appropriate remedy for such a failure to explain is remand to the agency. *See Sears Sav. Bank v. Federal Sav. and Loan Ins. Corp*. 775 F.2d 1028, 1030 (9th Cir. 1985) ("If the administrative record is inadequate to explain the action taken, the preferred practice is to remand to the agency for amplification."). Plaintiffs' motion for

summary judgment that FWS violated § 402.02 is GRANTED; Defendants' cross-motion is DENIED.

c. There is no Procedural Requirement that FWS Accept, Consider, and/or Address Comments Regarding the BiOp or its RPA.

Neither the ESA nor its implementing regulations require an opportunity for public comment or that FWS respond to any comments received. *See Kandra v. United States*, 145 F. Supp. 2d 1192, 1209 n.8 (D. Or. 2001) ("as the government correctly pointed out during oral argument, the ESA does not require public review or input during the consultation process"); *Ctr. for Biological Diversity v. Kempthorne*, 2008 WL 659822, *7 (D. Ariz. Mar. 6, 2008) ("Biological opinions, unlike DPS findings, are not subject to notice and comment rulemaking procedures pursuant to the ESA."). Plaintiffs' suggestion that FWS violated the ESA by "ignoring" comments on the draft BiOp is legally unsustainable. Plaintiffs' motion on this ground is DENIED; Defendants' cross-motion is GRANTED.

C. Stewart & Jasper Orchards' Argument Re: Reasonable and Prudent Measures.

Stewart & Jasper Orchards, et al., ("Stewart & Jasper") allege that FWS's failure to consider the economic impacts of implementing the reasonable and prudent measures ("RPMs") is arbitrary and capricious. Doc. 551 at 68 n. 24. Whenever FWS offers reasonable and prudent alternatives to avoid jeopardy to a

species, it must also specify "those reasonable and prudent measures that [FWS] considers necessary or appropriate to minimize" incidental taking of the species. 16 U.S.C. § 1536(b)(4)(C)(ii). Stewart & Jasper argues that by formulating RPMs that it believes "are necessary and appropriate to minimize the effect of the proposed action on the delta smelt," without "provid[ing] a statement that allows for Reclamation to take into consideration the economic impacts of implementing the RPMs," *see* BiOp at 294, FWS has allegedly "arbitrarily left open the question of whether the RPMs are in fact reasonable, necessary, and appropriate in light of the harm that their implementation will cause." Doc. 551 at 68 n. 24.

This argument is unsupported in law. Unlike 50 C.F.R. § 402.02's definition of a RPA, which provides that RPAs must be "economically and technologically" feasible, the regulatory definition of RPM lacks such language:

> Reasonable and prudent measures refer to those actions the Director believes necessary or appropriate to minimize the impacts, i.e., amount or extent, of incidental take.

50 C.F.R. § 402.02. Even if the definition of RPM included an economic feasibility requirement, this language does not require that FWS "balance the benefit to the species against the economic and technical burden on the industry before approving an RPA," because such a conclusion is inconsistent with the purposes of the ESA under *TVA v Hill*. *Greenpeace*, 55 F. Supp. 2d at 1267.

Stewart & Jasper's motion for summary judgment regarding the lawfulness of the RPMs for failure to consider economic effects is DENIED; Federal Defendants and Defendant-Intervenors' cross-motions are GRANTED.

D. Stewart & Jasper, et al.'s, Argument that FWS Illegally Arrogated Authority to Itself Over Bureau of Reclamation and California Department of Water Resources Operations.

The Stewart & Jasper Plaintiffs raise a novel argument that FWS "illegally arrogated" authority to itself over Reclamation and DWR, by "claim[ing] the ability to oversee [Project operations] indefinitely," rather than "advis[ing] Reclamation and DWR on how to avoid jeopardizing the delta smelt and destroying or adversely modifying its critical habitat." Doc. 551 at 80:

> In RPA Component 1, for example, FWS not only set forth actions "designed to reduce the delta smelt entrainment losses," but also stated that "[t]hroughout the implementation of RPA Component 1, FWS will make the final determination as to OMR flows required to protect delta smelt." BiOp at 280-81. Likewise, in RPA Component 2 that FWS "shall make the final determination regarding specific OMR flows," BiOp at 282, as well as the FWS' reasonable and prudent measures. See BiOp at 294 (noting that FWS "shall have the final decision on the operations of the Permanent Gates" and that the members of the Gate Operations Review Team "can provide suggestions to operate the gates, but the ultimate decision on how to operate the gates to protect delta smelt will be made by the Service").

Id.

Stewart & Jasper argue that this is unlawful because the ESA "does not give the FWS the power to order other agencies to

comply with their requests or to veto their decisions." *Id*. (citing *Sierra Club v. Marsh*, 816 F.2d 1376, 1386 (9th Cir. 1987)). The law is clear that FWS has no such authority, nor can FWS, as consulting agency, act *ultra vires* to usurp the operational authority of the Bureau and DWR over the Projects. The November 13, 2009 Decision found: "the action agency retains the ultimate responsibility for deciding whether, and how, to proceed with the proposed action after Section 7 consultation." Doc. 399, Mem. Decision re Cross-Motions for Summary Judgment on NEPA Issues, at 23-24 n.7. Even if FWS issues an RPA with specific requirements following a jeopardy or adverse modification finding, the action agency remains free to disregard such requirements, and FWS has no enforcement authority absent an ESA violation. Reclamation and DWR have provisionally adopted the RPA and have implemented many of its Actions, but the record does not show FWS employees have "claimed the ability to oversee these agencies indefinitely." Doc. 551 at 80.

Stewart & Jasper's contention that FWS's reserved to itself "an ongoing power of oversight, as well as a power to dictate new and different pumping restrictions," assumes that neither Reclamation, as action agency, nor DWR, as co-operator, have the ability to not comply with the RPA. Doc. 697 at 87. Reclamation is not legally compelled to blindly follow FWS's pronouncements. Reclamation retains the authority to reject the RPA at any time,

subject to its obligation to reinitiate consultation. Although FWS has not yet demonstrated a willingness or capability to protect interests other than the species, it cannot be assumed that Reclamation will not lawfully discharge its statutory water supply responsibilities.

Stewart & Jasper's motion for summary judgment regarding FWS's alleged unlawful arrogation of authority is DENIED; Federal Defendants and Defendant-Intervenors' cross-motions are GRANTED.

E. Information Quality Act Claim.

Family Farm Alliance ("FFA") Plaintiffs claim that Federal Defendants did not apply the IQA and its implementing guidelines in preparing and disseminating the BiOp.

(1) Legal Framework of the IQA.

The IQA provides in its entirety:

> (a) IN GENERAL.--The Director of the Office of Management and Budget shall, by not later than September 30, 2001, and with public and Federal agency involvement, issue guidelines under sections 3504(d)(1) and 3516 of title 44, United States Code, that provide policy and procedural guidance to Federal agencies for ensuring and maximizing the quality, objectivity, utility, and integrity of information (including statistical information) disseminated by Federal agencies in fulfillment of the purposes and provisions of chapter 35 of title 44, United States Code, commonly referred to as the Paperwork Reduction Act.
>
> (b) CONTENT OF GUIDELINES.--The guidelines under subsection (a) shall--
>
> > (1) apply to the sharing by Federal agencies of, and access to, information disseminated by Federal

> agencies; and
>
> (2) require that each Federal agency to which the guidelines apply--
>
> (A) issue guidelines ensuring and maximizing the quality, objectivity, utility, and integrity of information (including statistical information) disseminated by the agency, by not later than 1 year after the date of issuance of the guidelines under subsection (a);
>
> (B) establish administrative mechanisms allowing affected persons to seek and obtain correction of information maintained and disseminated by the agency that does not comply with the guidelines issued under subsection (a); and
>
> (C) report periodically to the Director--
>
> (i) the number and nature of complaints received by the agency regarding the accuracy of information disseminated by the agency; and
>
> (ii) how such complaints were handled by the agency.

Pub. L. 106-554, 114 Stat 2763, 2763A-153-2763A-154 (2000) (codified at 44 U.S.C. § 3516).

Subsection (a) mandates that the Office of Management and Budget ("OMB") issue, by no later than September 30, 2001, government-wide guidelines to ensure the "quality, objectivity, utility, and integrity of information" disseminated by federal agencies. *See* Pub. L. No. 106-554, § 515(a) (2000). The statute itself contains no substantive provisions regarding information quality, leaving the structure and design of any such

requirements to OMB. There is no relevant legislative history disclosing substantive Congressional intent regarding information quality.

Within one year of OMB's issuance of Guidelines, each federal agency was required to issue its own guidelines consistent with OMB's. *Id*. at § 515(b)(2)(A). OMB, the Department of the Interior, and FWS timely issued the required guidelines. *See, e.g.*, Guidelines for Ensuring and Maximizing the Quality, Objectivity, Utility, and Integrity of Information Disseminated by Federal Agencies, 67 Fed. Reg. 8,452 (Feb. 22, 2002) ("OMB IQA Guidelines"); Information Quality Guidelines of the U.S. Department of the Interior, 67 Fed. Reg. 50,687 (Aug. 5, 2002)) ("DOI IQA Guidelines"); FWS Information Quality Guidelines ("FWS IQA Guidelines")[48]. The IQA specifically required agencies to "establish administrative mechanisms allowing affected persons to seek and obtain correction of information maintained and disseminated by the agency...." and to "report periodically" on "the number and nature of complaints received by the agency regarding the accuracy of information disseminated by the agency" and "how such complaints were handled by the agency." *Id*. at § 515(b)(2)(B)&(C)(emphasis added).

FWS's own IQA Guidelines are specific to its activities and disseminations, including biological opinions, and state that in

[48] Available at http://www.fws.gov/informationquality/topics/IQAguidelines-final82307.pdf (last visited August 11, 2010).

order to ensure objectivity of information disseminated, the information will be presented in an "accurate[]," "clear[]," "complete[]," and "unbiased" manner. FWS IQA Guidelines III-8. In addition, FWS' IQA Guidelines require that a "preparer of a highly influential assessment or of influential information ... document the strengths and weaknesses of the data underlying the assessment/information so that the reader will understand the context for the FWS decision." *Id*. at § VI-10. Plaintiffs maintain that FWS failed to comply with these guidelines because the "effects of the BiOp were assumed, not supported by data and objective and scientific analyses." Doc. 551 at 82.

(2) Right to Judicial Review Under the APA.

Federal Defendants and Defendant Intervenors raise a threshold objection, arguing that there is no right of judicial review under the IQA.

It is undisputed that the IQA provides no private right of action. A party challenging an administrative agency's compliance with a substantive statute that lacks an internal private right of action must seek judicial review under the APA. *See Lujan v. Nat'l Wildlife Fed'n*, 497 U.S. 871, 882 (1990); *Village of False Pass v. Clark*, 733 F.2d 605, 609 (9th Cir. 1984) (because ESA contains no internal standard of review, APA § 706 governs review of actions brought under the ESA).

The APA authorizes suit by a plaintiff "suffering legal wrong because of agency action, or adversely affected or aggrieved by agency action within the meaning of a relevant statute." 5 U.S.C. § 702. There is a presumption of reviewability under the APA. *Shalala v. Illinois Council on Long Term Care, Inc.*, 529 U.S. 1, 44 n.11 (2000). However, the APA expressly precludes judicial review where: (1) any statute "precludes judicial review"; or (2) "agency action is committed to agency discretion by law." 5 U.S.C. § 701(a). If either of these exceptions applies, the lawsuit cannot proceed under the APA.

If neither exception applies, the APA permits judicial review of "[a]gency action made reviewable by statute and final agency action for which there is no other adequate remedy in a court...." 5 U.S.C. § 704. Where a statute lacks an internal judicial review provision, the "agency action made reviewable by statute" language is inapplicable, requiring the existence of a "final agency action." "Agency action" is defined to include "the whole or a part of an agency rule, order, license, sanction, relief, or the equivalent or denial thereof, or failure to act." 5 U.S.C. § 551(13). The APA requires that the agency action be upheld unless it is found to be "arbitrary, capricious, an abuse of discretion, or otherwise not in accordance with law," or "without observance of procedure required by law." 5 U.S.C. §

706(2).

a. APA § 702(a)(2)'s Exception for Agency Action "Committed to Agency Discretion by Law" Bars Judicial Review in this Case.

FFA does not allege that any statute expressly precludes judicial review of FFA's IQA claim. The issue is whether the IQA and/or its implementing guidelines, by law, commit to agency discretion the disputed agency actions challenged by Plaintiff's claim.

The general test for when an action is "committed to agency discretion by law" under the APA is whether there is "no law to apply." *Heckler v. Chaney*, 470 U.S. 821, 830 (1985) (internal quotation marks omitted). "Agency action is committed to the discretion of the agency by law when 'the statute is drawn so that a court would have no meaningful standard against which to judge the agency's exercise of discretion.'" *Steenholdt v. FAA*, 314 F.3d 633, 638 (D.C. Cir. 2003) (quoting *Heckler*, 470 U.S. at 830). "If no 'judicially manageable standard' exists by which to judge the agency's action, meaningful judicial review is impossible and the courts are without jurisdiction to review that action." *Id*. Here, the IQA itself contains absolutely no substantive standards, let alone any standards relevant to the claims brought in this case concerning the timing of responses to Requests and Appeals and the makeup of peer review panels. The statute itself commits the challenged agency actions to the

agency's discretion.

However, even "[w]here an action is committed to absolute agency discretion by law, ... courts have assumed the power to review allegations that an agency exceeded its legal authority, acted unconstitutionally, or failed to follow its own regulations." *United States v. Carpenter*, 526 F.3d 1237, 1242 (9th Cir. 2008); *see also Padula v. Webster*, 822 F.2d 97, 100 (9th Cir. 1987)("Judicially manageable standards may be found in formal and informal policy statements and regulations as well as in statutes, but if a court examines all these possible sources and concludes that there is, in fact, 'no law to apply,' judicial review will be precluded.")(quoting *Citizens to Preserve Overton Park, Inc. v. Volpe*, 401 U.S. 402, 410 (1971)). The critical issue is: Do the agency's own regulations create meaningful standards or do they preserve the discretion afforded by the statute?

Salt Institute v. Thompson, 345 F. Supp. 2d 589 (E.D. Va. 2004), aff'd sub nom. on alternate grounds, *Salt Inst. v. Leavitt*, 440 F.3d 156 (4th Cir. 2006), applied 701(a)(2) and *Steenholdt* to the IQA, finding that "[n]either the IQA nor the OMB Guidelines provide judicially manageable standards that would allow meaningful judicial review to determine whether an agency properly exercised its discretion in deciding a request to correct a prior communication." With respect to the request for

correction at issue in *Salt Institute*:

> [T]he guidelines provide that "[a]gencies, in making their determination of whether or not to correct information, may reject claims made in bad faith or without justification, and are required to undertake only the degree of correction that they conclude is appropriate for the nature and timeliness of the information involved." 67 Fed. Reg. at 8458. Courts have determined that regulations containing similar language granted sufficient discretion to agencies to preclude judicial review under the APA. *See Steenholdt*, 314 F.3d at 638 (holding that agency's decision under a regulation allowing an agency to take an action "for any reason the Administration considers appropriate" is committed to agency discretion and not reviewable under APA). Judicial review of [the agency's] discretionary decisions is not available under the APA because the IQA and OMB guidelines at issue insulate the agency's determinations of when correction of information contained in informal agency statements is warranted.

Id. at 602-603. Do the IQA Guidelines create meaningful standards regarding the content of a biological opinion, or do the Guidelines preserve agency discretion over these procedural matters?[49]

Plaintiffs' attempt to distinguish *Salt Institute* on the ground that, in preparing and disseminating "highly influential"

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[49] Plaintiffs attempt to distinguish the many cases that have found no right to judicial review under the IQA on the ground none of them involved "final agency action" cognizable under the APA, which provides for judicial review of a "final agency action for which there is no other adequate remedy in a court ...." 5 U.S.C. § 704. Plaintiffs are correct that the relevant cases do not concern "final agency actions," for purposes of the APA. For example, *Salt Institute* involved the issuance of information about a trial study, an action the district court found was not "a final agency action necessary for judicial review under the APA." 345 F. Supp. 2d at 602. Here, the issuance of the BiOp is indisputably final agency action. However, "final agency action" is a necessary but not sufficient prerequisite to judicial review under the APA. Judicial review may also be precluded where there is no "judicially manageable standard" by which to judge the agency's action. *Heckler v. Chaney*, 470 U.S. at 830.

scientific documents, the agency is mandated to follow a scientific approach to develop the best available scientific data used in that document. Specifically, Plaintiffs reference FWS IQA Guidelines VI-10, which provide:

> VI – 10 <u>How will FWS describe the strengths and weaknesses of the data used in influential scientific information and highly influential scientific assessments</u>?
>
> The preparer of a highly influential assessment or of influential information will document the strengths and weaknesses of the data underlying the assessment/information so that the reader will understand the context for the FWS decision. The narrative will be contained in the administrative record of the issue under consideration. The documentation may be done in a narrative that includes a complete literature cited section, and an assessment of the strengths and weaknesses of the information used for advising the decision at hand. The narrative's form and length is left to the preparer. The following bullet points provide questions to consider in the narrative.
>
> - What types of research studies does the assessment/information rely upon (e.g. experimental studies with controls, statistically designed observational studies that test hypotheses, monitoring studies, information synthesis, professional judgment etc.)?
> - How recent is the research?
> - What are the sources for the underlying data that support the assessment/information (e.g. peer reviewed article reporting primary data or data synthesis, unpublished peer reviewed reports, on-line publication, textbook, personal communication etc.)?
> - Which of the sources were most crucial to the conclusions reached in the assessment/information?

- What type of review did each source receive (anonymous independent peer review, external peer review, agency review, public review and comment etc.)?

- Were the reviewers independent of the FWS? Were the reviewers independent of individuals or groups advocating a certain course of action by FWS?

- Were the reviews in compliance with OMB M-05-03, "Final Information Quality Bulletin for Peer Review"?

Two examples of how one might provide such a characterization are provided below:

> Example 1: (A number of references are listed.) These references were the primary sources of data that provided the basis for the decision. They are peer reviewed studies with an experimental design that includes controls and testable hypotheses. They were completed within the last 5 years and were independently reviewed by non-FWS personnel and published in scientific journals.
>
> Example 2: (A number of references are listed.) These references were articles and sources of data that provided specific data points that were included in the decision document, but by themselves did not primarily contribute to the decision. These citations are a combination of fact sheets, summaries of information, professional judgments, and personal communications that have not been peer reviewed. Most of the data is current (within the last 7 years).

Although this biological opinion is undoubtedly the type of "influential document"[50] to which this provision applies,

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[50] The FWS IQA Guidelines further state that the term "influential, when used in the phrase 'influential scientific, financial, or statistical information,' means that [FWS] can reasonably determine that dissemination of the information will have or does have a clear and substantial impact on

Plaintiffs' overreach by suggesting that these guidelines require the agency to follow any particular scientific approach to the development of the best available scientific data used in a BiOp. All that this guideline affirmatively requires is that the agency prepare some kind of "narrative" that documents the strengths and weaknesses of the data upon which the document relies. There are no other "judicially manageable standards" included in this guideline.

Under this guideline provision, Plaintiffs have not claimed that no such narrative was prepared.[51] But, that is not the thrust of any of the IQA claims in this case, which seek to impose substantive standards on the presentation, use, and analysis of data by FWS. None of the guidelines cited by Plaintiffs set forth any "judicially manageable standards" against which the presentation, use, or analysis of data can be measured. The FWS guidelines disclaim any intent to do so or any right to judicial review. There is no right to judicial review of Plaintiffs' IQA claims. FFA's motion for summary judgment is

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important public policy or private sector decisions, and thus, a decision or action to be taken by the Director.... As a general rule, FWS considers an impact clear and substantial when a specific piece of information or body of information is a principal basis for a FWS position." FWS IQA Guidelines, § III-10.

[51] Whether such a claim would be subject to judicial review is not clear. The guidelines specify that they are "intended only to improve the internal management of FWS relating to the [IQA]. Nothing in these guidelines is intended to create any right or benefit, substantive or procedural, enforceable by law or equity against the United States, its agencies, its offices, or another person. These guidelines do not provide, in any by themselves, any right to judicial review." FWS IQA Guidelines Part IV.

DENIED. Federal Defendants' cross motion is GRANTED.

(3) To the Extent FFA Bases Any of its Claims against Reclamation on the ESA, Such Claims are Subject to the ESA's Pre-Filing Requirements.

To the extent FFA's IQA and ESA claims overlap, its ESA claims are subject to the ESA's pre-filing notice requirement. No suit may be commenced under the ESA "prior to sixty days after written notice of the violation has been given to the Secretary." 16 U.S.C. § 1540(g)(2)(A)(i). This requirement is jurisdictional and "[a] failure to strictly comply with the notice requirement acts as an absolute bar to bringing suit under the ESA." *Southwest Ctr. for Biological Diversity*, 143 F.3d at 520. Failure to comply with a statutory notice requirement is a jurisdictional objection that may be addressed "at any time." *See* Fed. R. Civ. P. 12(h)(3).

Here, FFA failed to notify Reclamation of its intent to sue. Plaintiffs argue that "[a]doption of a BiOp is a final agency action, and such actions are subject to judicial review under the APA," citing *Bennett v. Spear*, 520 U.S. at 178. However, allowing a plaintiff to circumvent the ESA's 60-day notice requirement by claiming that its cause of action arises under the APA would circumvent the ESA's notice requirement entirely. *Hawaii County Green Party v. Clinton*, 124 F. Supp. 2d 1173, 1193 (D. Haw. 2000).

To the extent that FFA's claims against Reclamation arise

under the ESA, their motion for summary judgment is DENIED on the ground that they failed to comply with the statutory notice requirement. Federal Defendants' and Defendant Intervenors' cross-motions are GRANTED.

F. Renewed Claim That FWS Violated NEPA.

Plaintiffs attempt to revisit the issue of whether FWS violated NEPA in issuing the BiOp and its RPA. Plaintiffs first renew an argument that was rejected in the Salmonid Consolidated cases, namely that *Ramsey v. Cantor*, 96 F.3d 434 (9th Cir. 1996), the only case in which the issuance of a biological opinion was found to violate NEPA, controls here. In *Ramsey*, the NEPA obligation was imposed on the consulting agency's issuance of a biological opinion in part because there was no federal action agency to comply with NEPA.

The November 12, 2009 NEPA decision in this case found *Ramsey* inapplicable because the action agency is Reclamation. *See* Doc. 399 at 16-17. Plaintiffs argue that the Courts' initial finding was incorrect because, here, as in *Ramsey*, the BiOp was not only imposed upon Reclamation's operations, but also upon the operations of DWR, a state agency. This argument was rejected in the Consolidated Salmonid Cases shortly after the cross-motions in the Consolidated Smelt Cases were filed. The March 5, 2010 Consolidated Salmonid Cases decision concluded:

> Plaintiffs ignore the interconnected nature of the SWP

> and CVP projects. Reclamation and DWR have, for many years, operated the projects in a coordinated manner. *See* OCAP Biological Assessment ("OCAP BA") at 1-2. The Biological Assessment ("BA"), prepared by Reclamation, describes the project for which consultation was being sought as "the ongoing operations of the CVP and SWP and potential future actions that are foreseeable to occur within the period covered by the project description." *Id*. at 1-1. The two water projects, which are jointly operated by Reclamation and DWR, share water resources, storage, pumping, and conveyance facilities to manage and deliver one third of the water supply for the State of California. Reclamation's BA provided NMFS with extensive analyses of the effects of coordinated operation of the CVP and SWP on the Listed Species.

Consolidated Salmonid Cases, 1:09-cv-1053 OWW DLB, Doc. 266 at 14 (emphasis in original). Plaintiffs offer no new law or persuasive authority compelling a finding of clear error to justify reconsideration.

Alternatively, Plaintiffs argue that "FWS's future choices with respect to OMR flows restrictions are 'major federal actions' within the scope of [NEPA's implementing regulations]." Doc. 551 at 87. This argument continues:

> [R]ather than DWR or Reclamation operating the CVP and SWP, respectively, the BiOp and its RPA have resulted in transferring operational control to FWS for up to six months year (i.e., December through June). FWS' future choices with regard to implementation of RPA Components 1 and 2 will cause distinct and separate impacts to the human environment within both the CVP and SWP service areas. Even if Reclamation shares a NEPA obligation with regard to its acceptance of the BiOp, Reclamation is not the proper federal agency to account for and analyze the environmental effects of FWS' actions that will occur within the SWP service area. These SWP impacts are solely attributable to the FWS' formulation of the RPA and its ongoing role in implementing that RPA, and they were not caused by

> Reclamation and are beyond Reclamation's discretion or jurisdiction. FWS will continue to make weekly water use and resource allocation decisions that amount to major federal actions significantly affecting the human environment in both CVP and SWP service areas without the benefit of the information required by a proper NEPA review and without satisfying the public disclosure and accountability purposes of NEPA.

Id.

This is an attempt to re-argue and re-frame arguments previously decided. The prior NEPA rulings determined that Reclamation bears the NEPA responsibility in this case as action agency. "Reclamation proposed the action (in the form of the Operations and Criteria Plan ('OCAP')) to FWS, which triggered the preparation of the BiOp." Doc. 399 at 28. "Reclamation was not 'bound' by the BiOp until it chose to proceed with the OCAP and implement the RPA. Once Reclamation did so, operation of the Projects became the relevant agency 'action,' and Reclamation, as action agency, is the more appropriate lead agency under NEPA." *Id*. at 30. Reclamation accepted the adaptive management protocol prescribed in the RPA "as a constraint upon its operations when it provisionally accepted the RPA." Doc. 399 at 30. FWS's day-to-day decisions to implement the adaptive management protocol are a natural incident of Reclamation's decision to adopt the RPA. Moreover, FWS's setting of specific OMR flows under RPA Components 1 and 2 is based on a weekly review of salvage data, distribution, flow and turbidity levels, population status, and other information, making NEPA review of such actions

impractical. *See Flint Ridge Dev. Co. v. Scenic Rivers Ass'n*, 426 U.S. 776, 788-89 (1976) (provision in applicable law requiring statement of record to become effective 30 days after filing made preparation of EIS "inconceivable"); *Kandra*, 145 F. Supp. 2d at 1205 (finding that "[a]n EIS takes at least several months to complete"). FWS has no legal or functional authority to operate the projects and adequate remedies exist to compel the Bureau to stop FWS, if FWS endeavors to do so.

Plaintiffs' motion for summary judgment as to FWS's liability under NEPA is DENIED; Federal Defendants' and Defendant-Intervenors' cross motion is GRANTED.

G. Reclamation's Liability under the ESA.

Following the issuance of a biological opinion, the ESA regulations require the action agency, here, Reclamation, to "determine whether and in what manner to proceed with the action in light of its section 7 obligations and the Service's biological opinion." 50 C.F.R. § 402.15(a). In making that determination, a federal action agency "may not rely solely on a FWS biological opinion to establish conclusively its compliance with its substantive obligations under section 7(a)(2)." *Pyramid Lake Paiute Tribe of Indians v. U.S. Dept. of Navy*, 898 F.2d 1410, 1415 (9th Cir. 1990). In *City of Tacoma v. Fed. Energy Regulatory Comm'n*, 460 F.3d 53, 76 (D.C. Cir. 2006), the D.C. Circuit summarized the caselaw culminating in *Pyramid Lake*:

> [The] interagency consultation process reflects Congress's awareness that expert agencies (such as the [NMFS] and [FWS]) are far more knowledgeable than other federal agencies about the precise conditions that pose a threat to listed species, and that those expert agencies are in the best position to make discretionary factual determinations about whether a proposed agency action will create a problem for a listed species and what measures might be appropriate to protect the species. Congress's recognition of this expertise suggests that Congress intended the action agency to defer, at least to some extent, to the determinations of the consultant agency, a point the Supreme Court recognized in *Bennett v. Spear*, 520 U.S. 154, 169-170 (1997). In *Bennett*, the Court stated that an action agency disregards a jeopardy finding in a BiOp "at its own peril" and bears the burden of articulating the reasons for reaching its contrary conclusion. *Id*.
>
> Accordingly, when we are reviewing the decision of an action agency to rely on a BiOp, the focus of our review is quite different than when we are reviewing a BiOp directly. In the former case, the critical question is whether the action agency's reliance was arbitrary and capricious, not whether the BiOp itself is somehow flawed. *Aluminum Co. of Am. v. Adm'r, Bonneville Power Admin.*, 175 F.3d 1156, 1160 (9th Cir.1999); *Pyramid Lake Paiute Tribe v. U.S. Dep't of Navy*, 898 F.2d 1410, 1415 (9th Cir.1990); *Stop H-3 Ass'n v. Dole*, 740 F.2d 1442, 1460 (9th Cir.1984); cf. *Nat'l Wildlife Fed'n v. Nat'l Marine Fisheries Serv.*, 422 F.3d 782, 790 (9th Cir. 2005) (direct review of a BiOp). <u>Of course, the two inquiries overlap to some extent, because reliance on a facially flawed BiOp would likely be arbitrary and capricious, but the action agency "need not undertake a separate, independent analysis" of the issues addressed in the BiOp</u>. *Aluminum Co.*, 175 F.3d at 1161. In fact, if the law required the action agency to undertake an independent analysis, then the expertise of the consultant agency would be seriously undermined. Yet the action agency must not blindly adopt the conclusions of the consultant agency, citing that agency's expertise. *Id*. Rather, the ultimate responsibility for compliance with the ESA falls on the action agency. 16 U.S.C. § 1536(a) (1)-(2). In Pyramid Lake, the Ninth Circuit balanced these two somewhat inconsistent principles and articulated the following

rule:

> [E]ven when the [consultant agency's] opinion is based on "admittedly weak" information, another agency's reliance on that opinion will satisfy its obligations under the Act if a challenging party can point to no "new" information- i.e., information the [consultant agency] did not take into account-which challenges the opinion's conclusions.

898 F.2d at 1415; *see also Defenders of Wildlife v. U.S. EPA*, 420 F.3d 946, 959, 976 (9th Cir. 2005); *Stop H-3 Ass'n*, 740 F.2d at 1459-60.

City of Tacoma, 460 F.3d at 75-76. The D.C. Circuit rejected the City of Tacoma's claim that the consultant agency in that case, FERC, was liable under the ESA because the City had not "presented FERC with new information that was unavailable to [NMFS] or [FWS] and that would give FERC a basis for doubting the expert conclusions in the BiOps those agencies prepared." *Id*. at 76.

Here, Plaintiffs attempt to side-step this standard, arguing that Reclamation should have independently recognized and addressed specified errors in the BiOp. For example, they argue Reclamation should have recognized the error caused by comparing CALSIM data to non-CALSIM Data because Reclamation had extensively analyzed the use of CALSIM in the BA. *See* AR 010698-010807. The BA stated:

> The simulation results of the OCAP BA are designed for a comparative evaluation because the CALSIM-II model uses generalized rules to operate the CVP and SWP systems and the results are a gross estimate that may

> not reflect how actual operations would occur.... Results should only be used as a comparative evaluation to reflect how changes in facilities and operations may affect the CVP-SWP system.

AR 010701. FWS took this information into account in the BiOp. *See* BiOp at 204-206, reviewing Calsim II modeling performed in the BA. Plaintiffs have not demonstrated that Reclamation was in possession of any "new information" not considered by FWS that provided Reclamation a basis for questioning the BiOp's expert conclusions. Absent such a showing, even though the BiOp is flawed in many ways, Reclamation could rely upon it without incurring ESA liability.

VIII. CONCLUSION

It cannot be disputed that the law entitles the delta smelt to ESA protection. It is significant that the co-operator of the Projects, DWR, in its endeavors to protect a substantial part of the State's water supply, opposes as unjustified and based on bad science some of the RPA Actions. It is equally significant that despite the harm visited on California water users, FWS has failed to provide lawful explanations for the apparent over-appropriation of project water supplies for species protection. In view of the legislative failure to provide the means to assure an adequate water supply for both the humans and the species dependent on the Delta, the public cannot afford sloppy science and uni-directional prescriptions that ignore California's water needs. A court is bound by the law. Resource allocation and

establishing legislative priorities protecting the environment are the prerogatives of other branches of government. The law alone cannot afford protection to all the competing interests at stake in these cases.

For all the reasons set forth above:

(A) Plaintiffs' and DWR's motions for summary judgment that the BiOp violates the ESA and the APA are GRANTED IN PART AND DENIED IN PART; and Federal Defendants' and Defendant Intervenors' cross-motions are GRANTED IN PART AND DENIED IN PART based on the following findings:

(1) It was not arbitrary, capricious, or clear error for FWS to base its jeopardy conclusion in part on Kimmerer (2008)'s predictions of relative increases in delta smelt entrainment.

(2) FWS's failure to apply a quantitative life-cycle model to evaluate the impacts of Project operations on the smelt did not violate the ESA.

(3) The BiOp's reliance on analyses using raw salvage figures to set the upper and lower OMR flow limits of Actions 1, 2, and 3 was arbitrary and capricious and represents a failure to use the best available science. Actions 1, 2, and 3 depend so heavily on these flawed analyses that this failure is not harmless. Remand is necessary.

(4) Comparison of Calsim II to Dayflow model runs created potentially material bias in the BiOp's evaluation of the impacts of Project operations on the position of X2 and related conclusions regarding population dynamics and habitat. FWS's failure to address or explain this material bias represents a failure to consider and evaluate a relevant factor and violates the ESA and APA. Remand is required.

(5) The use of Dayflow to represent the baseline did not improperly attribute past effects to the Projects.

(6) The flawed Calsim II to Dayflow comparison fatally taints the justification provided for Action 4. Remand is required.

(7) Plaintiffs' argument that Action 4 is unlawful because it is an "untested hypothesis" is an unfounded interpretation of the scientific method.

(8) FWS's reliance on Feyrer (2007), Feyrer (2008), and Bennett (2005) was not arbitrary, capricious, or clear error.

(9) The best science available at the time the BiOp issued supports the conclusion that X2 is a valid surrogate for delta smelt habitat.

(10) Plaintiffs' argument that FWS violated the best available science standard because the smelt are not

habitat limited is unfounded. The BiOp admits the delta smelt may not be habitat limited, but reasonably concludes that the species has become increasingly habitat limited over time, contributing to the population's decline, and that worsening habitat conditions may limit smelt recovery.

(11) FWS's use of a linear stock-recruit model, although scientifically criticized, was not arbitrary, capricious, or clear error.

(12) The BiOp has failed to sufficiently explain why maintaining X2 at 74 km (following wet years) and 81 km (following above normal years), respectively, as opposed to any other specific location, is essential to avoid jeopardy and/or adverse modification. Remand is required.

(13) Federal Defendants' reliance on turbidity as one of several triggers for Action 1 was not arbitrary, capricious, or clear error.

(14) Plaintiffs' argument that FWS violated the ESA and/or the APA by excluding data from 2007 in its analysis of entrainment effects, but including it in its calculation of the ITL is without merit. FWS offered a reasonable explanation for these choices.

(15) The BiOp provides a reasonable explanation for why

the 2006-2008 year range was used to calculate the adult delta smelt ITL, but unlawfully fails to explain why 2005 was added to the juvenile ITL calculation. Remand is required.

(16) The BiOp also fails to explain why FWS chose to set the ITL based on the average cumulative salvage index for the years selected. FWS shall explain this choice on remand.

(17) In general, the BiOp's conclusions about the causal connections between Project Operations and "other stressors" are ambiguous. However, the BiOp's assertion that Project Operations contribute to and/or exacerbate the impacts on delta smelt of predation, aquatic macrophytes, and microcystis are unsupported by record evidence and/or explanation. Remand is required.

(18) The record does not support the BiOp's conclusion that food web and pollutants/contaminant impacts are indirect effects of Project operations. Remand is required.

(19) Plaintiffs' omnibus challenge to the substance of the critical habitat analysis fails. However, the critical habitat analysis does not specifically explain its conclusion that Project operations are reasonably

certain to exacerbate the impact of contaminants to delta smelt habitat. In addition, because critical habitat conclusion 3(c) explicitly relies upon the flawed analysis regarding the movement of X2, this conclusion is without support in the record and is arbitrary and capricious. Remand is required.

(20) Although there is record support for the BiOp's conclusion that Project operations are likely to jeopardize the continued existence and/or adversely modify the critical habitat of the delta smelt, the analyses supporting the specific flow prescriptions set forth in the RPA are fatally flawed and predominantly unsupported. The BiOp does not justify or explain its attribution to Project operations adverse impacts caused by others stressors. When combined, the totality of these failures demand remand to the agency for further consideration and explanation.

(B) Plaintiffs' motion for summary judgment that the BiOp does not segregate discretionary from nondiscretionary actions is DENIED; Federal Defendants' and Defendant-Intervenors' cross motions are GRANTED.

(C) Plaintiffs' motion for summary judgment that the BiOp does not undertake the analysis required by 50 C.F.R. § 402.02 is GRANTED; Federal Defendants' and Defendant-

Intervenors' cross motions are DENIED. The BiOp completely fails to analyze economic feasibility, consistency with the purpose of the action, and consistency with the action agency's authority demanded by § 402.02. Further analysis in compliance with § 402.02 is required on remand.

(D) Plaintiffs' motion for summary judgment that FWS did not address comments on the draft BiOp is DENIED; Federal Defendants' and Defendant-Intervenors' cross motions are GRANTED.

(E) Stewart & Jasper's motion for summary judgment that the BiOp failed to consider the economic impacts of promulgating the RPMs is DENIED; Federal Defendants' and Defendant-Intervenors' cross motions are GRANTED.

(F) Stewart & Jasper's motion for summary judgment that FWS illegally arrogated authority to itself over Reclamation and DWR is DENIED; Federal Defendants' and Defendant-Intervenors' cross motions are GRANTED.

(G) Family Farm Alliance's motion for summary judgment on its IQA claim is DENIED; Federal Defendants' and Defendant-Intervenors' cross motions are GRANTED.

(H) Plaintiffs' renewed motion for summary judgment that FWS violated NEPA is DENIED; Federal Defendants' and Defendant-Intervenors' cross motions are GRANTED.

(I) Plaintiffs' motion for summary judgment that Reclamation

violated the ESA is DENIED; Federal Defendants' and Defendant-Intervenors' cross motions are GRANTED.

The 2008 BiOp and its RPA are arbitrary, capricious, and unlawful, and are remanded to FWS for further consideration in accordance with this decision and the requirements of law. Plaintiffs shall submit a form of order consistent with this memorandum decision within five (5) days of electronic service.

A status conference is set for January 4, 2011, at 12:00 noon, in Courtroom 3 (OWW), to address any need for further proceedings.

SO ORDERED

Dated: December 14, 2010

/s/ Oliver W. Wanger
Oliver W. Wanger
United States District Judge

UNITED STATES DISTRICT COURT

FOR THE EASTERN DISTRICT OF CALIFORNIA

The Consolidated Delta Smelt Cases	1:09-CV-00407 OWW DLB 1:09-cv-00480-OWW-GSA 1:09-cv-00422-OWW-GSA 1:09-cv-00631-OWW-DLB 1:09-cv-00892-OWW-DLB FINDINGS OF FACT AND CONCLUSIONS OF LAW RE PLAINTIFFS' REQUEST FOR INJUNCTIVE RELIEF AGAINST IMPLEMENTATION OF RPA COMPONENT 3 (Action 4)(Doc. 900)

I. INTRODUCTION

Plaintiffs State Water Contractors ("SWC"), Metropolitan Water District of Southern California ("MWD" or "Metropolitan"), Kern County Water Agency ("KCWA") and Coalition for a Sustainable Delta ("Coalition"), San Luis & Delta Mendota Water Authority (the "Authority") and Westlands Water District ("Westlands") (collectively herein "Plaintiffs"), seek an injunction prohibiting the implementation of Reasonable and Prudent Alternative ("RPA") Component 3, Action 4 (the "Fall X2 Action") set forth in the United States Fish and Wildlife Service's ("FWS") December 15, 2008, biological opinion ("BiOp"), which addresses the impacts of the coordinated operations of the federal Central Valley Project ("CVP") and State Water Project ("SWP") on the threatened delta smelt (*Hypomesus transpacificus*). Doc. 900. The California Department of

Water Resources ("DWR" or "Plaintiff Intervenors") joined in Plaintiffs' motion. Doc. 905. Federal Defendants and Defendant Intervenors opposed. Doc. 948. An evidentiary hearing on the motion was held on July 26, 27, 28, and 29, 2011. Docs. 998-1001. The parties were represented by counsel, as identified on the record.

Plaintiffs and Defendants submitted independent, lengthy proposed findings of fact and conclusions of law. Docs. 1004 & 1005. DWR and Plaintiffs also submitted notices of disapproval of Defendants' proposed findings of fact and conclusions of law. Docs. 1008 & 1009.

After consideration of the testimony of the witnesses, the exhibits received in evidence, the written briefs of the parties, oral arguments, and the parties' proposed findings of fact and conclusions of law, the following findings of fact and conclusions of law concerning the motion for injunctive relief are entered.

To the extent any of the findings of fact may be interpreted as a conclusion of law or any conclusion of law may be interpreted as a finding of fact, it is so intended.

II. BACKGROUND

A. The Challenged Action.

The 2008 Smelt BiOp, prepared pursuant to Section 7 of the Endangered Species Act ("ESA"), 16 U.S.C. § 1536(a)(2), concluded that "the coordinated operations of the CVP and SWP, as proposed, are likely to jeopardize the continued existence of the delta smelt" and

"adversely modify delta smelt critical habitat." Ex. 1[1] ("BiOp") at 276-78. As required by law, the BiOp includes the RPA designed to allow the projects to continue operating without causing jeopardy to the species or adverse modification to its critical habitat. *Id.* at 279-85. The RPA includes various operational components designed to reduce entrainment of smelt during critical times of the year by controlling exports out of and water flows into the Delta. *Id.*

At issue in this case is Component 3 (Action 4), which is designed to improve habitat for delta smelt growth and rearing, and requires sufficient Delta outflow to maintain a monthly average location of two parts per thousand salinity ("X2") no greater (more eastward) than 74 kilometers from the Golden Gate Bridge in "wet" water years and 81 kilometers from the Golden Gate Bridge in "above normal" water years. *Id.* at 282-83, 369. The average monthly location of X2 in the fall must be maintained in September and October (in November, the Fall X2 Action requires the Projects to adjust their upstream reservoir releases to prevent the storage of inflow) in accordance with an "adaptive management process" to be overseen by FWS. *Id.* at 282-83. The estimated cost to water users is 670,000 acre feet ("AF") of water if 2012 is a critically dry or dry year, or 300,000 AF if 2010 is a below normal or above normal year.

[1] All hearing exhibits, whether offered by Plaintiffs or Defendants, will be referenced generally as "Exhibit" ("Ex."). The exhibits were sequentially numbered so that no parties' exhibits overlap with those of any other party. The biological opinion, admitted as Exhibit 1, will be referenced as "BiOp."

B. Relevant Prior Rulings.

A December 14, 2010 Memorandum Decision Re Cross Motions for Summary Judgment ("12/14/10 MSJ Decision"), Doc. 757, *San Luis & Delta-Mendota Water Auth. v. Salazar*, 760 F. Supp. 2d 855 (E.D. Cal.), rejected some of Plaintiffs' challenges to the BiOp's rationale for the Fall X2 action, but found that the BiOp's X2 analysis was flawed in two critical respects. The rationale for the action rested in large part on a comparison of runs from two different computer models for Project operations, Calsim II and Dayflow. The Decision found that, in the absence of calibration of the two models, which was not performed, "the Calsim II to Dayflow comparison has the potential to introduce significant, if not overwhelming, bias to the analysis that the BiOp nowhere discussed or corrected." *Id.* at 922. The X2 action was remanded to the agency for further consideration of the implications of this error to the BiOp's findings. *Id.* at 913.

The Decision further held that the BiOp violated the Administrative Procedure Act's ("APA") requirement that FWS "examine the relevant data and articulate a satisfactory explanation for its action including a rational connection between the facts found and the choice made," *Motor Vehicle Mfrs. Ass'n v. State Farm Mutual Auto. Ins. Co.*, 463 U.S. 29, 43 (1983), as well as FWS's own Consultation Handbook implementing the ESA, which requires "a thorough explanation of how each component of the [RPA] is essential

to avoid jeopardy and/or adverse modification," ESA Handbook at 4-43, because the BiOp "fail[ed] to explain why it is essential to maintain X2 at 74 km and 81 km respectively, as opposed to any other specific location." *Id.* at 922-23. The practical result of the X2 Action is to allow large volumes of Project water to escape into the ocean.

A June 24, 2011 memorandum decision addressed Federal Defendants' and Defendant Intervenors' objection that this Court lacked jurisdiction to consider Plaintiffs' request for injunctive relief because an appeal was pending on related issues. Relying on *Natural Resources Defense Council v. Southwest Marine Inc.,* 242 F.3d 1163, 1164 (9th Cir. 2001), for the governing standard, the June 24, 2011 Decision found that *Southwest Marine* stands generally for the following propositions:

> (1) A district court may act to preserve the status quo while an appeal is pending.
>
> (2) The status quo is measured at the time the appeal is filed.
>
> (3) The district court may only act to effectuate the underlying purposes of the original judgment and may not materially alter the status of the appeal or change the core questions before the appellate panel.
>
> (4) It is impermissible to alter the status of the case on appeal by taking further action that cannot be undone by the appeal. In other words, the district court's post-appeal action must be grounded upon an issue that will receive a full and fair hearing before the appellate panel, leaving the burdened party's substantial rights unaffected if a reversal is issued.

Doc. 930 at 8. These principles apply to this case in the following way:

The first step is to determine the status quo. Federal Defendants point out that the BiOp and its RPA has been remanded but not vacated. Therefore, they argue that the status quo is operation of the projects pursuant to the RPA (including the Fall X2 Action) as described in the BiOp. This position is a material distortion of the record and cannot be adopted for two reasons. First, Plaintiffs indicated their intent to move for injunctive relief against the Fall X2 Action long before Final Judgment was entered or the appeal was filed. Defendants strenuously resisted immediate injunctive proceedings on the Fall X2 Action when a hearing was requested by Plaintiffs, on the ground that, at the time, it was not clear whether the Bureau would implement the Fall X2 Action during the 2010-2011 water year; i.e., it was premature for the district court to entertain an application for injunctive relief before it was certain the Fall X2 Action would be implemented based on this water year's hydrology.

Second, the 12/14/2010 Decision found the X2 Action was unlawful and unjustified on several grounds. This Fall X2 Action is unprecedented and had never before been implemented. Remand was ordered with the Court's understanding that any future unlawful action in Project operations would be the subject of provisional remedy proceedings. In remanding without vacature, the Court understood that, as has been the case throughout the over five years of active litigation over the Delta Smelt, as operational issues arise, the parties may seek and have sought provisional remedies during periods of remand of biological opinions to the Agency. The parties that sought remand without vacatur never disclosed they intended to argue that a remand without vacatur insulated CVP operations from judicial review during an appeal.

The disputed Fall X2 Action has never been triggered. The status quo as of the filing of the appeal on April 7, 2011 is that the implementation of the Fall X2 Action is an unprecedented possibility, which is projected to take one million acre feet of water from lawful users, and that Plaintiffs would have the opportunity to move to enjoin the Action if its implementation was reasonably certain.

The next inquiry is whether acting upon Plaintiffs' request for injunctive relief would effectuate the underlying purposes of the original judgment. The answer is unquestionably yes. The judgment found the Fall X2 Action was unlawful in a critical respect, namely that the

unprecedented specific water prescription imposed, which requires huge amounts of Project yield, was unjustified by the record. Permitting the Action to be implemented without even considering the totality of its on-the-ground consequences would undermine the purposes of the judgment and the obligation of a court sitting in equity to protect all competing human interests, health, and safety, not only the species.

The district court may not materially alter the status of the appeal, change the core questions before the appellate panel, and/or take further actions that cannot be undone by the appeal. Defendants argue that that Plaintiffs' merits brief rehashes issues already decided in the 12/14/2010 Decision. A preliminary review of the opening merits brief, Doc. 990, reveals that there is considerable overlap between the arguments there advanced and those addressed in the 12/14/10 Decision. *Southwest Marine* and related cases prohibit the district court from reconsidering issues already ruled upon, as this would impermissibly create a "moving target" for the appeal. *See Britton v. Co-op Banking Group*, 916 F.2d 1405, 1412 (9th Cir. 1990)(discussing the example of *McClatchy Newspapers*, in which the district court's modification of an order "reflected a change in the result of the very issue on appeal; if allowed to stand, the appeals court would be dealing with a moving target if it ruled on the revised order or, alternatively, its ruling would be obsolete if it ruled on the 'old' order").

However, the procedural posture of the cross-motions for summary judgment is distinct from a request for injunctive relief. The 12/14/2010 Decision ruled in favor of Plaintiffs and found the Fall X2 Action unlawful. Consideration of whether injunctive relief is required to prevent new, never imposed, operational prescriptions which may cause irreparable injury will not revisit or in any way modify the final judgment. Nor does the pending appeal preclude consideration of the <u>strength</u> of the scientific bases for the X2 Action in deciding a request for equitable relief. Considering whether the scientific rationale for an action is weak is legally distinct from finding that the agency violated the APA in advancing such a rationale.

Hoffman for and on Behalf of N.L.R.B. v. Beer Drivers and Salesmen's Local Union No. 888, 536 F.2d 1268 (9th Cir. 1976), explains that the general rule that an appeal to the circuit court deprives the district court of jurisdiction

> as to matters involved in the appeal "is not a creature of statute and is not absolute in character."
>
> > It is our opinion that the rule should not be applied in those cases where the district court, as here, has a continuing duty to maintain a status quo, and where, as the days pass, new facts are created by the parties and the maintenance of the status quo requires new action.
>
> *Id*. at 1276. This is such a case. New facts are constantly being created by environmental conditions and continuing operating requirements of the Projects. Such requirements may change hourly. Maintenance of the status quo may require changes to Project operations. The appeal does not remove the district court's jurisdiction over the BiOp's remand to the Agency and the ongoing operation of a federal Reclamation project.

Id. at 8-12.

The hearing on Plaintiffs' motion for injunctive relief was confirmed, four days of testimony was taken, and proposed findings have been submitted.

III. SUMMARY OF MOTION

Plaintiffs and DWR request injunctive relief on the following grounds:

- Federal Defendants intend to implement the Fall X2 Action beginning on September 1, despite the Court's determination that FWS acted arbitrarily and capriciously, and failed to use the best available science when it developed the Fall X2 Action. Plaintiffs assert that enjoining Federal Defendants' attempt to do so is an appropriate remedy to enforce this Court's Orders and Judgments and to maintain the status quo.

- Plaintiffs have already succeeded on the merits of their ESA and National Environmental Policy Act ("NEPA") claims, and the balance of hardships and public interest support the requested injunction. Plaintiffs will suffer irreparable harm from the significant amount of water that will be lost if Federal Defendants impose the Fall X2 Action this year. By contrast, the best available scientific data do not show that the location of X2 bears a rational relationship to the subsequent abundance of delta smelt, or is necessary to avoid adverse modification to its critical habitat. To the contrary, the best available scientific data show that enjoining the Fall X2 Action will not jeopardize the species or adversely modify its critical habitat.

IV. STANDARD OF DECISION

A. General Injunctive Relief Requirements.

Injunctive relief, whether temporary or permanent, is an "extraordinary remedy, never awarded as of right." *Winter v. Natural Resources Defense Council*, 555 U.S. 7, 24 (2008). The standard test for injunctive relief requires establishment of four factors by a preponderance of the evidence:

1. Likelihood of success on the merits;
2. Likelihood the moving party will suffer irreparable harm absent injunctive relief;

3. The balance of equities tips in the moving parties' favor; and

4. An injunction is in the public interest.

Winter, 555 U.S. at 20; *Am. Trucking Ass'n v. City of Los Angeles*, 559 F.3d 1046, 1052 (9th Cir. 2009).

Here, however, Plaintiffs seek post-judgment injunctive relief, after they prevailed in the lawsuit, which is governed by a modified standard that requires a plaintiff establish:

> (1) that it has suffered an irreparable injury;
>
> (2) that remedies available at law, such as monetary damages, are inadequate to compensate for that injury;
>
> (3) that, considering the balance of hardships between the plaintiff and defendant, a remedy in equity is warranted; and
>
> (4) that the public interest would not be disserved by a permanent injunction.

Sierra Forest Legacy v. Sherman, --- F.3d ---, 2011 WL 2041149, *16 (9th Cir. 2001) (citing *eBay Inc. v. MercExchange*, L.L.C., 547 U.S. 388, 391 (2006)).

B. <u>Scope of Review; Deference to Agency Action.</u>

In an injunctive relief proceeding, even in an APA case, a court is not limited to a review of the record. *E.g., Nat'l Parks & Conservation Assn. v. Babbitt*, 241 F.3d 722, 738 (9th Cir. 2001) (Ninth Circuit considered evidence of species impacts not before the district court); *Ctr. for Biological Diversity v. Wagner*, 2009 WL 2176049, *6 (D. Or. 2009) ("[e]xtra-record evidence may also be

considered in relation to a request for injunctive relief"); *N. Plains Resource Council v. Bureau of Land Mgmt.*, 2005 U.S. Dist. LEXIS 25238, *3-*4 (D. Mont. 2005) (district court held an evidentiary hearing with witnesses and exhibits on the appropriate scope of injunctive relief pending completion of the remand), aff'd, *N. Cheyenne Tribe v. Norton*, 503 F.3d 836 (9th Cir. 2007); *Natural Res. Def. Council v. Norton*, 2007 WL 14283, *5 (E.D. Cal. Jan 3, 2007) ("post-decisional information might be relevant in the context of a motion for interim injunctive relief").

In reviewing a claim brought under the ESA and/or APA, a court must defer to a federal administrative agency's reasoned opinions within its field of expertise. This deferential standard has been articulated numerous times in these consolidated cases, *see, e.g.*, 12/14/2010 MSJ Decision, *San Luis v. Salazar*, 760 F. Supp. 2d at 869-70, and is incorporated by reference. However, in a post-judgment injunctive relief proceeding, a court is not bound by the same deferential standard. The Ninth Circuit reasoned in *Sierra Forest Legacy*:

> Although the federal government is undoubtedly permitted to follow its own experts when making a decision, federal experts are not always entitled to deference outside of administrative action....
>
> ... It is reasonable that courts would defer to particular experts when the government has unique expertise, in fields such as national security or the internal functioning of the military. However, *Winter* applied no such deference concerning the possibility that sonar testing would irreparably harm whales. *See id.* at 383-84. Ecology is not a field within the unique expertise of the federal

> government.
>
> If the federal government's experts were always entitled to deference concerning the equities of an injunction, relief against federal government policies would be nearly unattainable, as government experts will likely attest that the public interest favors the federal government's preferred policy, regardless of procedural failures.

--- F.3d ---, 2011 WL 2041149, *18-*19 (citations omitted). The government cannot hide behind and is not entitled to deference in this *de novo* injunctive relief proceeding.

V. FINDINGS OF FACT

A. The Agency Action.

1. The agency action is the coordinated operation of the CVP and SWP, pursuant to an Agreement for the Coordinated Operation of the two projects ("COA").

2. According to the Rivers and Harbors Act of 1937, the dams and reservoirs of the CVP "shall be used, first, for river regulation, improvement of navigation and flood control; second, for irrigation and domestic uses; and, third, for power." 50 Stat. 844, 850 (Aug. 26, 1937).

3. The CVP was reauthorized in 1992 through the Central Valley Improvement Act ("CVPIA"), which modified the 1937 Act and added mitigation, protection, and restoration of fish and wildlife as co-equal project purposes. Pub. L. 102-575 § 3402, 106 Stat. 4600, 4706 (1992). One of the stated purposes of the CVPIA is to address impacts of the CVP on fish and wildlife. *Id.* at § 3406(a). The CVPIA made environmental protection and water deliveries co-purposes.

B. Facts Relevant to NEPA Claim.

4. It is undisputed that neither FWS nor Reclamation engaged in any NEPA analysis in connection with preparation or implementation of the 2008 Smelt BiOp. This has been found unlawful.

5. It is also undisputed that on November 13, 2009, the Court entered an Order granting San Luis Plaintiffs' motion for summary judgment on their claim that Federal Defendants violated NEPA when they implemented the 2008 Smelt BiOp without conducting the required NEPA analysis. Doc. 399.

6. Federal Defendants did not engage in a systematic consideration of impacts to the human environment and/or consideration of alternatives that took into account those impacts, ordinarily performed as part of a NEPA review.

C. Wet Conditions in 2011 Will Trigger Implementation of Fall X2.

7. The 2011 water year is classified as a wet year. Ex. 301, Leahigh Decl. at ¶ 12. Wet and above normal water years trigger implementation of the Fall X2 Action, which requires that X2 be maintained at a monthly average position of not greater than 74 km (in wet years) or 81 km (in above normal years) eastward of the Golden Gate Bridge. BiOp at 282-83.

8. While the Fall X2 Action is not formally triggered until September 1, the Projects would need to alter their reservoir release patterns as early as the second week in August to ensure that the 74 km requirement could be met in September. Ex. 301, Leahigh Decl. at

¶ 21; 7/28/11 Tr. at 196:23-197:3 (Milligan).

9. FWS and the Bureau have announced that they will implement the Fall X2 action starting in September 2011.

D. Status of the Species.

(1) Abundance Trends.

10. The delta smelt was listed as a threatened species under the ESA on March 5, 1993. 58 Fed. Reg. 12,584 (March 5, 1993). Critical habitat was designated for the delta smelt on December 19, 1994. 59 Fed. Reg. 65,256 (Dec. 19, 1994). FWS recently determined that delta smelt warranted uplisting from threatened to endangered, but that the action was currently precluded by higher priority listing actions. 75 Fed. Reg. 17,667 (Apr. 7, 2010).

11. The most recent Fall Midwater Trawl ("FMWT") data available, from 2010, show an index value of 29. Ex. 503. Although this is an increase over the 2009 value of 17, it is still well below the lowest pre-2003 value of approximately 100, as are the other six of the past seven years. *Id.*

12. The 2011 Summer Townet Survey ("STS") indicated a slight improvement over the previous year's index value (up to 2.2 from 0.8). Ex. 507 at 2.[2]

[2] Plaintiffs argue the Fall X2 action is unnecessary because this slightly improved STS index followed a fall in which X2 was located at 83-84km. *See* 7-28-11 Tr. at 217:10-12 (Feyrer). This argument is misplaced for several reasons. First, it is not yet known whether the fall 2011 index value will show improved abundance realative to the fall index value from last year. Second, this year's STS index value of 2.2 is still near the historic low, and is the seventh year in a row with an index value at or near the historic low. Ex. 507 at 2. Third, the Bureau's Mr. Feyrer testified that an unusually wet winter and spring, which translated into a

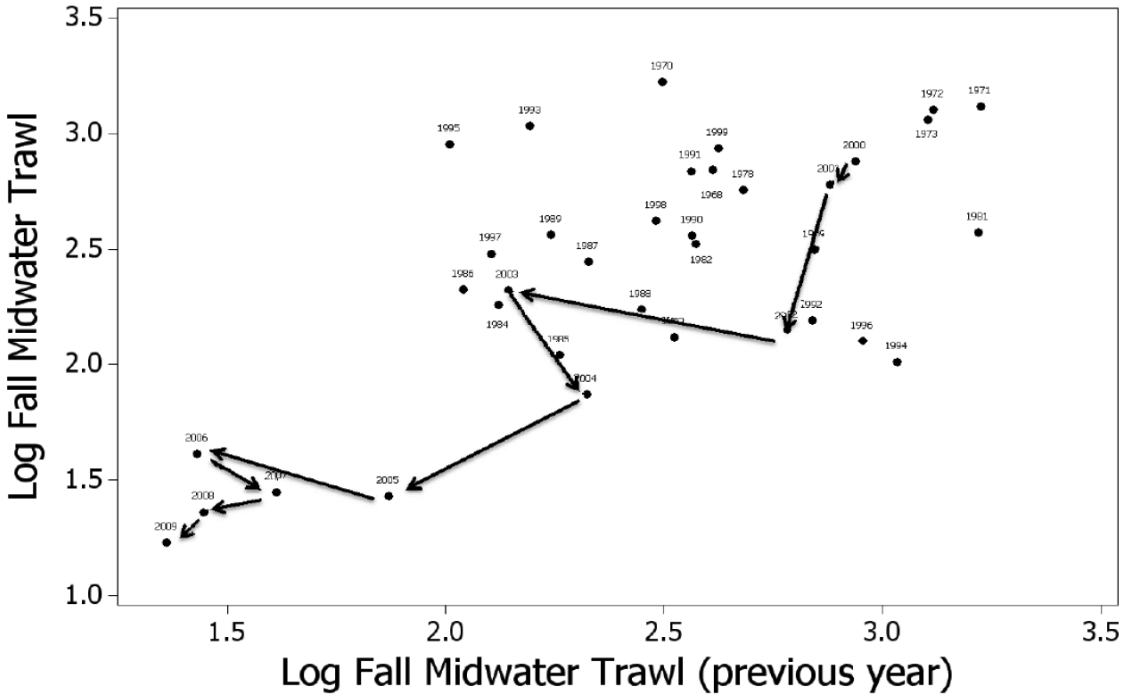
13. Plaintiffs suggest that this index value is artificially low because it does not account for nearly 60% of the estimated Delta-wide population found at the Cache Slough, Sacramento Deepwater Fish Channel, and Liberty Island areas ("Cache Slough Complex"), which were not included in the annual survey used to calculate the index. However, even if the index accounted for this additional population, no party contends that the delta smelt should not be listed under the ESA.

14. Evidence presented at the hearing suggests that the estuary does not support as many delta smelt as it once did. 7-29-11 Tr. at 105:4-14 (Nobriga). This may be because the "compensatory density-dependence" that historically enabled juvenile abundance to rebound from low adult numbers no longer exists. Ex. 505, Nobriga Decl. at ¶ 20. Thus, now, if adult numbers or adult fecundity decline, juvenile production will also decline. *Id.* (citing Kimmerer (2011)). Because juvenile carrying capacity has declined, juvenile production hits a "ceiling" at a lower abundance than it once did. *Id.* This limits adult abundance and possibly fecundity, which cycles around and limits the abundance of the next generation of juveniles. *Id.*

15. Exhibit 504 demonstrates an abrupt change in population dynamics starting in the early 2000s:

---

long spawning window, despite the easterly location of X2 last fall, combined with the fact that the Projects detected virtually no entrainment of delta smelt this Spring were likely responsible for this uptick in the STS index. 7-28-11 Tr. at 106:4-107:2.



Scatterplot of the log-transformed FMWT index versus the following year's log-transformed FMWT index. The abrupt change in population trend starting in the early 2000s, which moves toward the origin, indicates that the risk of extinction to delta smelt has increased.

16. The movement of the arrow toward the origin of the axes indicates that the risk of extinction to delta smelt has increased. Once the arrow reaches the origin, it indicates that no delta smelt are detected in any of the fish sampling trawls. 7-28-11 Tr. at 104:4-11 (Feyrer).

(2) Critical Habitat.

17. The delta smelt's designated critical habitat is composed of four primary constituent elements ("PCEs") that the BiOp found were significantly degraded by normal CVP and SWP project operations in the Fall. 7-29-11 Tr. at 178:12-179:13 (Norris); *see also BiOp* at

190-202, 239-244.

18. More specifically, the PCEs essential to the conservation of the delta smelt are physical habitat, water, river flow, and salinity concentrations required to maintain delta smelt habitat for spawning, larval and juvenile transport, rearing, and adult migration. Ex. 502, Norris Decl. at ¶ 22; *see also* BiOp at 190-202, 239-244.

19. The BiOp found that these PCEs are not located at all places within the delta smelt's designated critical habitat at all times. 7-29-11 Tr. at 177:16-20 (Norris). This is significant because features of delta smelt critical habitat may exist independently throughout the designation, but they only meet their intended conservation purpose when they coincide in space and during the life stage for which those features are required. *Id.* at 178:12-179:3 (Norris).

20. Under the ESA, the adverse modification threshold is exceeded when the proposed action will adversely affect the critical habitat's PCEs, or their management, in a manner likely to appreciably diminish or preclude the role of the designated critical habitat in the conservation of the species. Ex. 502, Norris Decl. at ¶ 20.

21. The BiOp found that the proposed continued operations of the CVP and SWP would adversely modify the delta smelt's critical habitat by preventing it from serving its intended conservation role

by degrading its PCEs and by limiting the co-occurrence of the PCEs at appropriate places and times. *Id.* at ¶ 23.

(3) Relationship of the Delta Smelt Population to X2.

22. Salinities in the Delta are typically measured as parts per thousand (ppt) or practical salinity units (psu), which are equivalent measures. 7/28/11 Tr. at 182:11-15 (Feyrer). The term "X2" refers to a salinity of 2 ppt or 2 psu. "Ocean salinity is usually around 33 psu." Ex. 578, Nobriga and Herbold (2009)), at 19.

23. Delta smelt are believed to typically reside in the low salinity zone[3]. Ex. 501, internal Exhibit B. Laboratory studies indicate that delta smelt are physiologically capable of tolerating salinities up to 19 psu, at which point, the salinity level becomes lethal. Tr. 7/28/11 at 182:24-183:8 (Feyrer). Nobriga and Herbold state: "In captivity, delta smelt can tolerate salinities as high as 10 psu for extended periods (Swanson et al 2000) but long-term monitoring shows that most juvenile delta smelt reside where specific conductance is about 1,000-10,000 microsiemens per centimeter, (about 0.6-6.0 psu)." Ex. 578, Nobriga and Herbold (2009)), at 19.

24. When X2 is at 79km or 80km, some individual delta smelt can

[3] The "low salinity zone" (LSZ) is the area of brackish water in the Delta where inflowing seawater mixes with outflowing freshwater. Some described the LSZ as being the area where salinity ranges from 0.5 to 10 practical salinity units ("psu" which is the same as parts pert thousand "ppt"). *See* Ex. 9, MacNally (2010), at 1419 ("[y]oung delta smelt move downstream in early summer and remain in the low-salinity zone (0.5-10 [on the practical salinity scale]) until they migrate for spawning."); *see also* Ex. 10, Thomson (2010), at 1433. Others define the LSZ as the area where salinities range between 0.5 to 6 ppt. Ex. 501, Feyrer Decl. at ¶ 23 ("low salinity zone is defined to include a range of salinities from approximately 0.5 to 6 ppt, [citing articles]."); 7/28/11 Tr at 107:3-9 (Feyrer). The LSZ moves up and down in the estuary both daily, with changing tidal conditions, and seasonally, with changes in rates of Delta outflow. *Id.* at 107:23-108:4 (Feyrer).

be found at higher salinity areas in Suisun Bay and Grizzly Bay. 7-28-11 Tr. at 213:14-19 (Feyrer). Mr. Feyrer also acknowledged that delta smelt can live their lives entirely in freshwater. Tr. 7/28/11 at 179:8-10.

25. Although delta smelt occupy a range of salinity and water clarity levels, the probability of observing a delta smelt is greatest at low salinities, centering on about 2 psu, and at relatively high levels of turbidity. Ex. 501, Feyrer Decl. ¶ 9; *see also* Ex. 586, Feyrer et al. (2007) ("Feyrer (2007)"), at 7 (AR 18272) (Figure 4(c)). According to Mr. Feyrer most delta smelt are typically caught in salinities between zero (freshwater) and 7 psu. 7/28/11 Tr. 186:17-187:9. Dr. Hanson testified that most delta smelt typically occupy areas between zero (freshwater) and "about 7 or 8 parts per thousand." 7/27/11 Tr. at 19:23-20:6. The probability of observing a delta smelt decreases as salinity increases above X2. 7-29-11 Tr. at 83:7-84:3 (Feyrer).

26. Several published studies, including Sommer *et al.* (2011) have demonstrated that the center of delta smelt distribution is at approximately the two parts per thousand isohaline, except during winter and spring for migration and spawning in freshwater. Ex. 501, internal Exhibit B.

27. This phenomenon is displayed graphically in the figure below, Figure 1 in Mr. Feyrer's declaration, which displays the empirically measured center of delta smelt distribution plotted

against the location of X2, in a tight-fitting relationship:

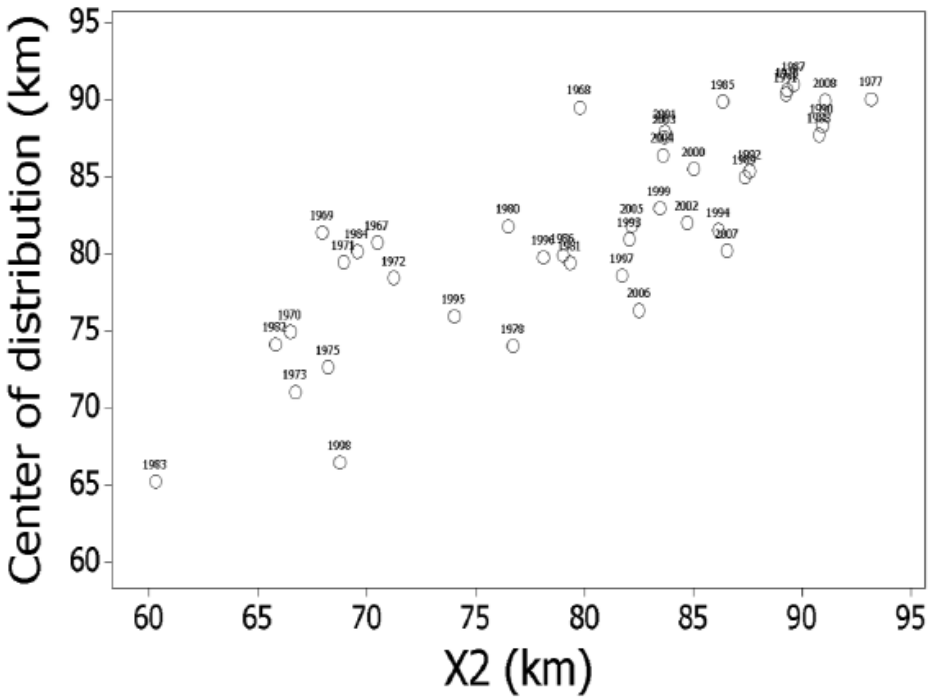


Figure 1. Center of delta smelt distribution plotted against X2.

Ex. 501, Feyrer Decl. at ¶ 9.

28. Dr. Hanson stated that he did not disagree with this figure or that delta smelt distribution centers on X2. 7-27-11 Tr. at 79:1-2. However, he noted that the "centroid" or "center of distribution" is not necessarily the area of greatest concentration, but rather is an index representing a weighted middle point based upon overall distribution. 7-27-11 Tr. at 29:13-17. For example, the "centroid" of the United States -- or the center of human distribution in the country -- might be Iowa, but that does not mean that the centroid is the area of greatest concentration. *See id.* at 29:18-21 (Hanson).

Dr. Hanson opined: "there are other facets of the distribution that need to be taken into account in order to interpret whether that's a meaningful metric." *Id.* at 29:24-30:1.

29. Dr. Hanson testified about a related issue: whether Fall X2 is related to the geographic distribution of delta smelt. He examined whether (1) when X2 is located between 70km and 75 km, the geographic distribution of smelt will expand; and (2) correspondingly, when X2 moves east into the narrower channels of the Sacramento River, the geographic distribution of smelt will contract. 7-27-11 Tr. at 10:11-25, 11:15-16 (Hanson); Ex. 103, figure depicting experimental inquiry. He also examined whether there was a relationship between the surface area of appropriate smelt abiotic habitat and smelt distribution. *Id.*

30. Dr. Hanson concluded the range of smelt distribution shifts further downstream when X2 is located further to the west and shifts further upstream when X2 is located to the east. 7-27-11 Tr. at 27:12-15 (Hanson). This range encompasses a broad geographic area spanning approximately 40 kilometers from Suisun Bay and Grizzly Bay in the west, to the Cache Slough Complex upstream to the north, regardless of the location of X2 in the fall or the extent of the "habitat area" depicted in Figure B-17 in the BiOp. 7-27-11 Tr. at 27:15-21 (Hanson); Ex. 102; 7-29-11 Tr. at 43:7-46:24 (Feyrer); Ex. 154, 155. Dr. Hanson concluded that moving the location of X2 westerly in fall months does not increase the area of habitat

utilized by delta smelt. 7-27-11 Tr. at 27:22-28:6 (Hanson).

31. Defendants criticize Dr. Hanson's analysis in a number of ways:

(a) According to Dr. Norris, one of the asserted purposes of the Fall X2 Action is to locate the centroid of the delta smelt population within the more productive areas of the estuary. Ex. 502, Norris Decl. at ¶ 24. Although Dr. Hanson's distribution maps did visually depict the relative number of smelt caught at each station, Ex. 100, Hanson Decl., Internal Exhibits 1a-e, Dr. Hanson's measurements of the breadth of smelt distribution looked only at the range of sites at which the mere presence of delta smelt was detected in survey data, and did not weight the catch in any way to account for the relative number of smelt caught at each station.

(b) Defendants also assert that Dr. Hanson's analysis is flawed because it is based on a comparison of disparate data sets. Specifically, Dr. Hanson compared FMWT data showing the location of smelt captures in the estuary to data showing a two-month average location of X2. 7-27-11 Tr. at 81:12-82:17. This comparison is of little utility in determining the relationship between smelt distribution and the location of X2 because using a two-month average location of X2 does not account for the location of X2 at the precise moment the smelt were captured. *Id.* at 82:15-17. Indeed, Dr. Hanson could not rule out the possibility that the smelt were located at X2

at the time they were captured. *Id.* at 81:25-83:18.[4]

(c) Defendants also maintain that Dr. Hanson formed a substantial portion of his opinion regarding the Fall X2 Action based on a small and unrepresentative subset of the available data. Ex. 501, Feyrer Decl. at ¶ 25. Specifically, Dr. Hanson states that he used data from 1990, 1996, 2002, 2003, 2005, 2006 and 2008. Ex. 100, Hanson Decl. at ¶ 20. This is only a handful of the 43 years of available data. Although Dr. Hanson states in a footnote that "[t]hese years were selected as examples of the geographic distribution of smelt under various hydrologic conditions," *id.* at 14 n.3, Defendants argue they do not represent relevant hydrological conditions. FWS only prescribed the Fall X2 Action to be implemented following springs classified as either wet or above normal. For unknown reasons, the seven years of data that Dr. Hanson chose "as examples of the geographic distribution of smelt under various hydrologic conditions," *id.*, included only a single example following a wet spring (1996) and a single example following an above normal spring (2006). Ex. 501, Feyrer Decl. at ¶ 25. In fact, of the 43 years of data available, 23 are years which follow a wet or above normal spring. *Id.* It is also unexplained why Dr. Hanson excluded 91% (21 of 23 years) of data points are appropriate.

(d) At best, Dr. Hanson's work on smelt distribution is

[4] Plaintiffs' notice of disapproval cites 7-27-11 Tr. at 82:2-83:3 as evidence that Dr. Hanson did consider the location of X2 on the day the smelt were captured. Those pages say no such thing and in fact reveal that Dr. Hanson admitted this could be done but that he did not do so.

valuable only to demonstrate that the breadth (in kilometers spanned) of smelt distribution does not shift dramatically as X2 shifts. It does not address how either the centroid or the majority of the smelt population moves with X2.

32. The 12/14/10 MSJ Decision found that X2 can rationally be used as a surrogate for delta smelt habitat. *San Luis v. Salazar*, 760 F. Supp. 2d at 918 (holding that "when all the disputed X2 studies are considered, X2 has a measurable effect on smelt abiotic habitat"); *id.* at 918 n.32 ("while X2 does not explain everything, it explains enough to consider X2 a proxy for critical habitat and to structure management prescriptions around X2").

33. The 2009 independent peer review conducted under the Information Quality Act ("IQA") determined that "hydrological events and actions that alter the [fall] X2 location directly *impact* suitable delta smelt abiotic habitat." Ex. 580 at 14. The IQA peer reviewers "strongly concur[red] with the USFWS's use of X2 as an index for identifying delta smelt abiotic habitat," finding that the "X2 index is extremely well supported and scientifically valid" and that "few ecological indices are as robust and well studied as X2." *Id.* In addition, DWR's own scientist, Dr. Ted Sommer, and others reiterated in a published and peer-reviewed journal article in 2011 that the "pre-migration distribution [of delta smelt] occurs in the low-salinity zone of the estuary as illustrated by the *strong association* between fish distribution and X2 during fall." Ex. 501,

Feyrer Delc., Internal Exhibit B, at 8 of 17.

E. Federal Defendants' Scientific Justification for the Fall X2 Action.

(1) Fall X2 Action and the Habitat Needs of the Smelt.

34. It is undisputed that during the fall, delta smelt are maturing pre-adults. They "live in the western portion of the estuary typically centered on the low salinity zone. That's the time of the year where they're growing and maturing into adulthood and preparing for their upstream migration for spawning." 7-28-11 Tr. at 110:17-21 (Feyrer). During this time, they "need enough food, enough calories to be able to grow, mature and start to produce eggs and to survive and make their way upstream and spawn again." *Id.* at 110:24-111:2 (Feyrer). If delta smelt do not eat enough prey and obtain sufficient caloric intake during this period, the species' overall reproduction could be impaired, and individual delta smelt "could produce less or fewer eggs or it might not even be able to reproduce at all." *Id.* at 111:3-12 (Feyrer). All else being equal, a female delta smelt that obtains more calories (prey) will grow larger and produce more eggs than a female delta smelt that obtains insufficient calories. *Id.* at 112:5-10 (Feyrer).

35. Mr. Feyrer opined that if delta smelt have access to more space, they will have more opportunity to encounter and consume prey than in an area where their habitat is more physically constricted. *Id.* at 112:11-17 (Feyrer). He further opined that delta smelt have increased opportunity to encounter and eat prey west of the

confluence of the Sacramento and San Joaquin rivers, and less opportunity to encounter and eat prey at or east of the confluence. *Id.* at 111:18-112:4 (Feyrer).[5]

36. The Fall X2 Action is designed to redistribute the current year's population of delta smelt into Suisun Bay, thereby increasing opportunities for feeding and rearing by increasing the ability of individuals to find food and avoid predation. Ex. 502, Norris Decl. at ¶ 17. Specifically, the Action, which requires increased Delta outflow, is designed to influence the spatial distribution of delta smelt so that it will overlap with biologically productive regions like Suisun Marsh, increasing opportunities for feeding and growth. *Id.* This repositioning is also designed to enhance the ability of pre-spawning delta smelt to escape predation because predation risk is lower in more turbid waters. *Id.*

37. FWS concluded that the ability of designated critical habitat to provide for the conservation of the delta smelt is compromised when the low salinity zone is disconnected from biologically productive areas that maximize the species' opportunity to find and consume prey, such as Grizzly Bay and Suisun Bay and Suisun Marsh areas, which are broader and shallower than the upstream

[5] Plaintiffs' object that these opinions are not based on data, but purely on the suppositions of Mr. Feyrer, whose work never considered food availability or analyzed whether altering the location of X2 would increase opportunities for delta smelt to encounter prey. Mr. Nobriga's work does provide limited support for Mr. Feyrer's conclusion by demonstrating the far western delta is the most biologically productive, with the Suisun area being slightly less productive but still more productive than areas east of the confluence. Nonetheless, Smelt abundance was highest in Suisun, where abiotic factors coincided with biological productivity. *See* Nobriga Decl. at ¶ 21.

confluence of the Sacramento and San Joaquin rivers. *Id.* at ¶ 24; *see also* 7-29-11 Tr. at 108:20-109:4 (Nobriga).

38. FWS also concluded that when the low salinity zone is upstream of the confluence, turbidity is lower than in the Grizzly Bay and Suisun Bay and Suisun Marsh areas, making it more difficult for delta smelt to avoid predation. Ex. 502, Norris Decl. at ¶ 24.

(2) <u>The Delta Smelt Habitat Index.</u>

39. To support the above-described conclusions regarding the Fall X2 ation, the BiOp relies almost exclusively on work by a Bureau of Reclamation scientist, Frederick Feyrer:.

40. The 12/14/10 MSJ Decision described the Feyrer's 2007 paper relied upon in the BiOp.

> [T]he BiOp's reli[ed] on a 2007 Canadian Journal of Fisheries and Aquatic Sciences paper by Feyrer, Nobriga, and Sommer, three scientists then working for Plaintiff DWR, entitled, "Multidecadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, USA." AR 018266-77. That paper used a generalized additive model to assess the relationship between changes in environmental quality for delta smelt (particularly salinity and turbidity) and the abundance of delta smelt. *Id.*
>
> The paper demonstrated that a statistically significant relationship existed between salinity and turbidity in the fall months and the abundance of juvenile delta smelt the following summer for the period of 1987-2004. *Id.* This time period was chosen because it corresponded to the invasion of the *Corbula amurensis* clam which has resulted in significant ecological changes to the Delta. AR 018270. The results demonstrated that 63 percent of sampling stations showed statistically significant declines in environmental quality in the fall, with the western and southeastern regions of the Delta suffering the most substantial long term declines in habitat quality, while the area at the confluence of the Sacramento and San

> Joaquin Rivers least affected by the changes in fall habitat quality. *Id.*
>
> The Feyrer (2007) analysis uses the results of a 2005 study by William Bennett published in the Journal of San Francisco Estuary and Watershed Science, which concluded: "Factors defining the carrying capacity for juvenile delta smelt are unknown, but may include a shrinking volume of physically suitable habitat combined with a high density of competing planktivorous fishes during late summer and fall." AR 017004.
>
> The BA acknowledged the results of this 2007 study, including the conclusion that fall habitat conditions have population level effects:
>
>> Based on a 36-year record of concurrent midwater trawl and water quality sampling, there has been a long-term decline in fall habitat environmental quality for delta smelt (Feyrer et al. 2007). The long-term environmental quality declines for delta smelt are defined by a lowered probability of occurrence in samples based on changes in specific conductance arid Secchi depth. Notably, delta smelt environmental quality declined recently coinciding with the POD (Figure 7-8). The greatest changes in environmental quality occurred in Suisun Bay and the San Joaquin River upstream of Three Mile Slough and southern Delta (Figure 7-9). There is evidence that these habitat changes have had population-level consequences for delta smelt. The inclusion of specific conductance and Secchi depth in the delta smelt stock-recruit relationship described above improved the fit of the model, suggesting adult numbers and their habitat conditions exert important influences on recruitment.
>
> AR 010626; *see also* AR 10628-29 (reproducing maps and graphics showing habitat declines and geographic distribution of declines from Feyrer (2007)).
>
> The conclusions in Feyrer (2007) were also recognized in the January 2008 report on the Pelagic Organism Decline by the Interagency Ecological Program, which reached nearly identical conclusions about the effects of declining fall habitat quality on delta smelt abundance. *See* AR 016938, 016954, 016957.

San Luis v. Salazar, 760 F. Supp. 2d at 915-16.

A 2011 paper published in the Journal of Estuaries & Coasts, Feyrer et al. (2011) ("Feyrer (2011)"), built upon this and other

previous work by Feyrer. Using FMWT survey data, Feyrer (2011) developed an abiotic habitat index, which incorporates both quantity and quality of abiotic habitat. Ex. 501, Feyrer Decl. at ¶ 10; *see also* Ex. 7, Feyrer (2011). The index represents the surface area of the estuary standardized for salinity and water clarity conditions that are favored by delta smelt. Ex. 501, Feyrer Decl. at ¶ 10. The index represents the statistically-computed probability of observing a delta smelt at the observed salinity and water transparency conditions. *Id*. The habitat index is represented in the following figure:

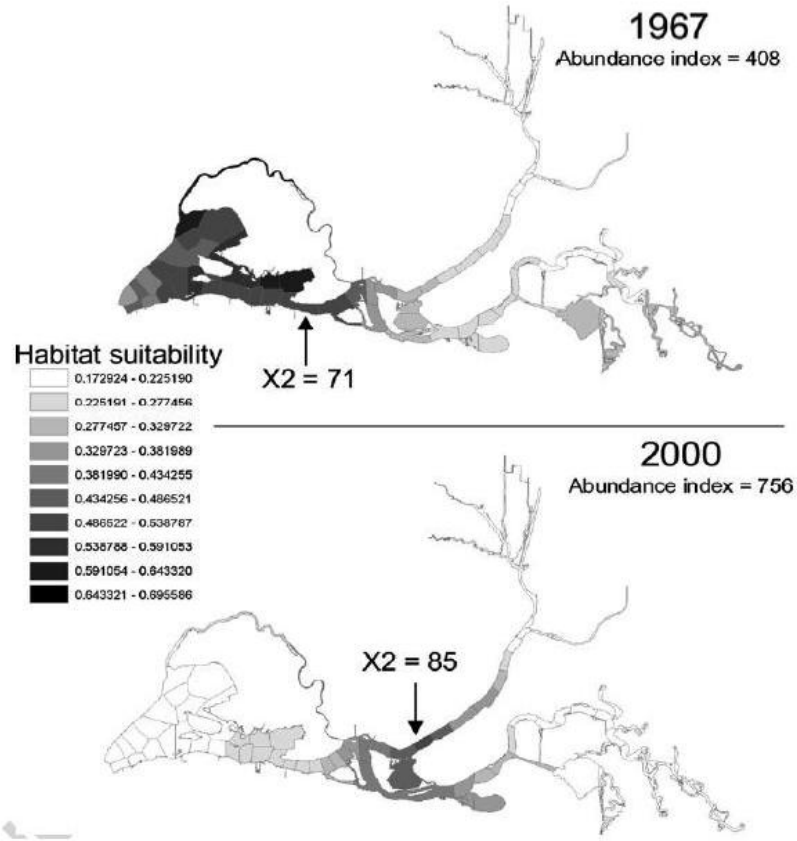


Figure 3. Spatial distribution of delta smelt habitat suitability for years in which X2 was either below (1967) or above (2000) the confluence of the Sacramento and San Joaquin Rivers. Abundance index is from the fall midwater trawl survey.

Ex. 501, Feyrer Decl. at ¶¶ 12-13.

41. In this image, "[t]he darker the shading means the higher suitability or the better it is for delta smelt." 7-28-11 Tr. at 122:2-3 (Feyrer). When the nominal location of X2 lies at 85 km, most of Suisun Bay and its turbid subsidiary bays, and biologically important parts of Suisun Marsh, are poorly suitable habitat according to the habitat index. Ex. 501, Feyrer Decl. at ¶¶ 12-13. The figure also shows that quality and quantity of delta smelt habitat increases as X2 moves westward toward Suisun Bay and Grizzly Bay. *Id.*

42. When explaining the image and the study's findings, Mr. Feyrer testified that "when X2 is located upstream of the confluence there, the habitat space for delta smelt and the habitat quality is much more restrictive compared to when X2 is to the west of the confluence. <u>And when X2 is located west of the confluence, that opens up the low salinity zone and delta smelt habitat to those broad shoals in Suisun Bay and other areas, so there's just a lot more and a lot more suitable habitat for delta smelt</u>." 7-28-11 Tr. at 122:9-16 (emphasis added).

43. The authors of Feyrer (2011) utilized fish catch data, salinity data, and turbidity data that were taken at the same place and time. *See* 7-28-11 Tr. at 115:12-18 (Feyrer). The study found "substantial decline in that habitat index over time." *Id.* at 120:10-11 (Feyrer); *see also* Ex. 7, Feyrer (2011), at 8

("deterioration of habitat represents a major issue for delta smelt because of its vulnerability to extinction").[6]

(3) Link Between Habitat Index and Delta Smelt Abundance Described in Feyrer Papers.

44. Feyrer (2007) concluded that incorporating abiotic habitat covariates into a basic stock-recruit model linking the abundance of sub adult delta smelt (as measured in the FMWT) to juvenile production (as measured in the STS) improved the fit of the model. Ex 586 at 6 (AR 18271) (Feyrer (2007)); *see also* Ex. 501, Feyrer Decl. at ¶ 17. Models that included the abiotic habitat variables accounted for approximately 20% more of the variance in the data set than those without the abiotic habitat variables (r-squared values improved from 0.39 to 0.59). *Id.*

45. Using FMWT fish catch and water quality data, Feyrer (2011) demonstrated a relationship between the abiotic habitat index and the delta smelt abundance index. Ex. 501, Feyrer Decl. at ¶ 18; 7-28-11 Tr. at 116:10-18. Feyrer (2011) concluded that "the habitat index was significantly positively correlated with the delta smelt abundance index..." 7-28-11 Tr. at 127:5-9. Mr. Feyrer presented the following figure, adapted from Feyrer (2011), to demonstrate the relationship between the abiotic habitat index and the FMWT abundance

[6] Plaintiffs dispute whether Feyrer (2011) considered all relevant smelt habitat, specifically whether Feyrer's habitat index analysis included habitat in the Cache Slough Sacramento Deepwater Ship Channel, and Liberty Island areas. Assuming, arguendo, that Feyrer (2001) did not take these areas into consideration, this would reduce the "denominator" of the habitat index. Ex. 4, Burnham Reply Decl. at ¶ 16. Including these areas would reduce the percent decline in the index observed over time. *Id.* Feyrer's testimony suggest that these areas may in fact have been included in his habitat index. 7-29-11 Tr. at 33:4-35:8 (Feyrer).

index.

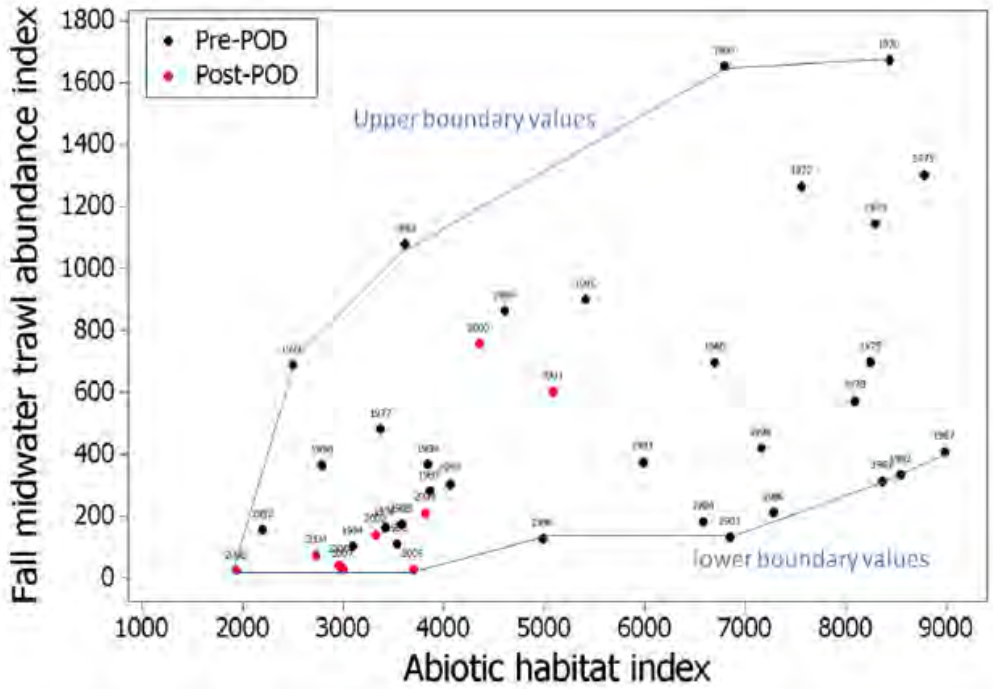


Figure 5. Delta smelt abiotic habitat index plotted against the Fall midwater trawl abundance index for the same year. Blue lines connecting the high and low boundary values were hand-drawn. Pre-POD period is 1967-1999. Post-POD period is 2000-2008. Figure is adapted from Feyrer et al. (2011).

Ex. 501, Feyrer Decl. at 11.

46. Mr. Feyrer opined: "the pattern of these data strongly suggests that although there is substantial variability in the relationship between the abiotic habitat index and the abundance index, there appears to be an upper limit to abundance that is an increasing function of abiotic habitat. A classic interpretation of these data is that delta smelt reach their population carrying capacity as a function of available habitat." *Id.* at ¶ 18.

47. However, both Dr. Deriso and Dr. Burnham opined that this correlation is meaningless, because the analysis in Feyrer (2011)

uses the same FMWT data on both axes, making some correlation inevitable. 7-29-11 Tr. at 207:8-208:9 (Burnham) ("There's the fall midwater trawl data underlying both axes ... And when you use the same data for things you then computed on both axes, it induces some degree of statistical correlation."). Mr. Nobriga agreed that any correlation between the habitat index and the FMWT would be "inherently circular because abundance and presence-absence are correlated," but further explained that Feyrer (2011) took this into account yet nevertheless reaffirmed the conclusion that the habitat index was significantly correlated with the FMWT. Ex. 505, Nobriga Decl. at ¶ 11. Mr. Nobriga does not explain how this correction was made.

48. These are legitimate criticisms and devalue the habitat index to an extent that cannot be determined with certainty.

(4) Other Criticisms of Feyrer's Work.

49. Plaintiffs argue that Feyrer's habitat index and the results of his research are flawed in several other ways.

a. Consideration of Statistical Uncertainty.

50. Plaintiffs argue that Feyrer's analysis fails to appropriately account for uncertainty. In its 2010 review of the available science supporting the Fall X2 Action, the NRC concluded:

> The controversy about the action arises from the poor and sometimes confounding relationship between indirect measures of delta smelt populations (indices) and X2. The weak statistical relationship between the location of X2 and the size of smelt populations makes the justification

> for this action difficult to understand. In addition, although the position of X2 is correlated with the distribution of salinity and turbidity regimes (Feyrer et al., 2007), the relationship of that distribution and smelt abundance indices is unclear. The X2 action is conceptually sound in that to the degree that habitat for smelt limits their abundance, the provision of more or better habitat would be helpful. The examination of uncertainty in the derivation of the details of this action lacks rigor. The action is based on a series of linked statistical analyses (e.g., the relationship of presence/absence data to environmental variables, the relationship of environmental variables to habitat, the relationship of habitat to X2, the relationship of X2 to smelt abundance), with each step being uncertain. The relationships are correlative with substantial variance being left unexplained at each step.

Ex. 12, NRC Report, at 53; 7-29-11 Tr. at 22:22-23:21 (Feyrer). Dr. Burnham agreed with the NRC and testified that it was "scientifically improper" for Mr. Feyrer to chain the results of multiple modeling efforts together without accounting statistically for the error introduced at each step. Ex. 2, Burnham Decl. at ¶ 22. According to Dr. Burnham, because Mr. Feyrer provided no analysis of the statistical uncertainty at each step of his habitat index, by the final step of his analysis it is impossible to assess the reliability of the correlations. 7-26-11 Tr. at 167:7-168:4 (Burnham). Defendants failed to adequately address this critique with countervailing competent scientific or mathematical analysis.

b. <u>Feyrer Analyses Limited to Abiotic Factors Only.</u>

51. Plaintiffs next argue that the Habitat Index is inherently flawed because the index considered only two <u>abiotic</u> habitat variables specific conductance (salinity) and Secchi depth

(turbidity). Ex. 7, Feyrer (2011) at 124; 7-29-11 Tr. at 7:8-13 (Feyrer).

52. Mr. Feyrer freely acknowledged that his work was limited to an examination of abiotic habitat factors, in part because of the absence of food supply data taken concurrently with the fish sampling trawls. *See* Hearing Ex. 7, Feyrer (2011) at 124; Ex. 586, Feyrer (2007), at 9-10 (AR 18274-75); Ex 505, Nobriga Decl. ¶ 12; 7-28-11 Tr. at 117:4-118:14, 120:22-121:5 (Feyrer). Where the habitat index is so heavily relied upon for management purposes, this is an unjustified exclusion.

53. In Feyrer (2007), which served as the basis for the "habitat index" analysis, the authors concede that "[b]iotic variables, most notably competition, predation and food availability, could have also played a major role in controlling the distribution of the [delta smelt, striped bass, and threadfin shad]." 7-28-11 Tr. at 246:3-14 (Feyrer). Mr. Feyrer further conceded that his analysis in Feyrer (2011) was "limited" because it only considered two abiotic variables in its analysis of "suitable" smelt habitat. 7-29-11 Tr. at 7:19-24. He agreed that a full and appropriate definition of "habitat" should take into consideration more than just abiotic conditions and that "[a]biotic habitat is a component of habitat." 7-28-11 Tr. at 244:17-21.[7]

[7] It was suggetsted by Mr. Feyrer that consideration of abiotic habitat alone was sufficient because "[a]biotic habitat factors are the underlying foundation that determines where an organism can live and reproduce." Ex. 501, Feyrer Decl. at ¶ 13. Likewise, Mr. Nobriga testified that a paper he published in 2005 demonstrates

54. The Feyrer (2007) and Feyrer (2011) studies provide some evidence of an association between delta smelt abundance and summer and fall abiotic habitat conditions. However, analyses utilizing the habitat index only explain a portion of the environmental influences on smelt abundance.

55. The Feyrer testimony revealed limitations of the habitat index, which are not satisfactorily explained. The extent to which this diminishes the efficacy of that index is significant, particularly in light of the magnitude of effect implementing the Fall X2 Action has on Plaintiffs. The disconnect between the weak scientific justification and the strong practical impact is corroborated by DWR's opposition to the X2 Action.

c. Failure to Separate Salinity from Turbidity.

56. Feyrer (2011) concluded that the habitat index variables of salinity and turbidity explain 25 percent of the variation in delta smelt abundance. 7-29-11 Tr. at 73: 5-16 (Feyrer). However, Mr. Feyrer acknowledged that the analysis in Feyrer (2011) does not provide a basis for calculating the proportion of the variation in the delta smelt abundance index attributable to salinity as a stand-alone variable. *Id.* at 74:16-75:2.

57. This adds an additional layer of uncertainty when using Feyrer's results to justify imposition of the Fall X2 Action. If

that "physical aspects have to be appropriate for delta smelt in order for the biological productivity [of habitat] to matter." Ex. 505, Nobriga Decl. at ¶ 21. But, that abiotic factors are the "underlying foundation" for or are necessary to smelt survival and reproduction does not necessarily render them more important than biotic factors. Defendants presented no evidence to suggest such priority.

turbidity is the dominant factor, how will controlling X2 accomplish anything? This is not explored or explained.

d. Failure to Consider Smelt Populations Residing in the Cache Slough Complex.

58. The latest STS foudn that 60 percent of the total smelt catch came from areas upstream of the confluence of the Sacramento and San Joaquin Rivers, specifically in the Cache Slough Complex. Ex. 521, Hanson Decl., App. B at 1. This is an area of freshwater or low salinity that is unaffected by the location of X2. 7-27-11 Tr. at 39:5-11 (Hanson).

59. These findings call into question the current understanding of smelt biology. For example, the Interagency Ecological Program's December 6, 2010, Pelagic Organism Decline Work Plan and Synthesis of Results raised questions about the current conceptual model for delta smelt population dynamics:

> The delta smelt has been considered semi-anadromous, but in recent years investigations centered on its northern Delta spawning and early rearing areas have detected delta smelt year-round, leading to the idea that these putative "resident" individuals might represent alternative life history contingents (Sommer et al. 2009, Sommer et al in review). The southern end of the Yolo Bypass, including Liberty Island, Cache Slough, and the Sacramento deep water ship channel are known to support delta smelt spawning and rearing (see Bennett 2005). During 2003-2005 the USFWS collected delta smelt during monthly sampling activities throughout the year, not just during spring time, suggesting that delta smelt were using this relatively shallow, flooded island habitat throughout their entire life cycle (USFWS unpublished data). Similarly, extensions of the 20-mm Survey, TNS [Tow Net Survey] and FMWT surveys into the Sacramento deepwater ship channel caught delta smelt consistently from June through October, the warmest months of the year (CDFG unpublished data). Like the "core" rearing habitat of delta smelt near the Sacramento-San Joaquin River confluence, Liberty Island and adjacent

> deeper habitats in the Ship Channel and Cache Slough are very turbid and have very little SAV [submerged aquatic vegetation] (Nobriga et al. 2005, Lehman et al. 2010, CDFG unpublished data). However, Liberty Island is somewhat warmer during the summer than the river confluence (Nobriga et al 2005) and may prove to be a challenging habitat for rearing. The following conceptual model applies only to the traditional view of delta smelt as a semi-anadromous species. We are currently evaluating how to integrate these observations into our conceptual model (T. Sommer, DWR, unpublished data)."

Ex. 501, Feyrer Decl., Internal Exhibit C (Baxter, et al., *Interagency Ecological Program 2010 Pelagic Organism Decline Work Plan and Synthesis of Results* (Dec. 6, 2010)) at 55-56.

60. The Cache Slough Complex was not included in the STS until 2009 and 2011. 7-27-11 Tr. at 35:7-37:11 (Hanson); *See also* Ex. 106. Consequently, Feyrer's 2007 and 2008 analyses, which only utilized FMWT data up until 2004 and 2006 respectively, *see* Ex 586, Feyrer (2007), at 724 ; Ex. 6, Feyrer et al. (2008) ("Feyrer (2008)"), at 6 (AR 018283), and could not possibly have considered data of a substantial delta smelt population in the freshwater upstream areas in the Cache Slough Complex. Feyrer (2011) used only FMWT data up until 2008, Ex. 7, Feyrer (2011), at 141, so it too did not consider any evidence of a substantial population of delta smelt in Cache Slough that is unaffected by downstream shifts in the location of Fall X2.

61. Plaintiffs criticize Mr. Feyrer's work for excluding these areas from his habitat index analysis. Some evidence suggests Mr. Feyrer's calculation of the habitat index <u>did</u> include Cache slough and the Sacramento Deepwater Ship Channel. 7-28-11 Tr. at 124:15-20

(Feyrer) (testifying that the maps depicting the habitat index did encompass these areas).[8] However, on cross-examination, Mr. Feyrer admitted that the core stations he used to develop the habitat index were all downstream of Cache Slough, Liberty Island, and the Sacramento Deepwater Ship Channel. Tr. 7-29-11 at 36:6-37:15. This inconsistent testimony cannot support the absolute limits for X2 the current RPA establishes.

62. Even assuming the habitat index excluded these upstream areas, Mr. Feyrer opined that including them "would simply add a constant number of units to the habitat index, which would not affect the shape of the X2-habitat index relationship." Ex. 510, Feyrer Decl. at ¶ 16. He admitted, however, that additional units would shift the curve to the right. 7-29-11 Tr. at 33:24-34:1; Exs. 102(a), 153. This is highly relevant to the reliability of the justification provided for the specific 74 km X2 standard to be imposed this Fall.

e. Life Cycle Modeling.

63. Plaintiffs' also criticize Feyrer's work and the BiOp's reliance on it on the ground that Feyrer's results are contradicted by several recent papers evaluating smelt population dynamics through the use of life-cycle models. Life-cycle modeling is a special type of population dynamics modeling that considers the survival and

[8] At the time he prepared the relevant charts Liberty Island (which is actually no longer an island at all, but rather a recently flooded area) was not in existence. 12-28-11 Tr. at 124:14-17.

reproduction of species over time. 7-26-11 Tr. at 169:16-170:6 (Burnham).

64. It is undisputed that life-cycle modeling is the best method for determining the effect of an environmental variable on the population dynamics of a species. *See San Luis v. Salazar*, 760 F. Supp. 2d at 885 (finding it "undisputed that application of a quantitative life-cycle model is the preferred scientific methodology" for determining the effects of a stressor on the population of a species like the delta smelt); *id.* ("life-cycle modeling is standard practice in the field of fisheries biology").

65. Feyrer (2007) states that the development of life-cycle models for the delta smelt was "likely to better quantify the relative importance of water quality on their population dynamics." Ex. 586, Feyrer (2007), at 731 (AR 018274). Mr. Feyrer also admitted that the use of a quantitative life-cycle model "would definitely help us reduce the amount of uncertainty" in the RPA, 7-29-11 Tr. at 17:25-18:10 (Feyrer), and that "well constructed life-cycle models can definitely ... improve our understanding of the delta smelt population dynamics." 7-28-11 Tr. at 219:12-16 (Feyrer).

66. Despite the recognized need for a quantitative life-cycle model to analyze the effect of the location of X2 and other environmental variables on the population of the delta smelt, "it is undisputed that an appropriate life-cycle model had not been developed at the time the BiOp issued" in 2008. *See San Luis v.*

Salazar, 760 F. Supp. 2d at 885. The Court previously found that "FWS had the time and ability to prepare the necessary life-cycle model. FWS made a conscious choice not to use expertise available within the agency to develop one." *Id*. This is evidence of agency intransigence. The court has repeatedly found that the agency's "lack of data" apologetic is the premise for the agency to do what it chooses without addressing Plaintiffs' objections.

67. Dr. Norris, the ESA regulator charged with determining whether there is a likelihood of jeopardy or adverse modification of critical habitat, testified that a life cycle model is not *per se* the best available science under ESA Section 7(a)(2). 7-29-11 Tr. at 182:4-186:6. She opined that a life cycle model is not automatically considered to be a credible resource, but rather must be evaluated for credibility based on the assumptions that went into it, the questions that were being asked, the data that were used, how the results were derived and what conclusions were drawn from those results. *Id*. at 186:7-16. Dr. Norris further explained that it is unlikely that any one life cycle model ever would be considered definitive or conclusive evidence that forecloses other evidence. *Id*. at 186:17-22.

68. Dr. Norris observed that scientific understanding with regard to the delta smelt is never static, and new information frequently is developed after a BiOp has been prepared. *Id*. at 186:23-187:6. For instance, Dr. Norris testified that Dr. Ken

Newman, of FWS's Stockton, California office, currently is working on a delta smelt life cycle model that will have several unique features, including spatial variability throughout the Delta, as well as temporal variability. *Id.* at 182:18-183:13. Dr. Newman's model also will include the full data set for the Fall Midwater Trawl, which is fairly extensive and expanded over what has been done previously. *Id.*

(1) Feyrer (2008) Life Cycle Modeling Effort.

69. The BiOp relied in part on a 2008 manuscript, Feyrer (2008), which utilized a life-cycle model to evaluate the relationship between the location of X2 and delta smelt abundance. BiOp at 236. The December 14, 2010 MSJ Decision summarized the paper as follows:

> [Feyrer (2008)] expanded upon the 2007 research, used statistical analyses, including both Ricker and Beverton-Holt type models, to compare Fall X2, habitat area for and subsequent abundance of delta smelt. *Id.* Like Feyrer (2007), it concluded that fall habitat quality had a statistically significant effect on subsequent delta smelt abundance, determining that the model incorporating prior abundance and X2 accounted for 66 percent of the variability in subsequent abundance. *Id.* The authors identified a number of reasons why the location and extent of fall habitat affected subsequent abundance:
>
>> First, positioning X2 seaward during autumn provides a larger habitat area which presumably lessens the likelihood of density-dependent effects (e.g., food availability) on the delta smelt population. For example, food availability during autumn for adult haddock (*Melanogrammus aeglefinus*) likely improves juvenile recruitment the following year (Friedland et al. 2008). Second, a more confined distribution may increase the probability of stochastic events that increase mortality rates of adults. For delta smelt, this includes both predation, as well as anthropogenic

> effects such as contaminants or water diversion loss (Sommer et al. 2007).
>
> AR 018293. The study concluded: "Comparing the first ten years of the time series to the last ten years, the amount of suitable abiotic habitat for delta smelt during autumn has decreased anywhere from 28% to 78%, based upon the least and most restrictive habitat definitions, respectively." AR 018293-94.

San Luis v. Salazar, 760 F. Supp. 2d at 917.

70. Responding to Dr. Deriso's critique at that time that the Feyrer (2008) model inappropriately made use of a linear additive model, rather than a multiplicative model, the MSJ Decision concluded this critique "raise[d] a scientific dispute among experts," and noted that peer reviewers did not recommend exclusion of the model and broadly supported the Fall X2 action based in part upon the model. *Id.* at 922.

71. The Feyrer (2008) manuscript, which was cited in the BiOp, was ultimately published as Feyrer (2011), Ex. 7, but with a narrowed focus on the habitat index, and leaving the draft life cycle model contained in the 2008 manuscript for later, to be incorporated into a different effort where that could be the sole focus. 7-28-11 Tr. at 135:14-136:15 (Feyrer).[9]

72. Plaintiffs argue that the Feyrer (2008) model suffered from

[9] Plaintiffs suggest that the omission of the draft life cycle model from the final publication in 2011 undermines the value of the conclusions in Feyrer (2008). The fact that the authors of Feyrer (2008) removed the draft life cycle model from the manuscript prior to submitting it for publication in 2010, *see* Ex. 501, Feyrer Decl. at ¶ 19, does not mean that FWS's reliance on the manuscript (including its many other parts) in developing the 2008 BiOp was arbitrary and capricious. The draft life cycle model was removed so that it could be the focus of a separate effort, and because the Feyrer (2011) article ultimately took on a different focus, namely, the creation of the abiotic habitat index. 7-28-11 Tr. at 135:14-136:15 (Feyrer).

significant structural problems. Specifically, the model predicted negative smelt abundance as often as 54% of the time under certain scenarios. 7/28/11 Tr. at 251:15-252:23 (Feyrer); *see also* Ex. 6, Feyrer 2008, at 12 (AR 018289).

73. In his testimony, Mr. Feyrer stated that the negative abundance values might possibly represent an extinction scenario rather than a flaw in the model. 7-29-11 Tr. at 88:6-25 (Feyrer). However, contrary to this testimony, Feyrer (2008) considered this possibility and dismissed it. Ex. 6, Feyrer 2008, at 12 (AR 018289) ("[O]ne could make an argument that the frequency of times that such an event occurred was a prediction of the probability of extinction. ... However, the probability of negative abundances was largely a function of uncertainty in the parameter values as increasing the initial number of adult fish in the fall, even to 1,000, did not noticeably affect the probabilities."). This disassembling calls Mr. Feyrer's credibility into question. His scientific objectivity is compromised by inconsistency.

74. The Feyrer (2008) life cycle model concluded that fall habitat quality had a statistically significant effect on subsequent delta smelt abundance and determining that the model incorporating prior abundance and X2 accounted for 66 percent of the variability in subsequent abundance. The model and its application were imperfect. They represent relevant but scientifically compromised findings regarding the relationship of Fall X2 to smelt abundance.

(2) Overview of Other Life-Cycle Modeling Efforts.

75. Since the BiOp was published in December 2008, the body of scientific information on delta smelt has grown. Three additional life-cycle models have been developed by Maunder & Deriso (2011), Mac Nally et al. (2010) ("Mac Nally (2010)"), and Thomson et al. (2010) ("Thomson (2010)"). Each is the subject of an article published in a peer-reviewed scientific journal. Exs. 8, 9 & 10.

76. The Maunder & Deriso (2011) model is a state-space multistage life-cycle model that analyzes delta smelt populations at every life stage using data from multiple seasonal surveys of delta smelt abundance. 7-26-11 Tr. at 46:2-15 (Deriso). The state-space model approach is capable of utilizing an array of surveys, which allows for more closely tailored testing of environmental factors within a particular life stage. *Id.* at 46:23-47:1 (Deriso).

77. Thomson (2010) endorsed the statistical approach taken in the Maunder & Deriso (2011) model, stating "[a]nother area of future work that may clarify mechanisms is to fit process models that include multiple life history stages of the fish species using data available from surveys that complement data from autumn midwater trawl surveys used here ... A life history model that linked the abundances of each life stage would provide a more continuous picture of the delta smelt population and would capitalize more fully on available data." Ex. 10, Thomson (2010), at 1446.

78. Similarly, Mac Nally (2010) recommended the statistical

approach taken in the Maunder & Deriso (2011) model: "A broader life-history model with a more general state-space approach to modeling the pelagic species decline should be more informative." Exh. 9, Mac Nally (2010), at 1427.

79. The Maunder & Deriso (2011) model was structured so that it could perform hypothesis testing about candidate environmental factors to determine if they were important in accounting for changes to the population growth rate. 7-26-11 Tr. at 47:23-48:2 (Deriso).

80. The Maunder & Deriso (2011) model found that three kinds of environmental factors were important: food abundance in spring as measured by the zooplankton index, spring water temperature, and fall predation index. In addition, density dependence was significant. *Id.* at 48:11-17 (Deriso).

81. The Mac Nally (2010) model, which was co-authored by Mr. Feyrer, used a different statistical technique called multivariate autoregressive modeling to determine the effects of 54 different environmental covariates. 7/28/11 Tr. 220:18-20 (Feyrer); Ex. 9, Mac Nally (2010).

82. The Thomson (2010) model, which was also co-authored by Mr. Feyrer, used another statistical technique, Bayesian change point analysis, to determine the effect of a number of covariates on delta smelt abundance. 7-28-11 Tr. at 220:15-17 (Feyrer); Ex. 10, Thomson (2010).

83. Each of the published life-cycle models used different data

sets, different covariates, and different modeling approaches. 7-26-11 Tr. at 134:4-11 (Deriso); Ex. 501, Feyrer Decl. at ¶ 21.

84. Using different modeling approaches, data sets, and covariates, all three of the published life-cycle models came to the conclusion that the location of X2 in the fall does not have a statistically significant effect on delta smelt abundance. 7-26-11 Tr. at 134:4-11 (Deriso); 7/29/11, 18:14-21 (Feyrer); 7/29/11, 121:11-14 (Nobriga). Federal Defendants' expert Mr. Nobriga admitted, based on the three published models, that the 40 years of historical data do not support a correlation between the location of X2 in the fall and delta smelt abundance: "I think that in terms of the historical data, that the three models probably indicate there's – that you're not going to find a correlation out of the historical data." 7-29-11 Tr. at 141:5-15.

85. However, all three life-cycle models also came to <u>different</u> conclusions regarding which factors affect delta smelt abundance. Ex. 501, Feyrer Decl. at ¶ 21; *see also* Ex. 505, Nobriga Decl., Internal Exhibit B (chart comparing life cycle models). This suggests that there is no one single factor that affects delta smelt abundance, and there is no single paper, model, or analysis that is the final word on what factors affect the smelt. There is substantial disagreement among scientists about the relative importance of various factors. Additionally, the relative importance of factors differs both within and among years. *See* Ex. 501, Feyrer

Decl. at ¶ 21 (citing Bennett and Moyle (1996); Bennett (2005); Sommer *et al.* (2007); Baxter *et al.* (2010)).

86. Model results "depend very strongly on how the model is set up and what covariates are considered." Ex. 505, Nobriga Decl. at ¶ 23. Since covariates affect the result, it is therefore "extremely important that the covariates (i.e., the model inputs) accurately characterize what they purport to characterize – and that they reflect the best use of available scientific and monitoring information." *Id.* at ¶ 25. The scientific disagreement over which covariates should be considered does not justify ignoring the results of these life cycle models.

(3) Specific Critiques of the Maunder & Deriso Approach.

87. Dr. Deriso testified in detail about the results of the life cycle he developed with Dr. Maunder. Defendants offer numerous reasons why the Maunder & Deriso model should not be afforded definitive weight here.

88. Defendants first assert that both the Feyrer (2011) analysis and the Maunder & Deriso life-cycle model produced similarly powerful results, namely that they both "account for approximately the same percentage of variation in the FMWT." 7-28-11 Tr. at 127:13-129:11 (Feyrer)(basing his testimony on Dr. Deriso's previous testimony that the Maunder/Deriso model only explains 24% of the variation in adult delta smelt abundance, leaving unexplained 76% of the variation which must be caused by some other factor or factors.

7-26-11 Tr. at 119:13-120:2 (Deriso)); *see also* Ex. 3, Deriso Decl., Internal Attachment A, at 13 of 49.

89. Plaintiffs argue in their Disapproval that this is comparing apples to oranges. The 24% figure to which Dr. Deriso referred was taken from the "Adult" column of Table 7 of Deriso & Maunder (2011), which represents the period of the delta smelt life cycle from the FMWT to the spring 10mm survey. Doc. 1009 ¶ 63. This apparently does not represent the variation in the FMWT in the same way as Feyrer (2011) measured. Rather, Plaintiffs assert the more appropriate figure is 43%, taken from the "Juvenile" column of Table 7, which represents the period of the delta smelt life cycle from juveniles to adults in the STS to the FMWT, "in other words the changes in population level that result in the FMWT measurement." Id. But, Plaintiffs failed to present any evidence demonstrating that this is a better form of comparison. More importantly, this explanation highlights the fact that the two types of modeling compared by Mr. Feyrer are not necessarily equivalent. Dr. Burnham explained that comparison of two R-squared values is improper, because the underlying analyses are entirely different. Tr. 7-29-11 at 208:19-210:13. This further inconsistency raises additional questions about reliability of Feyrer's final opinion reflected by the Fall X2 RPA

90. Dr. Deriso generally acknowledged that the Maunder & Deriso model is merely "a start towards answering the complicated question

regarding the Delta." 7-26-11 Tr. at 123:11-13 (Deriso); Ex. 5, Deriso Reply Decl. at ¶ 27. Dr. Deriso admitted that his "model is not the final word on the delta smelt, it can undoubtedly be improved." 7-26-11 Tr. at 123:3-6; Ex. 5, Deriso Reply Decl. at ¶ 27.

91. Defendants further complain that Dr. Deriso's model is a generic life-cycle model that is merely illustrated in his manuscript by application to delta smelt. 7-26-11 Tr. at 86:25-87:5 (Deriso). His model does not reflect delta smelt biology other than being designed for an annual species with various abundance measurements during the year. 7-26-11 Tr. at 88 (Deriso). It was not developed with fish biologists or ecologists with extensive experience in the Delta. 7-26-11 Tr. at 124 (Deriso). However, Dr. Deriso explained that the Maunder & Deriso (2011) model was tailored to the specific life stages of the delta smelt. 7-26-11 Tr. at 88:6-20.

92. Defendants also criticize the Maunder & Deriso (2011) model for failing to analyze prey abundance or turbidity.

(a) Dr. Deriso admitted that prey abundance is a key factor affecting survival. 7-26-11 Tr. at 64:17-19; *see also* 7-26-11 Tr. at 133:24-34:3. Yet, his model specifically excluded consideration of prey density in the fall, 7-26-11 Tr. at 104:10-12 (Deriso), despite the fact that "[n]ative and non-native zooplankton abundances are known to be enhanced in the western portion of the Delta during the fall," Ex. 4, Burnham Decl., Internal Attachment A (Delta Science

Program Review Panel Summary Report Re: Draft Plan for Adaptive Management of Fall Outflow for Delta Smelt Protection and Water Supply Reliability), at 36 of 49. This is an unjustified rationalization that weakens applicability of the Maunder & Deriso life cycle model.

(b) Dr. Hanson concurs "that as habitat moves further down into the Suisun Bay area there would be zooplankton availability as a food resource. And under that circumstance, you would expect that the delta smelt would have greater opportunities for foraging when they were located further downstream in the Suisun Bay area." 7-27-11 Tr. at 9:-13.

(c) Similarly, Dr. Deriso did not test the effect of turbidity on delta smelt in the fall. As explained in Reclamation's 2011 Fall X2 draft adaptive management plan, "turbidity at X2 is higher when X2 overlaps Suisun Bay than when it's in the river channels east of the [Sacramento-San Joaquin] confluence" and that "higher turbidity is expected to reduce predation rates on delta smelt." Ex. 501, Internal Exhibit A, at 25 of 48. Dr. Hanson agreed: "as habitat area moves further down into the Suisun Bay area, ... it's an area that characteristically has higher turbidities. You might expect that those higher turbidities would result in a reduction in the vulnerability of delta smelt to visual predators such as striped bass. That would reduce predation mortality and increase delta smelt survival." 7-27-11 Tr. at 9:1-7.

(d) While Dr. Deriso did find that predation in the fall is a significant factor affecting smelt abundance, 7-26-11 Tr. at 107:14-20, he failed to include a turbidity variable in his fall X2 analysis that would measure whether increased turbidity would reduce the negative effect of fall predation, 7-26-11 Tr. at 108:12-17.

(e) Although prey abundance and turbidity were not directly tested in the Maunder & Deriso analysis, Plaintiffs point out that Defendants' theories are dependent upon the assumption that moving the location of X2 will redistribute smelt into areas where, in part because turbidity and prey abundance are favorable to the smelt, their abundance will increase. Dr. Deriso tested whether the location of X2 is correlated to changes in smelt abundance and found no correlation.[10]

93. There is also a dispute over whether the data inputs Dr. Deriso used were appropriate. To illustrate his model, Dr. Deriso chose to use covariates developed by Dr. Manly and Dr. B.J. Miller, rather than raw IEP data employed by the Thomson and Mac Nally models. *See* Ex. 5, Deriso Reply Delc., at ¶ 25. Dr. Deriso concluded that this data, which refined the raw data to represent actual smelt habitat locations and conditions, would produce more accurate and useful results than the raw data. *Id.* This was a

[10] Defendants also criticize Dr. Deriso's work because the data set used by Dr. Deriso in his published manuscript excluded salinity altogether as a factor affecting delta smelt. 7-26-11 Tr. at 102:18-20 (Deriso). But, Dr. Deriso performed a separate analysis of X2 using his life cycle model, from which he concluded that the location of X2 in the fall has no effect on delta smelt abundance. Ex. 3, Deriso Decl. at ¶¶ 23-31.

reasonable exercise of scientific judgment.

94. Additionally, Dr. Deriso's life cycle model uses a food supply variable based on zooplankton data that are collected at fewer and different stations from the fish sampling trawl, and at different times. Ex. 505, Nobriga Decl. ¶¶ 13, 32-33. This approach could "potentially bias the data" because both delta smelt and zooplankton can move quickly, either passively on currents, or under their own volition in response to local hydrodynamics. 7-29-11 Tr. at 119:19-120:5 (Nobriga); *see also* Ex. 303, Nobriga Decl. ¶ 13; *see also id.* ¶ 32 ("the key is to use concurrently collected data because the predator (delta smelt) and its prey (calanoid copepods) are always moving – both due to hydrodynamics and their own swimming behaviors"); 7-29-11 Tr. at 112:3-13 (Nobriga). Yet, on cross-examination, Mr. Nobriga admitted that there is no prey data collected concurrently with the FMWT. Tr. 7-29-11 at 133:14-134:9. This reduces the reliability of the data used.

95. Finally, Defendants assert that Dr. Deriso's model is flawed because it "does not reflect the current population status of the delta smelt." Doc. 1004, Defendant's Proposed Findings of Fact # 177. Specifically, Defendants point out that Dr. Deriso's model found strong evidence for density dependence for survival from juvenile delta smelt to adults. 7-26-11 Tr. at 110:3-5. Dr. Deriso acknowledges that this finding of a density dependent relationship is "heavily influenced" by three consecutive years of data from 1976-

1978, *id.* at 112:9-13, and that the juvenile-to-adult life stage of delta smelt is currently density independent, *id.* at 113. Defendants complain that, despite the current, density independent pattern, Dr. Deriso's model was specifically designed "to evaluate population impacts in the presence of density dependence." Ex. 3, Deriso Decl., Internal Attachment A, at 26 of 48.

96. Plaintiffs rejoin that this entire line of reasoning is misleading because the Ricker-type model that underlies the Maunder & Deriso (2011) model operates accurately to predict survival rates that are density independent at very low population levels, Doc. 1009, Disapprovals at 75, but Plaintiffs cite nothing in the record to support this assertion.

97. Overall, Defendants critiques of Dr. Deriso's work do not undermine its essential value as a peer-reviewed life cycle model that concludes there is no correlation between the position of X2 and delta smelt abundance.

f. Comparison of the Life Cycle Modeling Results.

98. Plaintiffs assert that the Mac Nally, Thomson, and Maunder & Deriso models should be given definitive weight because these three life-cycle models agree that the location of Fall X2 has no effect on delta smelt abundance. But, the evidence suggests that none of these models are universally accurate. Each approach asks different questions using different tools and inputs, and each result has its strengths and weaknesses. This is a classic scientific dispute.

99. These competing scientific results compared against one another do not produce a certain paradigm. They are all considered in the final balancing of the equities. The one clear conclusion that can be drawn from this dispute is that the Feyrer papers are neither definitive nor dispositive, and do not provide the level of confidence on which such unprecedented action should be based. They provide some evidence for the Fall X2 Action that is undermined and contradicted by the three most recent life cycle modeling efforts.[11]

F. Dr. Hanson's Testimony.

100. Plaintiffs' expert, Dr. Charles Hanson, a fish biologist, testified at length about his own independent investigation into the biological support for the Fall X2 Action. He first examined the purported relationship between the monthly average location of X2 in the Fall and the subsequent abundance of delta smelt. After examining the relevant scientific literature, Dr. Hanson identified four mechanisms by which movement of the location of X2 could possibly affect the population dynamics of delta smelt: (1) that X2 has an impact on the geographic distribution of delta smelt in the

[11] Federal Defendants assert generally that reliance on statistical applications and modeling computations are not a complete substitute for local biological and ecological knowledge. For example, recent work by Kimmerer indicates that losses of delta smelt to export pumping can be nearly undetectable with regression analysis yet have a very significant population-level effect. Feyrer Decl. ¶ 20 (7-1-11) (Hearing Exhibit 501) (citing Kimmerer (2011)) (Doc. 944). While Kimmerer may provide support for finding an effect despite statistical insignificance under the circumstances analyzed in his paper for losses of smelt to export pumping, no such analysis has been presented here regarding the impact of Fall X2 on smelt abundance. FWS cannot simply assume that the location of X2 affects smelt population dynamics. Record evidence is necessary. Here, such evidence is in the form of statistical analyses. The Fall X2 action must rise or fall on that information.

fall; (2) that X2 effects survival of pre-spawning delta smelt in the fall; (3) that X2 affects reproduction of delta smelt the following spring; and/or (4) that X2 affects delta smelt food availability. 7-27-11 Tr. at 8:13-9:16, 9:20-25 (Hanson); *see also* 7-26-11 Tr. at 234:18-235:1 (Hanson).

101. The results of Dr. Hanson's inquiry into the effect of Fall X2 on smelt geographic distribution were discussed above at Findings of Fact ## 28-31. Bvt5

(1) Relationship Between Fall X2 and Delta Smelt Survival.

102. Dr. Hanson examined whether there was a relationship between the position of Fall X2 and delta smelt survival. He did so by developing a survival index derived from FMWT survey data. 7-27-11 Tr. at 43:19-44:12, 44:20-21 (Hanson); Exhs. 108A, 109.[12] The survival index was mapped against the corresponding X2 location derived from Dr. Hutton's work. 7-27-11 Tr. at 46:9-10 (Hanson); Ex. 109.

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[12] Using DFG's estimates of delta smelt abundance for September, October, November, and December from the FMWT surveys, Dr. Hanson developed a survival index that plotted the change in abundance over the seasonal period, with the slope of the resulting regression serving as an index of the survival rate. 7-27-11 Tr. at 45:21-46:8 (Hanson).

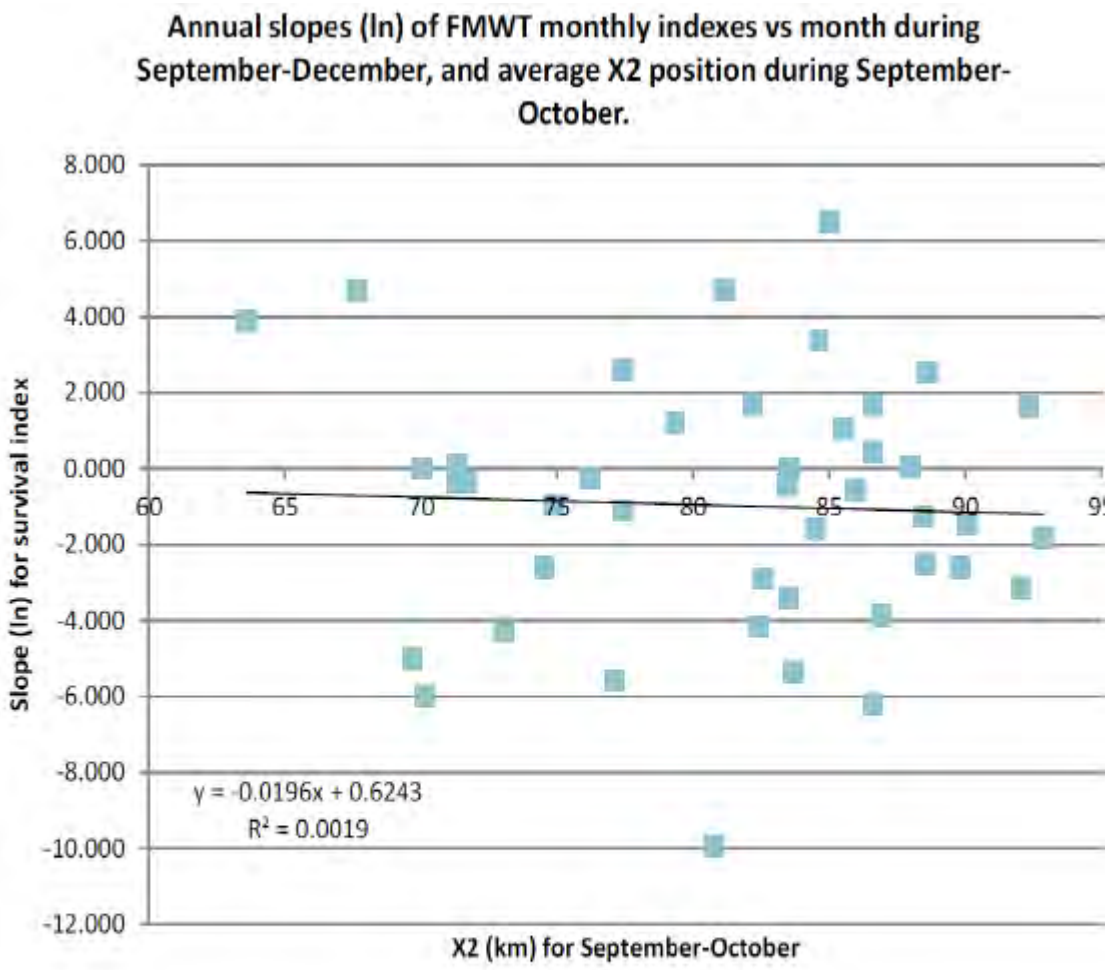

Figure 7. Estimated survival of delta smelt collected in the CDFG FMWT and September-October X2 location.

Ex. 100, Hanson Decl. at 19. When actual FMWT data were thus arrayed, they demonstrated that no relationship exists between the survival of delta smelt in the fall and the corresponding location of X2 in September and October. 7-27-11 Tr. at 46:13-47:14, 50:14-16, 52:5-19; Ex. 109.

103. Dr. Hanson also evaluated the location of X2 in the fall and delta smelt survival using data from a paper authored by Dr. Ken Newman of FWS that attempted to correct for sampling inefficiencies

in the FMWT data and reached exactly the same conclusion, namely that there is no evidence of a statistically significant relationship between delta smelt survival estimates using the "corrected" FMWT data and either the September or October location of X2 or the "habitat area," as estimated in Figure B-17 of the BiOp. 7-27-11 Tr. at 52:16-19, 52:20-53:3 (Hanson); Ex. 102.

104. Defendants assert Dr. Hanson's opinion with regard to the relationship between Fall X2 and delta smelt survival is subject to criticism because it is based on an analysis of data that included significant sampling bias. Specifically, Dr. Hanson used individual regression lines -- each of which were based on only four data points -- that included positive survival for delta smelt in the fall, something that is biologically impossible. 7-27-11 Tr. at 88:15-90:19; *see also* 7-26-11 Tr. at 182:23-184:17 (Dr. Burnham confirming his understanding that data points presented by Dr. Hanson in Figure 7 represented an increase in survival for delta smelt between the months of September and December, something that was "biologically impossible" if you "took [Figure 7] as truth," while explaining that uncertainty in the estimates may be responsible for the increase). Dr. Hanson admitted that he used this data for his analysis and made no effort to correct for the bias. 7-27-11 Tr. at 90:15-91:7. However, he also explained that such data points are caused by variability and uncertainty inherent in the fishery sampling process. 7-27-11 Tr. 48:14-50:3. The same data points were used by Mr. Feyrer

in his analyses. 7-27-11 Tr. 50:22-23 (Hanson). This admitted bias weakens Dr. Hanson's study.

(2) Relationship Between Fall X2 and Delta Smelt Reproductive Success.

105. Dr. Hanson then tested the BiOp's assertion that fall X2 location and the size of the zone characterized by FWS as "habitat area" might affect delta smelt reproduction -- i.e., when X2 is located further upstream and the delta smelt "habitat area" is supposedly smaller, delta smelt reproduction per adult should be reduced, and when the delta smelt "habitat area" is located downstream in Suisun Bay and the available "habitat area" is supposedly larger, food availability, fecundity, and other factors result in a higher rate of juvenile smelt production per adult. 7-27-11 Tr. at 53:21-54:6 (Hanson); Ex. 110A.

106. Using data from the California Department of Fish and Game ("CDFG") 20 Millimeter Survey for the larval stage and STS for the juvenile stage of delta smelt, Dr. Hanson created a normalized dataset by dividing juvenile abundance in the spring by the FMWT index of adult delta smelt abundance from the prior fall. 7-27-11 Tr. at 54:23-55:16, 4:7-12 (Hanson). The resulting reproduction ratio can be plotted as a function of either "habitat area" based on data from Figure B-17 in the BiOp, Ex. 111, or the location of X2 in the fall based on analyses performed by Dr. Hutton, Ex. 112A; *see also* 7-27-11 Tr. at 55:16-57:14 (Hanson). Doing so demonstrates that reproduction per adult in the spring is independent of the location

of X2 the prior fall. 7-27-11 Tr. at 4:12-13; 57:5-6, 57:10-13 (Hanson); Ex. 112A. Moreover, there is no significant relationship between the area referred to by FWS as the "habitat area" and the subsequent reproduction of per adult the following spring. 7-27-11 Tr. at 56:7-10, 57:10-13 (Hanson); Ex. 111.

(3) Relationship Between Fall X2 and Food Availability.

107. Dr. Hanson also analyzed the assumed relationship between the average monthly location of X2 in the fall and the availability of zooplankton, the principal food resource for delta smelt. To do so, he tested whether, when X2 is located downstream in Suisun Bay and, according to Federal Defendants, the "habitat area" is greater, more zooplankton are available, and when X2 moves further upstream, whether zooplankton availability is reduced. 7-27-11 Tr. at 59:10-21 (Hanson); Exh. 114A.

108. After examining DFG data collected since 1972 at various locations within the estuary, in combination with data from the FMWT surveys on *Eurytemora* and *Pseudodiaptomus* (zooplankton species that are substantive components of the delta smelt diet), Dr. Hanson found there is no relationship between zooplankton densities in the fall and the location of X2 in the fall. 7-27-11 Tr. at 4:14-16, 5:1-6, 60:7-9, 60:24-25, 61:13-16 (Hanson); Ex. 115. Instead, zooplankton densities were independent of the average monthly location of X2 in the fall, and the location of X2 provided little information about the variability inherent in zooplankton densities. 7-27-11 Tr. at

61:13-20, 63:12-13 (Hanson); Ex. 115.

109. Overall, Dr. Hanson's analyses lend support to the findings of the three most recent life-cycle models, Thomson, Mac Nally, and Maunder & Deriso, all of which concluded that Fall X2 had no relationship to delta smelt survival.

G. Effect of Project Operations on the Position of X2.

110. The BiOp concludes that "there has been a long-term shift upstream" in the location of X2 during the fall. *See, e.g.,* BiOp at 236. The BiOp reasons:

> The effects of project operations outlined above on X2 during the fall months have considerably altered the hydrodynamics of the estuary in two important ways other than which have already been described. First, the long-term upstream shift in fall X2 has created a situation where all fall seasons regardless of WY type now resemble dry or critical years (Figure E-27). In other words, all fall seasons have now been converted into uniform, low flow periods. Second, the effects have also manifested in a divergence between X2 during fall and X2 during the previous spring (April-July spring averaging period), and the modeling studies indicate this condition will persist in the future (Figure E-28).
>
> Combined, these effects of project operations on X2 will have significant adverse direct and indirect effects on delta smelt. Directly, these changes will substantially decrease the amount of suitable abiotic habitat for delta smelt, which in turn has the possibility of affecting delta smelt abundance through the depensatory density-dependant mechanisms outlined above. Because current abundance estimates are at such historic low levels, depensatory density-dependence can be a serious threat to delta smelt despite the fact that the population may not be perceived to be habitat limited. It is clear from published research that delta smelt has become increasingly habitat limited over time and that this has contributed to the population declining to record-low abundance levels (Bennett 2005; Baxter et al. 2008; Feyrer et al. 2007, 2008; Nobriga et al. 2008). Therefore, the continued loss and constriction of habitat proposed under future project operations significantly threatens the ability of a self-sustaining delta smelt population to recover and persist in the Estuary at abundance levels higher than the current record-

lows.

Id. at 237. This is part of the rationale for imposition of the Fall X2 Action.

111. The BiOp reached this conclusion after analyzing historic trends in the movement of X2 between 1967 and 2007. BiOp 271; 7-27-11 Tr. at 154:20-156:7. This analysis revealed an easterly shift of 17 km over that time period in the Fall. It also revealed a considerable reduction in the variability of X2 in the fall. *Id.* The accuracy of the BiOp's analysis of this data set is undisputed.

112. Plaintiffs, through the testimony of Dr. Paul Hutton, challenge the choice of time frame (1967 – 2007) analyzed in the BiOp, suggesting instead that a more appropriate analysis would consider all available historic data, which dates back to 1930. 7-27-11 Tr. at 153:3-13. Dr. Hutton organized his data into two time periods: pre-project (1930-1967) and post-project (1968-2010). He then compared pre- and post-project average position of X2 and the variability (as measured by standard deviation). Hutton's alternative reveals a far more modest rate of change in the average location of X2, on the order of about 0.01 kilometers per decade, over an eight- as opposed to a four-decade measuring period. 7-27-11 Tr. at 118:4-5, 14-18; 120:21-121:2; Ex. 119, Hutton Decl. at ¶¶ 2, 4; Ex. 121. In September, Hutton's analysis indicates X2 has actually moved 6.5 to the *west*. 7-27-11 Tr. at 121:6-12, 124:13-16; 125:17-19; Ex. 122. Dr. Hutton's analysis also demonstrated an

increase, rather than a decrease, in variability in the position of X2. 7-27-11 Tr. at 129:18-24; Ex. 123.

113. Dr. Hutton also specifically examined the movement of Fall X2 in wet and above normal years, as those are the years targeted for action under the Fall X2 action. In wet years, for example, the full DAYFLOW record shows that the average X2 position decreased (i.e., moved westerly) in the post-Project period (1968-2010) compared to the pre-Project period (1930-1967) in all of the post-Project fall months (September, October and November). In above normal years, the average X2 position decreased in September, but increased in post-Project October and November. Ex. 119, Hutton Decl. at ¶ 8.

114. Hutton opines that the difference between his results and those in the BiOp may be explained by the fact that the beginning point of the BiOp's Fall X2 analysis, 1967, occurred during a period of sustained below average Fall X2 resulting from an unusually wet period. But, Dr. Hutton's choice of 1930 as the starting point only creates a different kind of bias. His analysis begins with years from the Dust Bowl era, a period of severe drought that spanned the years 1928-1934. 7-27-11 Tr. at 162:4-16.

115. That there was data available for the period from 1930-1967 does not necessarily mean FWS acted arbitrarily by not including those years in its analysis. The year 1967 coincided with the first year CDFG collected smelt abundance survey information via the FMWT, making 1967 a non-arbitrary starting point for the BiOp's evaluation.

7-27-11 Tr. at 12:14-15 (Hanson).

116. The BiOp was not alone in its conclusion that X2 shifted upstream as a result of project operations. A peer reviewed, published journal article that was co-authored by a DWR engineer concluded that Fall X2 had shifted upstream in the past ten to twenty years as a result of increased pumping by the SWP and CVP. Ex. 1001; 7-27-11 Tr. at 178-183. The State Water Resources Control Board ("SWRCB") also concluded that fall outflow had declined since 1987, and had declined further since 2000, which they found was, "consistent with the observation of Feyrer et al 2007 that fall X2 has moved upstream and this has reduced the amount of available habitat for smelt in fall." 7-27-11 Tr. at 173:10-176:2.

117. Even if the data running back to 1930 is considered, Dr. Hutton's approach is not necessarily the only way to analyze that larger dataset. Mr. Feyrer opined that Dr. Hutton's analyses are "simply not appropriate to address the question of how project operations affect fall X2 as described in the BiOp. It was simply not possible for Dr. Hutton to have observed the effects in question with the way he organized the data." Ex. 501, Feyrer Decl. at ¶ 31. Feyrer advocates dividing the larger post-project period employed by Dr. Hutton (1968-2010) into two separate post-project periods (1968-1999 and 2000-2009). *Id.* at ¶ 32. This is necessary because of significant operational changes that occurred to the projects in the year 2000, most importantly, the completion of the 800,000 AF Diamond

Valley reservoir, which began filling in 1999 and completed filling in 2003. 7-27-11 Tr. at 164:6-19; 7-28-11 Tr. at 55:8-11. The action under examination in the BiOp is the current operation of the projects, which occur under parameters that most closely resemble this post-2000 period, rather than the entire period from 1968 on. *See* 7-28-11 Tr. at 149:10-12 (Feyrer).

118. Dividing the post-project period in two in this manner, Mr. Feyrer re-analyzed the entire 81-year data set in a series of charts. As illustrated in Figure 9 from Mr. Feyrer's Declaration, presented below, since 2000, exports have increased substantially compared to both pre-project and pre-2000 project levels, in both above normal and wet years. *See* Ex. 501, Feyrer Decl. at ¶ 36.

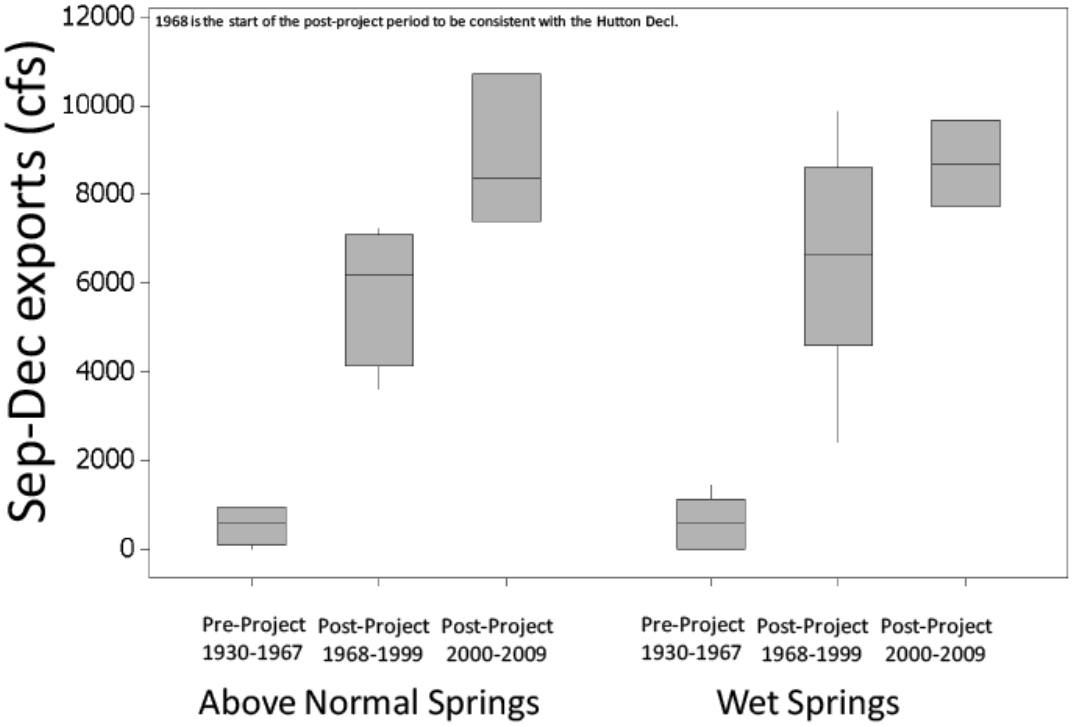

Figure 9. Box plots of exports for three time periods following above normal and wet springs.

119. According to Mr. Feyrer's analysis, outflow has likewise been reduced and rendered less variable post 2000, as compared to both pre-2000 and pre-project levels:

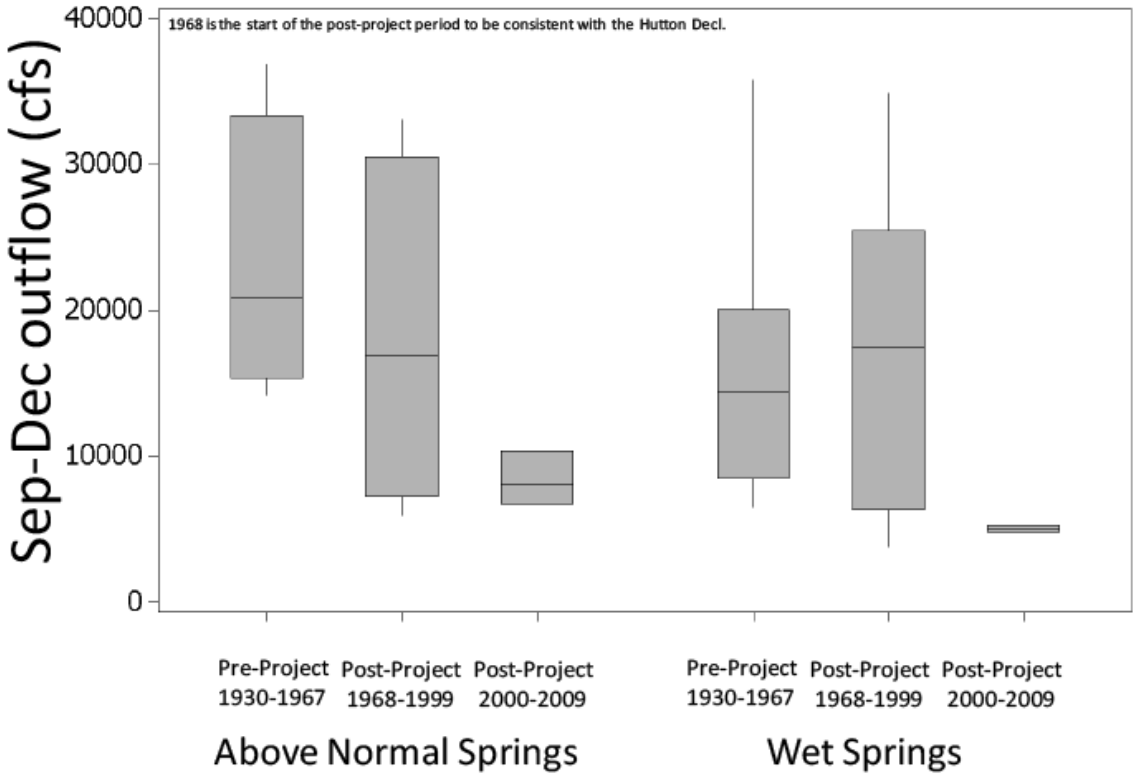

Figure 8. Box plots of Delta outflow for three time periods following above normal and wet springs.

Ex. 501, Feyrer Decl. at 21.

120. The post-2000 period reveals a shift in X2.

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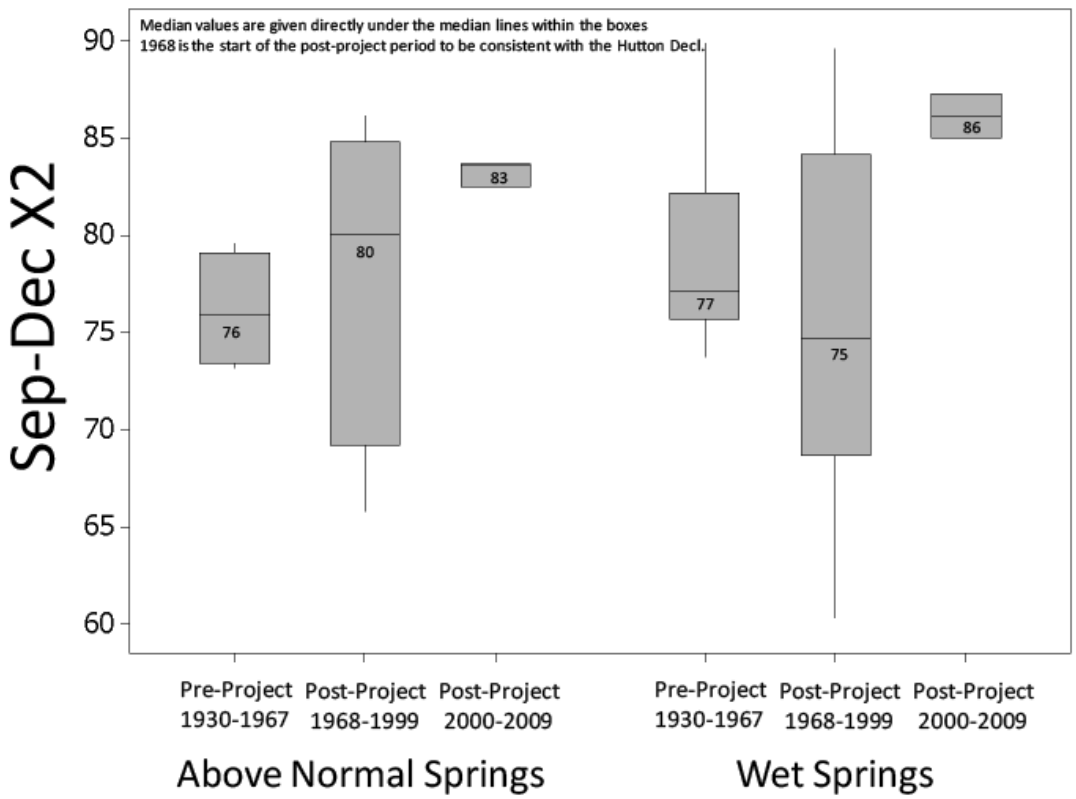

Figure 11. Box plots of X2 for three time periods following above normal and wet springs.

Id. at 24.

121. Mr. Feyrer's evaluation of the trends in the location of X2 from 1930 forward is also subject to criticism. Plaintiffs argue that his post-2000 period (2000-2009) is made up of only ten years, which is insufficient to identify factors that drive variations in Delta salinity and Delta outflow. 7-27-11 Tr. at 148:10-18; Ex. 120, Hutton Reply Decl. at ¶ 7. More specifically, this period contains only one wet year, making it difficult, if not impossible, to draw conclusions about trends in wet years. 7-27-11 Tr. at 148:5-9; 149:14-19; Ex. 120, Hutton Reply Decl. at ¶ 6. Enright and Culberson, respected researchers in the field of hydrology, recommend

evaluating variation in Delta outflow and salinity based on a minimum of 20 to 25 years, not 10 years, in order to ensure consideration of lower frequency changes in climatic conditions. 7-27-11 Tr. at 148:13-18; Ex. 120, Hutton Reply Decl. at ¶ 7.

122. In addition, rather than presenting DAYFLOW data on a month-by-month basis, Mr. Feyrer examined a four-month (September through December) average, even though there is no Fall X2 Action in December. 7-27-11 Tr. at 148:23-149:4; Ex. 120, Hutton Reply Decl. at ¶ 8b. The four-month average is also inappropriate because the Fall X2 Action itself is defined differently for the months of September and October than it is for the month of November. 7-27-11 Tr. at 149:5-13; BiOp 282-283.

123. Again, the record reveals that there is serious dispute over the appropriate way to evaluate the impact of project operations on the position of X2. There is no unequivocally "correct" answer, although there is partial merit to Mr. Feyrer's opinion that Dr. Hutton's breakdown of the analysis into two large time periods, pre-1967 and post-1967, fails to address the key question at issue in the biological opinion, what is the predicted current impact of the proposed action. It is undisputed that the proposed action describes project operations markedly different from operations in the 1960s, 1970s and 1980s.

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H. Federal Defendants' Rationale for the Specific 74 km and 81 km Markers for Action 4.[13]

124. FWS initially proposed tying the required fall X2 location to the location of the previous spring X2, with the fall X2 location allowed to be no more than 15 km upstream of the previous spring X2 location. *See, e.g.*, AR 006514 (peer review); *see also* AR 009455-57 (notes from initial meeting at which 10km-difference standard was proposed). An independent peer review criticized this approach as "not well supported by the analyses presented." AR 006526. It was also criticized by Plaintiff DWR, which instead "suggest[ed] that keeping fall X2 downstream of about 80 km may increase the area of habitat." AR 006994. DWR also argued that monitoring compliance with a variable fall X2 position would be impractical, especially when compared with using existing monitoring locations. *See* AR 007003 ("[I]t it would be difficult to measure an X2 at 85 km, whereas it would be much easier to measure at Collinsville (81 km) ....").

125. In response to these comments, FWS revised the proposed

[13] Ironically, Plaintiffs object to Defendants presenting a scientific justification for the 74 km and 81 km markers on the ground that, because the 12/14/11 MSJ Decision found that the BiOp contained no such justification, any contrary finding here amounts to a request to "alter or amend its final judgment," which is improper given that the MSJ ruling is on appeal. Plaintiffs' objection is baseless. At the summary judgment stage, the district court was required to evaluate whether, based on the administrative record, the agency had articulated a sufficient basis for the use of these markers. Here, the court is determining anew, based on a record not limited by the APA, whether it makes sense to impose the RPA utilizing these markers. The information presented by Defendants is necessary to this determination. Plaintiffs have also been permitted to significantly expand the evidence presented.

fall X2 location, setting it at fixed points of 75km (in wet years)[14] and 80km (in above-normal years). AR 006399 (December 4, 2008 draft RPA). These locations were later slightly refined to 74 km and 81 km. *See* BiOp at 282. These locations happen to correspond with existing salinity monitoring sites located at Chipps Island and Collinsville, respectively, and are thus familiar compliance points. AR 018798; *see also* AR 010295 (mapping in August 2008 Biological Assessment).

126. The 74 km and 81 km fall X2 locations are also correlated to the outflow water quality objectives for fish and wildlife beneficial uses required by SWRCB Decision 1641 ("D-1641"), which generally requires a minimum daily outflow of 7,100 cfs or that X2 should be located at or downstream of Collinsville (81 km), or Chipps Island (74 km) under certain higher inflow conditions, from February into June. *See* D-1641 at 184-86, 191.[15]

127. That the 74 km and 81 km points correspond to existing monitoring stations and/or D-1641 compliance points does nothing to establish that maintaining Fall X2 at those locations is necessary to the survival and recovery of the species.

128. Defendants maintain that selection of these specific

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[14] Defendants cite AR 013820 for the proposition that the 75km location was "based on regression relationship," presumably to suggest that the 75km location was chosen for a scientific reason based on statistical analysis. But, another record citation offered by Defendants, AR 014227, as "explaining regressive analysis" in fact reveals that the "regression model" referenced is the formula used to estimate the X2 position based on hydrologic inputs and has nothing to do with the biology of the smelt or the impact of X2 on population dynamics.

[15] Available at http://www.waterrights.ca.gov/Decisions/D1641rev.pdf (last visited August 29, 2011).

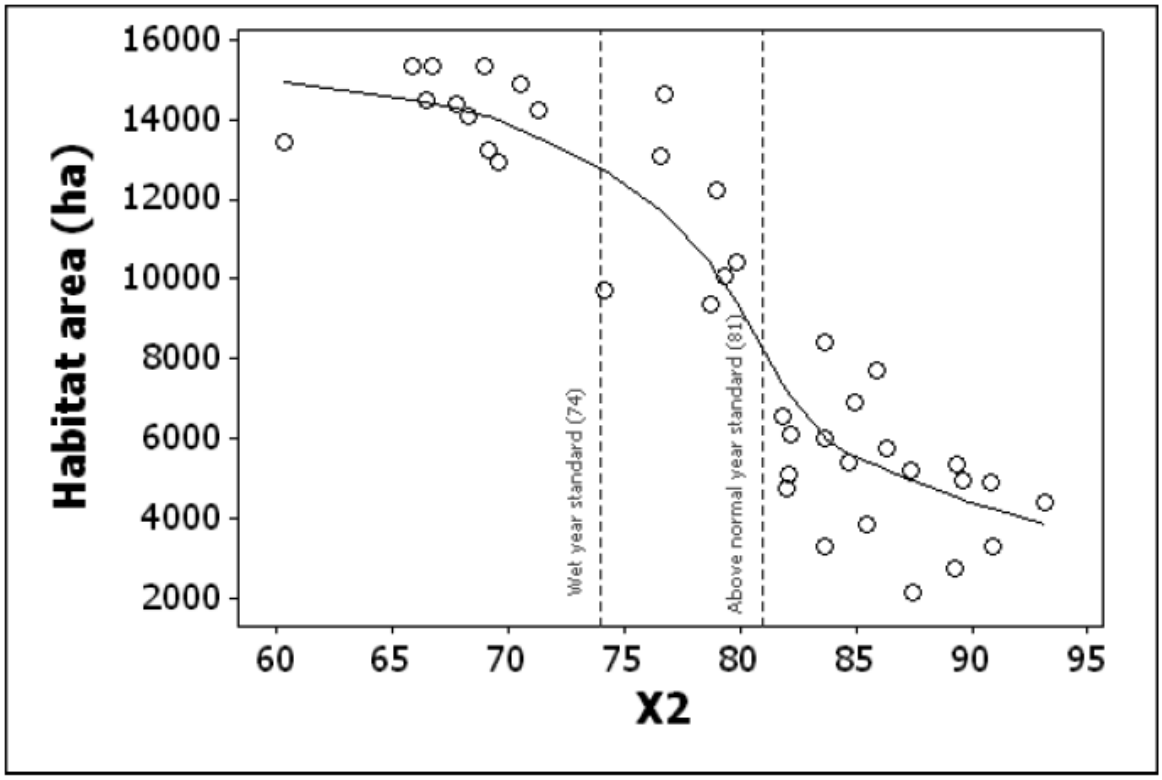
locations is independently supported by biological evidence presented in the BiOp. As discussed above, the BiOp relies heavily on studies that have "found a statistical association between fall X2 and the production of young delta smelt during the following year." BiOp 372. The BiOp also examined the impact of Project Operations on the position of X2, and concluded that the impact was most significant in wet and above-normal years. *Id.; see also* AR 006984 (excerpt from draft BiOp displaying historic differences between fall X2 and spring X2 by year type). Accordingly, the Fall X2 Action targeted only these water year types, reasoning "actions in these years are more likely to benefit delta smelt." AR 006615, 006732.

129. As a first step in determining the specific distance-based outflow requirements for the Fall X2 Action, FWS determined, using historical DAYFLOW data, that the median 1967-2007 fall X2 location was 79 km upstream of the Golden Gate Bridge. BiOp at 235. As discussed above, the BiOp concluded that the average fall X2 location has exhibited a long-term increasing (*i.e.*, moving upstream) trend, and this is especially so since the year 2000. BiOp at 236. In particular, the average fall X2 location during the years following the Delta's Pelagic Organism Decline (2000-2005) was several kilometers upstream when compared to the pre-Pelagic Organism Decline years (1995-1999). BiOp at 179.

130. The second step of FWS's evaluation of historical fall X2 data was to estimate the total surface area of suitable habitat

corresponding to a given year's fall X2 location. *See id.* at 235 (describing methodology). The results of that analysis are presented in the BiOp at page 374 in Figure B-17.

Figure B-17. Relationship between X2 and habitat area for delta smelt during fall, with standard shown for wet and above normal years.



In this figure, the plotted points represent the amount of abiotic habitat index available when X2 is placed at certain kilometer distances. The line among the points is a "LOESS smooth" fitted to the graph with statistical software. As Mr. Feyrer explained at the hearing in response to the Court's question, discussing this figure,

> ... some of the discussions we had internally at Reclamation while we were preparing the adaptive management plan and taking our own evaluation of whether or not 74 and 81 would be justified was, in fact, looking at the potential water cost in moving X2. And what we discussed in the plan is that, as you can see in this relationship here, there's really two tiers of habitat in this relationship.

> You have the lower tier, which is essentially 80 and above at X2, and then you have that steep portion of the relationship, and then essentially from about 74 or so up is that upper tier. And with respect to the 74 value, 74 is pretty much -- it's right about near the asymptote of that curve. It's pretty much as far to the right as you can get to get habitat area -- the habitat index up into that upper tier at the least amount of water cost with respect to moving X2.
>
> So in other words, you could provide a lot more X2 movement to the west all the way out to 60, but you're not going to get a whole lot more of the habitat index. So to get up into that upper habitat tier, 74 is pretty far to the right on that area. You could look at this in terms of -- you could argue that you could push 74 further out to the west, but you're not going to get really any more habitat benefit. And likewise, with the above normal year standard 81, 81 is pretty much near the bottom of the ascending limb of that curve. And that's about the minimum point where you get out of that lower tier of habitat conditions.

7-29-11 Tr. at 28:13-29:15.

131. In Figure B-17, the largest degree of change (steepest portion of the curve) in the habitat index occurs at X2 values approximately between 85km and 70km, with less change beyond those values. Ex. 501, Feyrer Decl. at ¶ 12. Feyrer opined that, across this 15-km range of X2, habitat suitability increases approximately two-fold. *Id.* The 74 km and 81 km markers approximate the ascending and descending asymptotes of the curve displayed in Figure B-17. Assuming this graph accurately represents habitat availability, the significance of this is that moving X2 further westward than 74 km in wet years is not likely to yield substantially greater benefits to delta smelt than keeping it at 74 km. Likewise, if you maintain X2 above 80 in the river channels, the center of the delta smelt population is aligned with severely degraded abiotic habitat conditions. This change in habitat is due largely to geography.

Id.; see also 7-28-11 Tr. at 125:19-126:9 (Feyrer).

132. The National Research Council's report reviewing the BiOp's RPA reported that the lowest smelt abundances all occurred when the habitat-area index was less than 6,000 hectares, which could mean that, while it is not the only cause of smelt population collapses, "reduced habitat area is a necessary condition for the worst population collapses." Ex. 12 at 53; AR 018153 (Reclamation observing that "delta smelt abundance is generally reduced when X2 is located upstream of Chipps Island [(74 km)]," that "when X2 is downstream of this point [abundance] increases in at least some of the years"); AR 010052 (OCAP BA noting that analyses of historical data indicate that habitat conditions are relatively poor and contribute to delta smelt producing fewer offspring in years when X2 is located above Collinsville (81 km) during Fall). Plaintiffs' witness Dr. Hanson testified that, according to Figure B-17, when X2 is at 74 km, the result is roughly 13,000 hectares, or 30,000 acres, of habitat in the salinity range preferred by delta smelt. 7-27-11 Tr. at 7:7-19.

133. Mr. Feyrer admitted that adding additional habitat units to represent the Cache Slough complex might shift this entire curve to the right, likewise shifting the location of the asymptotes up. Exs. 102a, 153. The exact impact of any such shift has not been calculated by any party. Nor is it clear whether any shift would change the reasoning described in the NRC Report, as a revised graph

would simply have revealed that the lowest smelt abundance occurred when the habitat index was less than some number above 6,000 hectares.

134. Mr. Feyrer suggested that the most significant gains in habitat area occur when X2 is located upstream of kilometer 80, above which the river channels become smaller with significantly less habitat area. He said:

> That gets back to some of what I explained earlier. And it's -- it's really nothing more than a function of the geography of the estuary. When the X2 is located downstream of approximately 80, downstream [of] the confluence of the Sacramento San Joaquin rivers, X2 and low salinity zones are in those vast large shallow base, those shoals of Suisun Bay, Grizzly Bay, Honker Bay, and so there's a lot of area there. That's why the habitat index is bigger. And then when you move upstream, above 80, approximately and up into the river channels, those river channels obviously are a lot smaller, lot less area there. And so the habitat index is therefore smaller.

7-29-11 Tr. at 125:23-126:9.

135. According to Federal Defendants' analyses of historical Fall X2 position, the 74 km and 81 km locations corresponded with actual fall X2 locations in wet and above-normal years prior to the POD, which began in 2000. *See id.* at 369 ("This will help return ecological conditions of the estuary to that which occurred in the late 1990s when smelt populations were much larger."); *id.* at 179 ("X2 ... during fall in the years following the POD (2000-2005) was several km upstream compared to that for the pre-pod years (1995-1999)").

136. As discussed above, Federal Defendants' method of evaluating the movement of X2 is subject to considerable criticism.

This location rationale is corroborated by Table 2 of Dr. Hutton's June 20, 2011 declaration, which shows that the 74 km marker for wet years corresponds with the average X2 location for all post-project wet years, from 1968 to 2010. Similarly, the 81 km marker for above normal years corresponds with the average X2 location for all post-project above normal years.

Table 2. X2 Average Position by Fall Month for Various Time Periods in Wet and Above Normal Years

	All Years	Pre vs. Post-Projects			Feyrer et al. (2007)		
Month	1930-2010	1930-1967	1968-2010	Δ	1968-1986	1987-2004	Δ
Wet Years (km)							
September	75.6	78.2	73.8	-4.4	71.6	76.9	5.3
October	75.4	76.1	74.9	-1.2	71.1	79.9	8.8
November	72.7	72.8	72.6	-0.2	68.5	77.5	9.0
Above Normal Years (km)							
September	81.5	82.7	80.8	-1.9	78.1	83.7	5.6
October	80.0	78.0	81.2	3.2	77.2	84.3	7.1
November	77.0	73.5	78.9	5.4	73.1	83.0	9.9

Ex. 119, Hutton Decl. at 6; Ex. 124 (reproducing Table 2); *see also* 7-28-11 Tr. at 154:11-155:25 (Feyrer) (post-project averages in Dr. Hutton's table correspond with 74 km and 81 km markers in Action 4 in the RPA).

137. This figure demonstrates that the average position of X2 from 1968-2010 in wet and above normal years corresponds to the 74 km and 81 km compliance points, respectively.

138. According to Federal Defendants' analyses of X2 variability, the 74 km and 81 km points also restore inter-annual variability in fall outflow to historical conditions. Historically, there was natural variability in the location of fall X2 to match the

type of water year experienced that year. This is depicted in the following plot:

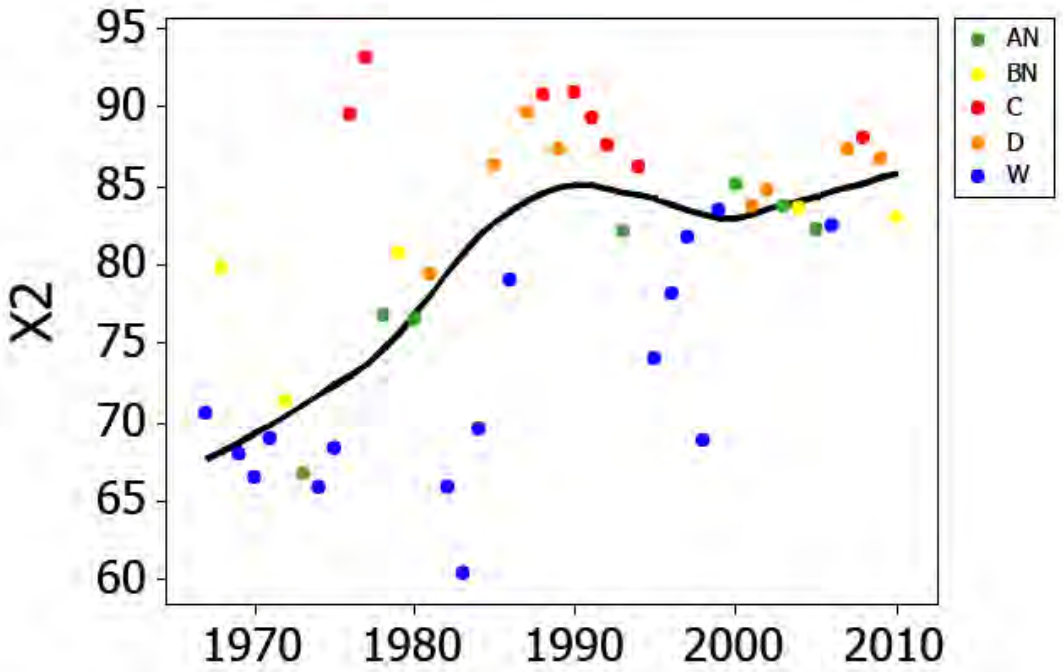


Figure 12. Time series of fall X2 since 1967. Water year types represent the preceding spring. A LOESS smooth is fitted to the data.

Ex. 501, Feyrer Decl. ¶ 40, Fig. 12 (displaying loss of X2 variability between dry (red/orange) and wet (green/blue) years); BiOp at 273 (similar plot); 7-28-11 Tr. at 152:8-154:10 (Feyrer).

139. In other words, according to Federal Defendants' analysis of X2 variability, a wet year would naturally result in fall X2 being located relatively further downstream than its location in a dry year. *See* Ex. 501, Feyrer Decl. ¶ 40, Fig. 12; Ex. 501, Internal Exhibit 1 (Reclamation Draft Plan) at 13-14.

140. The BiOp concludes that "[t]he persistence of this

significant hydrologic change to the estuary threatens the recovery and persistence of delta smelt." BiOp at 374; Ex. 501, Internal Exhibit 1 (Reclamation Draft Plan) at 16 (concluding that "[i]t seems clear that outflow affects the quality and extent of abiotic smelt habitat. It also seems clear that restoring lost abiotic habitat availability is likely to produce subsequent abundance benefits to delta smelt, probably by raising the carrying capacity.").

141. By setting the required fall X2 locations at 74 km and 81 km, FWS sought to reduce the intensity of this divergence and its consequent harms to both critical habitat and delta smelt persistence and recovery, by "restoring flow variability to the Delta environment so that smelt populations can recover through allowing these essential periods of population rebound." BiOp at 375.

142. That the 74 km and 81 km points are related to historical average positions of X2 and arguably restore inter-annual variability renders them non-arbitrary, but does not provide biological support for their imposition, particularly in light of the highly disputed evidence to support a link between X2 and smelt abundance and the high water costs required to maintain X2 at these positions.

I. <u>Adaptive Management Plan.</u>

143. The BiOp describes the Fall X2 Action as being "subject to adaptive management," whereby the Action may be modified as additional scientific information is gathered:

> The objective of this component is to improve fall habitat for delta smelt through increasing Delta outflow during

fall. Increase in fall habitat quality and quantity will both benefit delta smelt.

Subject to adaptive management as described below and in Action 4 in Attachment B, during September and October in years when the preceeding precipitation and runoff period was wet or above normal as defined by the Sacramento Basin 40-30-30 index, Reclamation and DWR shall provide sufficient Delta outflow to maintain monthly average X2 no greater (more eastward) than 74 km (from the Golden Gate) in Wet WYs and 81 km in Above Normal WYs. The monthly X2 target will be separately achieved for the months of September and October. During any November when the preceding water year was wet or above normal as defined by the Sacramento Basin 40-30-30 index, all inflow into CVP/SWP reservoirs in the Sacramento Basin shall be added to reservoir releases in November to provide an additional increment of outflow from the Delta to augment Delta outflow up to the fall X2 of 74 km for Wet WYs or 81 km for Above Normal WYs, respectively. In the event there is an increase in storage during any November this action applies, the increase in reservoir storage shall be released in December to augment the December outflow requirements in SWRCB D-1641.

Given the nature of this Action and to align its management more closely with the general plan described by the independent review team and developed by Walters (1997), the Service shall oversee and direct the implementation of a formal adaptive management process. The adaptive management process shall include the elements as described in Attachment B. This adaptive management program shall be reviewed and approved by the Service in addition to other studies that are required for delta smelt. In accordance with the adaptive management plan, the Service will review new scientific information when provided and may make changes to the action when the best available scientific information warrants. For example, there may be other ways to achieve the biological goals of this action, such as a Delta outflow target, that will be evaluated as part of the study. This action may be modified by the Service consistent with the intention of this action based on information provided by the adaptive management program in consideration of the needs of other listed species. Other CVP/SWP obligations may also be considered.

The adaptive management program shall have specific implementation deadlines. The creation of the delta smelt habitat study group, initial habitat conceptual model review, formulation of performance measures, implementation of performance evaluation, and peer review of the performance measures and evaluation that are described in steps (1) through (3) of Attachment B shall be completed before September 2009. Additional studies addressing elements of the habitat conceptual model shall be

> formulated as soon as possible, promptly implemented, and reported as soon as complete.
>
> The Service shall conduct a comprehensive review of the outcomes of the Action and the effectiveness of the adaptive management program ten years from the signing of the biological opinion, or sooner if circumstances warrant. This review shall entail an independent peer review of the Action. The purposes of the review shall be to evaluate the overall benefits of the Action and to evaluate the effectiveness of the adaptive management program. At the end of 10 years or sooner, this action, based on the peer review and Service determination as to its efficacy shall either be continued, modified or terminated.

BiOp at 282-83.

144. On June 6, 2011, Reclamation released a document entitled "Draft Plan: Adaptive Management of Fall Outflow for Delta Smelt Protection and Water Supply Reliability" (Hearing Exhibit 501 at 33-79) ("Reclamation Draft Plan"). The purpose of this document was for Reclamation to

> review[ ] the basic rationale provided in the BiOp, bringing to bear information that has become available since the BiOp was completed. New information includes the 2010 POD synthesis, some published studies bearing directly on outflow effects and other issues, commentaries from several review panels, complaints about the RPA that were raised by the State and Federal water contractors in letters and in litigation, and commentaries by DWR and NRDC that were provided to us in May 2011. The main questions Reclamation asks in this review are the following. What kind of action seems appropriate, given the present array of available information?

Ex. 501, Internal Exhibit 1 (Reclamation Draft Plan) at 6.

145. In conducting this review, Reclamation examined: "(1) delta smelt habitat; (2) X2 as a surrogate for delta smelt habitat; (3) evidence for associations between habitat and abundance; (4) project effects on Delta hydrology, X2 and delta smelt habitat; and (5) the

specific X2 action prescribed in the BiOp." *Id.* at 6-7.

146. Reclamation found that "[w]hile it is true that a complete description of habitat includes physical, chemical, and relevant biological characteristics, suitable physical and chemical characteristics are often necessary preconditions for suitability. The LSZ is not quite the rocky intertidal zone, but the power of salinity and turbidity to reliably predict where fish will be found during the fall months indicates that these variables are useful descriptors of habitat." *Id.* at 11. Reclamation thus concluded that "[b]iotic factors, including food supply, that characterize an area become an important issue only after abiotic conditions are such that smelt can reside in the area without incurring excessive physiological costs or other detrimental effects." *Id.*

147. In examining "Project effects on Delta hydrology, X2, and delta smelt habitat," Reclamation, as the operator of the CVP, concluded:

> Average X2 is largely determined by water project operations before winter storms begin in the fall. Since 1967, average fall X2 has moved upstream (Figure 7). In the last decade of the post-reservoir era there was substantial interannual variation in fall conditions. After wetter springs, there were often flood control releases in the fall months that moved X2 downstream for weeks. In the POD era very little interannual variation has been observed in the fall, and fall outflow conditions resemble what formerly occurred after drier springs regardless of actual spring hydrology.

Id. at 13.

148. Reclamation also concluded that "[s]ince 1967, the upstream

shift in X2 has resulted in a decline in the average delta smelt abiotic habitat index, with the effect most pronounced in wet or above normal years (Figure 8; Feyrer (2010) calculates 78%). This decline in delta smelt habitat has coincided with the long-term decline in delta smelt abundance (Feyrer 2010)." *Id.* at 14.

149. The BiOp requires Action 4 to "mitigate the effects of X2 encroachment upstream in current and proposed action operations, and provide suitable habitat area for delta smelt." BiOp at 373. In addressing the question "how to achieve [that] mitigation," Reclamation found that "[i]t has been demonstrated in both the BiOp and the discussion above that project operations have affected average X2 during the fall (September-December). A closer examination of the data using Kendall trend tests reveals that there are significant negative trends in X2 for September, October, and November but not December in both wet and above normal years." *Id.* at 15.

150. With respect to the specific 74 km and 81 km markers, Reclamation further found:

> Feyrer et al.'s habitat index (Figure 4) reveals two habitat tiers: a high habitat tier corresponding to X2 at approximately 74 km or downstream, and a low tier for X2 at approximately 86 km or upstream. The curve is empirical and these figures are approximate. That there are tiers is a consequence of geography (Feyrer et al. 2007). The high habitat tier corresponds to X2 opening into Suisun Bay, with the low tier corresponding to X2 in the more constrained river channels upstream. During most of the post-reservoir era, average X2 fell in the high habitat tier in falls after many wet and above-normal springs. This has not been the case in the Pelagic Organism Decline era.

> Feyrer *et al.*'s results suggest that reaching the high habitat tier (X2 at 74 km or less) approximately doubles the expected abiotic habitat index above POD-era values. Because the loss of high-tier habitat represents the biggest fall outflow change since the end of the post-reservoir era, an outflow action that restores it in the years that used to have it appears to us to be justified and very likely to produce habitat and subsequent abundance benefits. The use of an 81 km target for falls after above-normal years provides about 50% more of the abiotic habitat benefits than maintaining X2 at 86 km, and at present represents a reasonable intermediate action to restore late post-reservoir era conditions and variability.

Id. at 16.

151. Reclamation thus concluded that "[i]t seems clear that outflow affects the quality and extent of abiotic smelt habitat. It also seems clear that restoring lost abiotic habitat availability is likely to produce subsequent-abundance benefits to delta smelt, probably by raising the carrying capacity. Consequently, we conclude that the biological rationale for the 2008 RPA action is sound." *Id.*

152. The Reclamation Draft Plan also describes several monitoring and study efforts to be undertaken by Reclamation as part of the adaptive management requirements for Action 4 as set forth in the BiOp. *See, e.g.*, BiOp at 375 ("The Service will require that Action 4 be implemented with an adaptive management program to provide for learning and improvement of the action over time. The adaptive management program will include commissioning studies to clarify the mechanism underlying the effects of fall habitat on the delta smelt population"). The goal of these monitoring and study projects is that, "[b]y laying out a framework for rigorous, science-based

adaptive management, we hope the plan will enable us to learn what we need to know about the effects of Fall outflow, so that the most appropriate conservation action can be identified and implemented at lowest possible water cost." Ex. 501, Internal Exhibit 1 (Reclamation Draft Plan) at 2. .

153. Reclamation submitted the Draft Plan to an independent peer review panel for feedback. Ex. 210. The review panel criticized the draft adaptive management plan and made 17 primary recommendations regarding the plan. *Id.* at 3-5. The panel strongly urged Reclamation and other agencies to formulate an explicit work plan capable of evaluating changes in the health and condition of delta smelt in response to X2 manipulation. *Id.* at 4. The panel found that the draft plan was "woefully deficient on the details regarding the project's most important dependent variables," and that the question facing Reclamation is that "[i]n the absence of reliable abundance data, how will health and condition of the [delta smelt] population be evaluated?" *Id.* at 20; 7-28-11 Tr. at 237:4-11. The panel also had "serious reservations" about the successful implementation of the adaptive management plan because of concern regarding (1) explicit clarity of the hydrologic manipulation of the system to achieve the X2 criteria, and (2) explicit clarity of the key independent and dependent variables that will be evaluated to document success of the experimental manipulation. Ex. 210 at 23; 7-28-11 Tr. at 237:12-25.

154. The peer review panel did not criticize the need for, or the rationale behind, Action 4 itself, but rather, the studies that Reclamation is planning to undertake during and after Action 4 to measure its effectiveness. 7-29-11 Tr. at 85:7-86:25 (Feyrer). The peer review panel also found that the implementation of Action 4 "in a wet year represents a rare opportunity for a quantum leap in our fundamental understanding of Delta processes. This will help stake holders develop a common knowledge of key linkages between enhancing outflow, rate of export flows and the benefits to the biological resources and have profound implications to the future management of the Delta." Ex. 210 at 5.

155. On August 10, 2011, Reclamation completed its revised adaptive management plan for this year's Fall X2 Action. *See* Doc. 1002 ("Revised Plan"). The Revised Plan includes revisions from the draft plan in response to comments received from the independent peer reviewers of the draft plan and others, including agency scientists and policymakers, academics, stakeholders, and managers of the Interagency Ecological Program. *Id.*, Attachment 1 at 2 (transmittal letter from Reclamation to FWS).

156. The Revised Plan concludes:

> It seems clear that outflow affects the quality and extent of abiotic smelt habitat. It also seems clear that restoring lost abiotic habitat availability is likely to produce subsequent-abundance benefits to delta smelt, probably by raising the carrying capacity. We are also left with important unanswered questions that bear on the management of fall outflow. What are the key underlying ecological mechanisms that link outflow to delta smelt abundance, and how important and manageable is each link?

> How does fall outflow fit in with other drivers of delta smelt abundance? Are there more water-efficient ways to provide the necessary benefits?

Revised Plan at 16. "By adopting a more aggressive, active approach, Reclamation hopes to achieve more rapid learning – thereby finding the best and most efficient action faster – while alleviating adverse modification of delta smelt critical habitat and avoiding jeopardy." *Id.* at 1.

157. Specifically, Reclamation's Revised Plan focuses on monitoring and assessing a wide array of measurable variables to compare with projected outcomes. Table 1 in the Revised Plan describes these predictions and associated monitoring and studies with particularity. *Id.* at 55. The final plan includes a detailed discussion of how monitoring, studies, and analysis and modeling will occur. *Id.* at 57-74. The Revised Plan also includes quantitative models to assess the effects of the Fall X2 Action, including process equations for the growth, survival and movement of delta smelt in the Fall. *Id.* at 89-96. "[B]ecause of the broad agency interest in [the adaptive management plan] and its complexity," the multi-agency, multi-disciplinary Interagency Ecological Program will be in charge of conducting monitoring and analyses." *Id.*, Attachment 1 at 3. "The IEP has established expertise in long-term Delta ecosystem monitoring and investigation, including the Pelagic Organism Decline studies." *Id.*

158. The Revised Plan anticipates significantly better habitat conditions and delta smelt responses from locating Fall X2 at 74 km

as opposed to further upstream at 81 km or 85 km. Revised Plan at 55, Table 1. Among other things, Reclamation predicts higher delta smelt growth, survival and fecundity in the fall, and better health and conditions in the fall for delta smelt when Fall X2 is at 74 km as opposed to 81 km. Locating Fall X2 at 74 km this year will also provide much more vital scientific knowledge to guide recovery and restoration efforts in the future. As Reclamation explains:

> Because we have observed an almost unbroken string of low-outflow Falls since 2000, it is clear that the most informative Fall outflow action in 2011 would be a high-outflow action. With 2011 now officially designated as a "wet" year, we recommend that the Fall 2011 action should be the 74 km "wet"-year action described in the 2008 RPA.

Id. at 26.

159. The fact that Reclamation is following an adaptive management approach does not somehow render Action 4 speculative, uncertain, or arbitrary and capricious. Action 4 is not an impermissible "experiment," as Plaintiffs argue, simply because more favorable water conditions have triggered it this fall for the first time and the Defendant agencies are attempting to measure its effects and learn as much scientific knowledge from it as they can.

160. Plaintiffs emphasize that the Revised Plan admits that "many uncertainties regarding the mechanisms that link delta smelt responses to outflow conditions and the position of the LSZ remain." Doc. 1002, Attachment 2, part 2, p. 51. As Dr. Norris explained, while the underlying *mechanisms* that drive the relationship between fall outflow and smelt abundance are not well understood, that is

irrelevant for management purposes, because, in her opinion, "[t]he relationship itself is well established." 7-29-11 Tr. at 174:19-175:20. It is the underlying *mechanisms* that Reclamation's Draft Plan seeks to better understand.

161. Neither the Draft nor the Revised Adaptive Management Plans add anything to the dispute here. Reclamation says it will assure more intensive study and reiterates its position that there is support for the Fall X2 Action as it is currently drafted, ignoring and without specifically addressing any of the criticisms raised by Plaintiffs here. The Plans acknowledge, as they must, that substantial uncertainty remains regarding the mechanisms that link smelt abundance to X2. The issue presented is whether there is in fact a link between X2 and abundance, a question that must be answered based on the record now before the court.

J. Irreparable Harm.

(1) Water Supply Impacts.

a. No Impacts to the CVP.

162. No water supply impacts to CVP are anticipated as a result of implementation of the Fall X2 Action this year. Ex. 303; 7-28-11 Tr. at 199:23-200:9 (Milligan) ("So for September/October, we don't believe that implementing the action, as we currently understand it in those two months, would reduce CVP exports or supplies in any way."); *id.* at 202:2-5 (Milligan). Counsel for the federal contractor Plaintiffs conceded that "CVP exports will not be impacted

unless the Bureau of Reclamation forecast is wrong and the Delta inflows are lower than projected." 7-26-11 Tr. at 31 (Sims); *see also* Ex. 200, Snow Decl. at 2:16-17 (admitting that "there will not likely be an impact to CVP water supplies from implementation of RPA Component 3 this year."); *see also id.* at ¶ 15 ("I do not expect a reduction in CVP water supplies next year from implementation of RPA Component 3").

b. Impacts to SWP.

163. California recently emerged from a three-year drought (2007-2010), Erlewine Decl. (Doc. 983) at ¶ 13, leaving considerable deficits in storage, *see id.* at ¶ 14. Prudent water management calls for storing water in wet years as a buffer against inevitable dry years. 7-28-11 Tr. 18:7-17, 72:5-13; 81:14-20.

164. Water year 2011 was a "really good water year." 7-28-11 Tr. at 63:16 (Erlewine). The allocation for the SWP was 80 percent, the highest allocation since 2006. 7-27-11 Tr. at 206:23 (Leahigh); *id.* at 232:5-12. Undisputed evidence showed that the SWP is likely to export more water from the Delta in water year 2011 than ever before in the history of the projects. 7-28-11 Tr. at 211:20-212:5 (Milligan).

165. In 2011, in addition to the 80% Table A allocation for SWP contractors, 400,000 AF of surplus (also known as "interruptible") water supply under Article 21 was delivered to the SWP contractors. 7-27-11 Tr. at 232:20-233:2 (Leahigh).

166. MWD received at least 180,000 AF of Article 21 water. Ex. 567 at 3; 7-27-11 Tr. 233:17-21 (Leahigh). With this Article 21 water, Metropolitan received the equivalent of 90% of their Table A contract allocation amounts. 7-27-11 Tr. at 234:8-11 (Leahigh).

167. In addition to its Table A allocation of 80%, Plaintiff Kern County Water Agency ("KCWA") received Article 21 water, and as a result arguably received the equivalent of 100% of their Table A contract allocation amounts. *Id.* at 234:12-235:6 (Leahigh).

168. Much, but not all, of the storage depleted in drought years has been replenished. At the end of 2011, Metropolitan is likely to have more water in storage than ever before. *See* 7-28-11 Tr. at 75:18-20 (Erlewine); Ex. 567 at 5 (noting "all time high" storage levels). Metropolitan has been able to completely refill the approximately 1.5 million AF of its "in-region" storage reserves depleted during the 2007-2010 drought period. 7-28-11 Tr. at 47:13-16, 59:2-10 (Erlewine); Ex. 136, Erlewine Decl. at ¶ 10. Metropolitan has enough available reserve capacity in its out-of-region storage to put additional water to beneficial use. 7-28-11 at 47:17-49:4 (Erlewine). Metropolitan provided 800,000 AF of groundwater replenishment deliveries to its member agencies in 2011. *Id.* at 59:11-60:2 (Erlewine).

169. During the drought, Metropolitan used three-quarters, or one and a half million AF, of its storage reserves. *Id.* at 47:9-12 (Erlewine).

170. Kern County Water Agency is "maximizing" groundwater recharge this year. *Id.* at 84:10-15 (Erlewine). Groundwater levels in Kern County rebounded in 2010 and have continued to rebound. *Id.* at 83:18-21 (Erlewine). Recharge this year will be significant. *Id.* at 84:5-9 (Erlewine); *see also id.* at 31:18-21.

171. Metropolitan will not have to access its storage next year if its SWP allocation exceeds 50%. *Id.* at 77:22-78:1 (Erlewine). Based upon the 2009 Reliability Report, the average SWP allocation is 60%. *Id.* at 78:2-4 (Erlewine). Kern County needs an allocation of about 60 to 70 percent to meet its current water demands. *Id.* at 81:7-11 (Erlewine).

a. Likely Impact of Implementation of the Fall X2 Action in 2011 to the SWP.

172. The outflow requirement to maintain X2 at an average of 74 km can be met by increased upstream releases or decreased exports. 7-27-11 Tr. at 204:6-9 (Leahigh). The preferred method of meeting outflow requirements is increased upstream releases because there is an opportunity to recover these impacts during the winter. *Id.* at 204:10-205:1 (Leahigh).

173. Notwithstanding this preference, DWR is effectively constrained from relying exclusively on reservoir releases to meet the Fall X2 Action requirements for the October 15 to November 30, 2011 period by virtue of a 1983 agreement ("1983 Agreement") between DWR and the California Department of Fish and Game ("DFG") relating to DWR's Federal Energy Regulatory Commission license regarding the

operation of Oroville Dam. Ex. 301, Leahigh Decl. ¶ 17. The 1983 Agreement effectively restricts the volume of releases that can be made from Lake Oroville to the Feather River from October 15 to November 30. 7-27-11 Tr. at 205:6-13 (Leahigh); Ex. 301, Leahigh Decl. at ¶ 17. In order to manage the SWP to meet the Fall X2 Action requirements, the 1983 Agreement would compel the SWP to reduce exports during the October 15 to November 30 period, rather than making storage releases. 7-27-11 Tr. at 205:11-20 (Leahigh).

174. The final SWP allocation decision for 2011 has already been made, and therefore, an injunction will not change the 2011 Table A allocation. *Id.* at 207:5-8, 208:11-15 (Leahigh); 7-28-11 Tr. at 14:22-15-4 (Erlewine).

175. Mr. Leahigh testified at the hearing that the maximum potential water impact to SWP from the implementation of the Fall X2 Action is 850,000 AF, assuming 2012 is a dry year. 7-27-11 Tr. at 211:18-212:7 (Leahigh). Of this potential impact, 410,000 AF is attributable to a reduction in exports and 440,000 AF is attributable to increased releases from upstream storage. Ex. 301, Leahigh Decl. at ¶¶ 18-19.

176. This figure was calculated based upon DWR's May 1 Bulletin 120 Forecast and Water Supply Index. Since then, precipitation in the northern Sierra Nevada in June was 320% of the monthly average. 7-27-11 Tr. at 230:15-18 (Leahigh); Ex. 302, Leahigh Reply Decl. at ¶ 12. Additionally, the 850,000 AF impact figure was calculated based

upon assumptions of operations prior to the July 21, 2011 Reclamation Memorandum, which clarifies November operations. Mr. Erlewine stated that operations in accordance with the memorandum would lessen impacts. 7-28-11 Tr. at 57:2-7 (Erlewine).

177. After the hearing, at the behest of the Court, Mr. Leahigh filed a supplemental declaration, revising his estimates of impact to reflect up-to date hydrology, storage conditions, and the July 21, 2011 Reclamation Memorandum. Doc. 1006, Second Supplemental Leahigh Decl. at ¶¶ 6-8. His updated estimate indicates that implementation of the Fall X2 Action in 2011 will cause:

(a) 370,000 AF of storage impact, with a 75% probability of recovery in 2012. *Id.* at ¶ 7(a); *see also* 7-27-11 Tr. 211:9-11 (Leahigh) (In a median water year, no impacts to upstream storage are expected).

(b) 300,000 AF of export impact, with a probable elimination of these impacts in wet years. Doc. 1006, Second Suppl. Leahigh Decl. ¶ 7(b).

178. Reflecting the fact that storage impacts are unlikely unless drier conditions prevail, Mr. Leahigh summarizes his revised analysis as follows:

(a) 670,000 AF of impacts to SWP deliveries in 2012 if 2012 is a critically dry or dry year;

(b) 300,000 AF of impact to SWP deliveries in 2012 if 2012 is a below normal or above normal year;

(c) little to no impact to SWP deliveries in 2012 if 2012 is a wet year.

Id. at ¶8.[16]

179. It is more likely than not that all storage impacts caused by upstream releases north of the Delta will be recovered in 2012. 7-27-11 Tr. at 230:19-21 (Leahigh).

180. Likewise, it is more likely than not that at least a 300,000 AF impact to SWP deliveries in 2012 will occur, as only in a wet year will less impact occur.

b. Impact of Export Reductions on SWP Contractors.

181. If 2012 is a year with median hydrology, the export reductions resulting from imposition of the Fall X2 Action will adversely affect the ability of State Water Contractor member agencies to recharge depleted groundwater basins and, potentially, their ability to deliver water directly in 2012. 7-28-11 Tr. at 16:3-13 (Erlewine). At the hearing it was estimated that if the Fall X2 Action is imposed and 2012 is a median year, the resulting export reductions would equate to a 10% reduction in SWP Table A water deliveries. *Id.* at 19:4-10 (Erlewine). Subsequent estimates suggest

[16] Defendants emphasize that SWP contractors already received more surplus water this year than they could possibly lose as a result of export impacts from the Fall X2 Action. In 2011, in addition to the 80% Table A allocation, 400,000 AF of Article 21 water was delivered to SWP contractors, which is approximately equal to the total estimated export reductions that might result from the Fall X2 Action. 7-27-11 Tr. at 232:20-233:2 (Mr. Leahigh); 7-28-11 Tr. at 65:15-66:3 (Mr. Erlewine). Defendants maintain that this will offset any water supply impact from the Fall X2 Action. This ignores the fact that SWP Contractors are contractually entitled to surplus water when it is available for delivery. Ex. 137, Erlewine Reply. Decl. at ¶ 7.

the impact would be smaller than originally anticipated. *See generally* Doc. 1006, Second Suppl. Leahigh Decl.

182. KCWA receives roughly one quarter of total SWP Table A water deliveries. 7-28-11 Tr. at 19:12-14 (Erlewine). A 10% reduction in SWP deliveries in 2012 will equate to a loss of approximately 100,000 AF to KCWA. *Id.* at 19:12-14 (Erlewine). 100,000 AF of water is sufficient to irrigate 35,000 acres of permanent crops based on average water duties, or is sufficient to supply half a million urban water users for a year. *Id.* at 40:17-41:2 (Erlewine). KCWA's water supply impacts will increase to 200,000 acre feet if 2012 is a dry year. *Id.* at 42:8-11 (Erlewine). Mr, Leahigh's subsequent estimates suggest the impact will not be as significant as originally anticipated, but will nevertheless be substantial.

183. Because much of the agricultural acreage within Kern County is planted with permanent trees and vines which must always be watered, most of the water demand by users within KCWA remains at the same or similar levels regardless of the availability of SWP water. *Id.* at 21:13-16, 22:9-13, 24:2-16 (Erlewine); Ex. 136, Erlewine Decl. at ¶¶ 18, 19. As a result, a loss to KCWA of a certain volume of SWP deliveries in 2012 is likely to result in an equal volume of groundwater being pumped from the KCWA portion of the San Joaquin Valley Groundwater Basin that otherwise would not be extracted. 7-28-11 Tr. at 24:13-16. Some areas of KCWA, particularly areas on the

west side of its service area, do not have access to usable groundwater and thus rely heavily upon SWP water. *Id.* at 22:19-23:16.

184. An SWP water supply loss and the resultant additional groundwater pumping undertaken to make up for that loss, may also prevent KCWA from being able to recharge its groundwater reserves. *Id.* at 19:15-23; *see also* Exs. 138-141 (Kern Water Bank hydrographs); Exs. 142-144 (Kern County groundwater levels, 2007, 2010, 2011). Continued recharge of available storage space, and SWP deliveries, are needed to return groundwater to the levels necessary to survive future droughts. Ex. 136, Erlewine Decl. at ¶ 19. If 2012 is a dry year, KCWA would lose not only its recharge capability, but also the ability to deliver directly to its customers SWP supplies sufficient to prevent them from needing to extract further volumes of groundwater. *See* 7-28-11 Tr. at 42:1-7 (Erlewine).

185. At the end of 2006, the last wet year prior to the current year, the SWP had significant amounts of water in storage, including approximately 900,000 AF in San Luis Reservoir and more than 3 million AF in Lake Oroville. *Id.* at 16:14-24 (Erlewine). Individual contractors also had significant amounts of water in their own, separate storage facilities, with Metropolitan having approximately 2 million acre feet of water in storage available for its use and Kern County Water Agency's Kern Water Bank at high levels. *Id.* at 16:25-17:4 (Erlewine); Exs. 138-141 (Kern Water Bank hydrographs); Exs. 142

(Kern County groundwater levels 2007). During the 2007-2010 drought, a substantial volume of SWP storage was depleted and a number of extraordinary measures were imposed, including demand reduction measures, water transfers from other areas, and other water management activities. 7-28-11 Tr. at 17:5-8, 19-22 (Erlewine); *cf.* Exs. 142, 143 (Kern County groundwater levels 2007 and 2010).

186. Farmers in the San Joaquin Valley were aided in their ability to withstand the adverse effects of water shortages during 2007 through 2010 because they were able to receive and store surplus water during wet years. Ex. 271, Mettler Decl. at ¶ 3; Ex. 270, Stiefvater Decl. at ¶ 4. Specifically, when SWP water supplies were insufficient to meet their operational needs, farmers purchased supplemental water from local groundwater wells, groundwater storage banks, and other sources. *Id.* The availability of this stored water is the only reason farmers were able sustain their crops during recent drought periods. *Id.* During the 2006 to 2010 period, the disproportionate harm suffered by some CVP water users in the Central Valley, relative to many SWP water users, was largely due to insufficient local CVP water storage. Ex. 136, Erlewine Decl. at ¶ 23.

187. This is the nature of a conjunctively managed water supply. Groundwater is only available as supply in dry years if it is recharged in wet ones.

188. At least two other water contractors in the San Joaquin

Valley, Tulare Lake Basin Water Storage District and Dudley Ridge Water District, are also particularly dependent on SWP exports because they do not generally overlie usable groundwater basins in their service areas. 7-28-11 Tr. at 44:17-45:2; Ex. 136, Erlewine Decl. at ¶ 21. The impacts to these and other agricultural districts in the San Joaquin Valley that use SWP water would be similar to those of Kern County Water Agency. 7-28-11 Tr. at 44:4-16.

189. Metropolitan, the largest SWP contractor, holds approximately half of the entitlement to the SWP's total Table A water amount, equating to about 2 million AF of water. *Id.* at 18:22-19:14; Ex. 136, Erlewine Decl. at ¶ 6. If Metropolitan loses 10% of its SWP allocation in 2012 as a result of implementation of the Fall X2 Action, it will suffer SWP delivery reductions of approximately 200,000 acre feet. 7-28-11 Tr. at 47:25-48:22. This loss would reduce Metropolitan's ability to put additional water into its storage programs to prepare for future dry years. Ex. 136, Erlewine Decl. at ¶ 12.

c. Is There Sufficient Storage Capacity for SWP Contractors to Take Advantage of Increased Exports if Fall X2 Action is Enjoined or Modified?

190. Federal Defendants suggest that potential export impacts to the SWP as a result of the Fall X2 Action are likely to be lessened or eliminated, because the SWP may not have storage capacity available south of the Delta to store additional exports. Water storage in San Luis Reservoir is expected to be at least 1.2 million

AF at the end of the summer. Ex. 563. Storage in San Luis Reservoir this year is higher than the historic average. *Id.*; 7-27-11 Tr. at 237:22-24 (Leahigh). Given the "high storages that we see now" in San Luis Reservoir, there is a "fair probability" that the SWP will fill its share of San Luis Reservoir in the next six months, or by the end of January, 2012. *Id.* at 239:1-9 (Leahigh). Increased exports this fall would increase storage levels in San Luis Reservoir, which could increase the likelihood that the reservoir will fill. *Id.* at 240:23-25. If the state share of storage in San Luis Reservoir fills, that would reduce the impact of Action 4. 7-28-11 Tr. at 60:15-22 (Erlewine). Oroville storage is also nearly full. Ex. 584 at 6 of 6.

191. Metropolitan is already carrying over about 300,000 AF of its Table A allocation in San Luis Reservoir this year that could be risk of being lost if San Luis refills. 7-28-11 Tr. at 49:5-19 (Erlewine). Metropolitan concluded:

> Notably, storing water in SWP Carryover Storage is less desirable under current conditions than it has been in other years. This is because conditions on the SWP system should result in higher storage levels in San Luis Reservoir and Lake Oroville, which also leads to an increased chance of higher SWP Table A allocations next year. When this condition is combined with the fact that In-Region surface storage (Diamond Valley Lake and DWR Flexible Storage) is essentially full, it significantly increases the chances that any water stored in SWP Carryover Storage will be lost in early 2012 as San Luis Reservoir reaches its maximum capacity.

Ex. 567 at 4-5.

192. Nonetheless, SWP Member agencies attempt to manage

deliveries to avoid loss of carryover storage. 7-27-11 Tr. 239:10-17. While Metropolitan has been able to refill a portion of its reserves during 2011, it has remaining capacity to store or otherwise beneficially use the water it will lose if the Fall X2 Action is implemented. 7-28-11 Tr. at 47:13-49:4. Moreover, even in the highly unlikely event Metropolitan is unable to utilize further SWP water supplies, those supplies would be made available to other SWP contractors. If, for example, 100,000 AF is made available as Article 21 water as a result of Metropolitan's not taking its Table A entitlement, KCWA has sufficient capacity to take and beneficially use all of that water by placing it into groundwater storage. *Id.* at 50:21-52:4 (Erlewine). KCWA has sufficient recharge capacity and capability to place more than 100,000 acre feet of additional SWP supplies into storage in 2011-2012, if such further water supplies are made available as a result of not implementing the Fall X2 Action. *Id.* at 41:3-17 (Erlewine).

193. Defendants offer no alternative estimates of the likely loss of carryover storage and the impact such losses would have on the estimates of water loss caused by the Fall X2 action. Evidence presented by Plaintiffs suggests that except in the unlikely event that 2012 is a very wet year, the State Water Contractors have the ability to either beneficially use or store SWP water deliveries they will otherwise lose if the Fall X2 Action is implemented.

(2) Environmental Impacts to Plaintiffs.

194. In addition to the direct impact of reduced groundwater levels associated with implementation of the Fall X2 Action, if KCWA, its Member Units and individual farmers within their service areas are compelled to rely upon groundwater to make up any shortfall in SWP water deliveries, the additional pumping will result in increased energy usage due to the increased pumping lifts needed to access deeper groundwater. 7-28-11 Tr. at 24:13-16, 43:7-15 (Erlewine)

195. Implementation of the Fall X2 Action may also result in water quality impacts associated with declining groundwater levels. *Id.* at 8:22-9:7 (Erlewine); Ex. 136, Erlewine Decl. at ¶ 22. In Kern County, for example, large areas of saline, poor quality groundwater are adjacent to usable, higher quality groundwater. 7-28-11 Tr. at 9:2-4 (Erlewine). Drawing down groundwater levels in the areas with good-quality groundwater will potentially cause the poor-quality groundwater to be intermixed with good-quality water, leading to significant groundwater quality impacts. *Id.* at 8:22-9:7 (Erlewine). Shortage of water supplies could also lead to subsidence, Ex. 136, Erlewine Decl. at ¶ 24, but there is no evidence that subsidence is likely to occur as a result of the imposition of the Fall X2 action this year.

196. However, the likelihood of some of the alleged environmental impacts is unclear. Plaintiffs allege future environmental impacts based upon the dual assumptions of a current

loss of the ability to replenish groundwater or other storage reserves and below normal hydrology over the next several years. *See, e.g., id.* at ¶ 24 ("if next year or multiple subsequent years are below normal, dry, or critically dry, the loss now of the ability to replenish groundwater or store water for future dry years during times of water abundance will likely result in fallowed land, loss of permanent crops, worsened groundwater overdraft, and other serious environmental and economic impacts"). However, future hydrology is unknown. *Id.* at ¶¶ 12, 24; *see also* 7-27-11 Tr. at 226:19-23 (Leahigh) (acknowledging that the fact that this year's June hydrologic conditions were 320% of normal demonstrates that hydrologic conditions fluctuate).

(3) Lack of Access to Credit.

197. It is undisputed that water supply uncertainties interfere with farmers' abilities to secure financing. Ex. 270, Stiefvater Decl. at ¶ 9; Ex. 270, Mettler Decl. at ¶ 4. Lenders will not lend on the basis of SWP water alone, and demand additional and substantial sources of supplemental water. Ex. 270, Stiefvater Decl. at ¶ 9. Continued SWP shortages require depletion of supplemental water supplies such as local groundwater and water banking projects. Ex. 270, Mettler Decl. at ¶ 4. The depletion of these supplies adversely affects farmers' abilities to obtain adequate financing and continue their farming operations. *Id.* Water supply constraints and increased payments for supplemental water interfere with farmers'

cash flows, affect hiring decisions, strain liquidity, and create difficulties in meeting payroll obligations. Ex. 270, Stiefvater Decl. at ¶ 7; Ex. 270, Mettler Decl. at ¶ 3.

198. However, given that 2011 was such a good water year and that groundwater deficits have been able to substantially recharge, the evidence is insufficient to establish that credit access problems are likely to occur in the near future as a result of the implementation of the Fall X2 action.

199. This is also arguably a purely economic harm that may not be considered in the balance of the harms under the ESA.

(4) Employment other Sociological Impacts.

200. Previous testimony before this Court established that water supply losses can be linked to employment losses and related sociological impacts, including hunger and increased crime. *Consolidated Delta Smelt Cases*, 717 F. Supp. 2d 1021, 1055-56 (E.D. Cal. 2010) (May 27, 2010 ruling on Plaintiff's motion for emergency injunctive relief against imposition of Component 2 in that dry year).

201. In the context of the present motion for injunctive relief, Plaintiffs present the declarations of Dr. David Sunding to support a finding that such impacts will result from imposition of the Fall X2 Action this year. Exs. 204 & 205. Dr. Sunding, an economist with expertise in water resources, bases his opinions on employment trends from 2001 to 2009 and concludes that the 2009 delivery reduction

resulting from imposition of the BiOp's RPA resulted in the loss of 9,091 jobs in the San Joaquin Valley, relative to the year 2005. *Id.* at ¶ 3. He admits that his research did not isolate the mechanism by which the reduced deliveries caused job losses, but he surmises that reduced water deliveries resulted in less acreage under production, which in turn resulted in fewer jobs. *Id.* at ¶ 24. Dr. Sunding was able to demonstrate that the 2009 delivery reductions did in fact result in reduced acreage under production. *Id.* at ¶ 26.

202. Dr. Sunding did not attempt to opine as to the employment impact from imposing Fall X2 this year, an admittedly wet year in which exports are at historic levels and groundwater and surface storage is being replenished at historic rates. While it is safe to say that if reduced deliveries do occur in 2012 or subsequent years as a result of implementation of Fall X2 this year, some employment impact will occur, it is impossible to estimate the magnitude of any such impact with any certainty

(5) <u>Modifying the Fall X2 Action will Substantially Decrease Water Supply Impacts.</u>

203. Maintaining an X2 position in the Delta that is more easterly (upstream) than the 74 kilometer location required by the Fall X2 Action will result in less water cost to the Projects.

(a) In his Second Supplemental Declaration, Mr. Leahigh states that, if X2 were positioned at kilometer 79 during the months of September and October 2011, and up to kilometer 79 in November 2011, the estimated water supply impacts to the SWP in 2012 would be

reduced by 550,000 acre feet if 2012 is a critically dry year or by 210,000 acre feet in most other water year types, compared with the impacts of locating X2 at kilometer 74. Doc. 1006 at ¶ 14. That is, if X2 were positioned at kilometer 79, the SWP would experience water supply impacts in 2012 of 120,000 acre feet if 2012 is a critically dry year, or 90,000 acre feet in most other water year types, rather than the 670,000 acre feet (2012 critically dry or dry year) to 300,000 acre feet (most other water year types) of impacts, if X2 is located at kilometer 74. *Id.* at ¶ 11.

(b) Alternatively, if X2 were positioned at kilometer 80, the estimated water supply impacts to the SWP in 2012 would be reduced by 590,000 acre feet if 2012 is a critically dry or dry year, or by 220,000 acre feet in most other water year types, compared with the impacts of locating X2 at kilometer 74. *Id.* at ¶ 15. That is, if X2 were positioned at kilometer 80, the SWP would experience water supply impacts of 80,000 acre feet in 2012 in most water year types, rather than the 670,000 acre feet of impacts in critically dry and dry years, or 300,000 acre feet in most other water year types, if X2 is located at kilometer 74. *Id.* at ¶ 13.

K. <u>Consistency Determination</u>

204. The SWP has obtained a consistency determination from CDFG, pursuant to the California Endangered Species Act ("CESA"), which authorizes the take of delta smelt by the SWP, "provided DWR implements the Project as described in the BO, and complies with the

measures, RPAs and other conditions described in the BO." Ex. 1004, Doc. 474-2

2. The consistency determination further states the BiOp's RPA "must be implemented and adhered to." *Id.* The Fall X2 Action is one of the components of the RPA that is identified in the consistency determination. *Id.*

3. The incidental take permit that contains this consistency determination contains a clause that permits DWR to request a new consistency determination in the event the BiOp's RPA is modified. How the California Department of Fish & Game would respond to such a request is unknown. 7-29-11 Tr. at 268:1-10 (Mr. Lee).

VI. CONCLUSIONS OF LAW

A. Jurisdiction.

1. Jurisdiction exists under 28 U.S.C. § 1331 (Federal Question), as this case arises under the ESA, 16 U.S.C. § 1536 *et seq.*, NEPA, 42 U.S.C. § 4331 *et seq.*, and the APA, 5 U.S.C. § 702 *et seq.*

B. Evidentiary Disputes.

(1) Plaintiffs' Objection to Defendants' Request for Judicial Notice.

2. Plaintiffs object to certain documents relied upon by Defendants in their Proposed Findings, for which Defendants request judicial notice. These documents are:

- Doc. 945-15 (Letter from Director of CDFG);
- Doc. 945-16, Ex. 541 (CDFG Report);
- Doc. 945-17, Ex. 542 (Report of the Independent Workshop Panel on Salmonid Integrated Life Cycle Models);
- Doc. 945-18, Ex. 547 (CDFG Comments on BDCP EA).

As none of these documents have been relied upon in this decision, the objection is moot.

(2) Motion to Strike.

3. At the outset of the evidentiary hearing, the district court denied Defendants' motion to strike, Doc. 947: (1) materials that pertain to issues already litigated, which Defendants had challenged on law of the case grounds; (2) materials discussing economic harm, which Defendants had challenged as not properly before the Court under the ESA; (3) extra-record and post-decisional materials, which Defendants had moved to strike on the ground that such material may not be considered under the APA standard of review; and (4) materials presented by Plaintiffs for the first time in this motion that could have been raised during the summary judgment stage. 7-26-11 Tr. at 4:2-11:18. Specific rulings were made on the record. *Id.* Those rulings are incorporated by this reference.

4. The Court also permitted all parties to raise further objections on a question-by-question basis during the hearing, and noted Defendants' standing objections to the testimony of witnesses who would testify by declaration only pursuant to the parties'

stipulation. *Id.* at 11:6-12:17. Defendants now request rulings on specific objections, presumably on the ground that they were not previously addressed.

a. Declaration of Terry Erlewine.

5. Defendants propose to strike paragraphs 11-13, 24-25, and lines 5-8 of Paragraph 20 of the initial Erlewine Declaration (Ex. 136), on the ground that these paragraphs concern environmental impacts that result from groundwater overdraft as well as impacts to air quality, from subsidence, and related matters about which Mr. Erlewine has no expertise or credentials. However, Mr. Erlewine has personal knowledge of the operations, Table A contract amounts, and storage facilities of MWD, as well as groundwater levels, energy use, water quality and other environmental impacts experienced in the SWP service area as a result of reduced SWP deliveries, particularly in Kern County. 7-28-11 Tr. at 7:7-9:13, 20:3-25, 42:23-43:15. This objection is OVERRULED.

6. Defendants propose that Paragraphs 3 to 5 of Mr. Erlewine's initial declaration (Ex. 136) be stricken. Defendants do not offer a separate justification for striking these paragraphs, which relate exclusively to SWP water supply impacts associated with implementation of the Fall X2 Action. Defendants concede that Mr. Erlewine has been qualified as an expert witness regarding SWP operations. Doc. 1004, Defendants' Proposed Findings, ¶ 256. This objection is OVERRULED.

b. Declarations of Jeffrey Mettler and Rod Stiefvater.

7. Plaintiffs have offered the testimony of two farmers, both of whom provide evidence of economic harms associated with potential water supply reductions from the implementation of the Fall X2 Action. *See* Declaration of Rod Stiefvater (Ex. 270); Declaration of Jeffrey R. Mettler (Ex. 271). Neither Mr. Stiefvater nor Mr. Mettler has been qualified as an expert in CVP or SWP operations or economics. Defendants argue that both offer opinion testimony based on scientific, technical, or other specialized knowledge that is not permitted under Federal Rule of Evidence 701. *See United States v. Durham*, 464 F.3d 976, 982 (9th Cir. 2006) (finding that "opinion testimony of lay witnesses must be predicated upon concrete facts within their own observation and recollection – that is facts perceived from their own senses, as distinguished from their opinions or conclusions drawn from such facts") (internal quotations and citation omitted).

8. As an example, Defendants argue that Mr. Stiefvater's opinion that his existing 80% SWP allocation is in danger of being reduced by 10% is a speculative harm that no party is alleging in this case. *See* Ex. 270 at ¶ 6. Mr. Mettler states that "[i]n 2010, the SWP allocation was sufficient for my crop needs, but the cost of this supply was substantially higher than if a higher SWP allocation was available." Ex. 271 at ¶ 3. Defendants maintain Mr. Mettler and Mr. Stiefvater offer no basis for these opinions, and therefore the

opinions are barred by Federal Rule of Evidence 701.

9. Similar arguments have been rejected numerous times in these consolidated cases. *See, e.g., San Luis & Delta-Mendota Water Auth. v. Salazar*, 2009 WL 1516798, *3-*6 (E.D. Cal. May 29, 2009). Here, Mrs. Mettler and Stiefvater are farmers personally familiar with the water allocations their farms receive and the cost increases that will likely occur if water supplies are decreased. Personal knowledge acquired through management and operation of one's business, as well as experience in the industry, provides a foundation for lay testimony and opinion about the economic aspects of one's own business, general practices in the industry, and how one's business actions might change under different circumstances. *United States v. Hill*, 643 F.3d 807, 840-42 (11th Cir. 2011) (permitting officer or employee of a corporation to offer lay opinion testimony about industry standards and pricing); *Eckelkamp v. Beste*, 315 F.3d 863, 872 (8th Cir. 2002) (perceptions based on industry experience provide foundation for lay testimony); *National Hispanic Circus v. Rex Trucking*, 414 F.3d 546, 551-52 (5th Cir. 2005) (corporate manager permitted to testify about matters related to business expertise).

10. Mr. Mettler's and Mr. Stiefvater's observations regarding past and prospective reduced water allocations, and the effects of such reductions, are lay opinions; they are opinions or inferences "predicated upon concrete facts within their own observation and

recollection." Defendants' objections are OVERRULED. The nature of their experience goes to the weight their lay testimony will be afforded vis-à-vis other, expert witness testimony.

c. Declaration Dr. David L. Sunding.

11. Defendants' reiterate a previously-articulated objection to the Declarations of Dr. David L. Sunding, which was offered facially "to respond to" the Declaration of Cameron Speir filed in the *Consolidated Salmonid Cases*, 1:09-cv-1053 OWW (Doc. 563), regarding "employment trends in the San Joaquin Valley from 2001 to 2009." Ex. 204, Sunding Decl. at ¶ 2. Defendants object that, because the Speir declaration was not introduced by Defendants in any injunctive relief proceeding in this case and is not properly before the Court on this motion, Dr. Sunding's declaration is not relevant here. This elevates form over substance. While Dr. Sunding may have been "responding to" this earlier Declaration in an intellectual sense, he offers independent evidence that stands alone.

12. Defendants also object that, because Dr. Sunding's declaration addresses employment trends in the San Joaquin Valley from 2001 through 2009, his opinions are not relevant to the question of Plaintiffs' allegations regarding the likelihood of irreparable harm from implementation of Action 4 in 2011. This goes to weight not admissibility. "'Relevant evidence' means evidence having any tendency to make the existence of any fact that is of consequence to the determination of the action more probable or less probable than

it would be without the evidence." Fed. R. Evid. 401. Dr. Sunding's opinions has some tendency to confirm a relationship between reduced water deliveries and unemployment, as well as serving to explain the costs of groundwater depletion and the fact that groundwater pumping is not a sustainable solution to long-term reductions in water availability. That his opinions focus on data from 2001-2009 and examine the impacts of reduced deliveries during a time of water shortage, rather than plenty, go to weight, not admissibility. This objection is OVERRULED.

C. Threshold Issue: Does the CDFG Consistency Determination Render Redressability (A Standing Requirement) Speculative?

13. Defendants argue that Plaintiffs lack standing to bring this motion for injunctive relief because Plaintiffs cannot establish redressability, one of the elements of standing. Plaintiffs bear the burden of proving that it is "likely, as opposed to merely speculative, that the injury will be redressed by a favorable decision." *Friends of the Earth, Inc. v. Laidlaw Envt'l Servs. (TOC), Inc.*, 528 U.S. 167, 181 (2000).

14. Specifically, Defendants point to the CDFG Consistency Determination, which authorizes the take of delta smelt by the SWP under CESA, so long as "the Project as described in the BO, and complies with the measures, RPAs and other conditions described in the BO." Ex. 1004, Doc. 474-2. Defendants argue that Plaintiffs have provided no evidence that CDFG is likely to issue a revised consistency determination if this Court were to grant Plaintiffs'

requested injunction. The CESA incidental take permit that contains this consistency determination contains a clause that permits DWR to request a new consistency determination in the event the BiOp's RPA is modified, but it is not known how CDFG would respond to such a request. The State Water Contractors filed a separate challenge to CDFG's incorporation of the RPA provisions into the state incidental take permit. 7-28-11 Tr. at 87:25-88:11 (Erlewine). The parties to that lawsuit stipulated to stay further proceedings pending the outcome of this case. *See* 7-29-11 Tr. at 198:21-196:3.

15. Where redress of a plaintiff's harms depends on independent decisions of governmental entities not a party to the pending lawsuit, standing does not exist. *See Lujan v. Defenders of Wildlife*, 504 U.S. 555, 568-71 (1992) (plaintiffs had no standing to challenge regulation interpreting ESA § 7(a)(2) as being limited in geographic scope to projects undertaken in the United States and the high seas; redressability was speculative because agencies funding projects overseas were not parties to the case and maintained the challenged regulation was not binding upon them, therefore requested relief (termination of funding until consultation) was not likely to result from successful lawsuit). "There is no redressability, and thus no standing, where ... any prospective benefits depend on an independent actor who retains 'broad and legitimate discretion the courts cannot presume either to control or to predict.' " *Glanton ex rel. ALCOA Prescription Drug Plan v. AdvancePCS Inc.*, 465 F.3d 1123,

1125 (9th Cir. 2006) (quoting *ASARCO, Inc. v. Kadish*, 490 U.S. 605, 615 (1989)). In *Glanton*, for example, the "[p]laintiffs claim[ed] that, if their suit [was] successful" in proving that the defendant, a pharmacy benefit manager, charged their health plans too much for prescription drugs, "the plans' drug costs [would] decrease, and that the plans might then reduce contributions or co-payments." *Id*. But the Ninth Circuit found no standing, explaining that "nothing would force [the health plans] to" pass any savings down to the plaintiffs and that the plans "would be free" to keep the savings for themselves. *Id*.

16. This is arguably a procedural injury case in which certain aspects of the redressability requirements are relaxed.

> A showing of procedural injury lessens a plaintiff's burden on the last two prongs of the Article III standing inquiry, causation and redressibility. Plaintiffs alleging procedural injury must show only that they have a procedural right that, if exercised, could protect their concrete interests.

Salmon Spawning & Recovery Alliance v. Gutierrez, 545 F.3d 1220, 1226 (9th Cir. 2008) (emphasis in original) (internal citations and quotations omitted).

17. However, nothing in the procedural injury standing jurisprudence relaxes the rule that redress cannot depend on independent decisions of governmental entities not a party to the pending lawsuit. *See Nuclear Info. Res. Serv. v. Nuclear Regulatory Comm'n*, 457 F.3d 941, 955 (9th Cir. 2006) ("*NIRS*"). In NIRS, the plaintiffs challenged the NRC's decision to revise regulations

governing exemption standards for the transportation of radioactive material. Plaintiffs alleged that NRC failed to comply with its procedural obligations under NEPA. NRC objected that the plaintiffs' procedural injuries were not redressable because the Department of Transportation ("DOT") had promulgated identical exemption standards that would be unaffected by the lawsuit. The Ninth Circuit agreed with NRC and held that plaintiffs lacked standing:

> The parties agreed at oral argument that NRC licensees are required to follow DOT's regulations for the transportation of nuclear material.... Thus, even if we were to set aside the current NRC rule and remand to NRC with instructions that it prepare an EIS, nothing requires DOT to revisit its identical exemption standards, which govern the universe of NRC licensees.... [T]he DOT rule would control even if the NRC rule was wiped off the books. And the DOT regulation is not before us. We cannot see how an order remanding to NRC would remedy the asserted injury from the ... exemption standards because DOT would be under no obligation to reconsider its own, identical rule.

NIRS, 457 F.3d at 955.

18. Redressability may be shown if "a causal relation [ship] is 'probable' ..., even if the chain cannot be definitively established." *Envtl. Def. Ctr. v. EPA*, 344 F.3d 832, 867 (9th Cir. 2003); *see also Coalition v. Koch*, 2009 WL 2151842, at *13 n. 6 (E.D. Cal. Jul. 16, 2009) ("So long as there is evidence that the third party, whether possessing a four-chambered heart or not, will behave in a predictable manner, the causal chain is not necessarily rendered 'tenuous' for the purposes of the standing analysis."); *see also Loggerhead Turtle v. County Council*, 148 F.3d 1231, 1247 (11th Cir.1998) ("standing is not defeated merely because the alleged

injury can be fairly traced to the actions of both parties and non-parties" (citing *Lujan*, 504 U.S. at 560)).

19. A related redressability issue was addressed in connection with a challenge to CDFG's sportfishing regulations designed to protect the Delta's striped bass population. Plaintiffs in that case claimed that protecting striped bass, known predators of delta smelt, constituted unlawful "take" of delta smelt, which in turn impacted smelt abundance and caused Plaintiffs harm from water supply impacts resulting from same 2008 Smelt BiOp RPA's challenged in this lawsuit. *Coalition for a Sustainable Delta v. Carlson*, 2008 WL 2899725 (E.D. Cal. July 24, 2008). Redress of that harm was found to be speculative:

> [E]ven if [plaintiff] were to prevail in this case, its injury would not necessarily be redressed. If the regulations were invalidated, even if the striped bass population were reduced to a level that measurably protected salmonid species on which they prey, there are other predators (the pikeminnow) and other causes: operation of the Projects, toxics, in-Delta diverters, alien invasive species, all of which contribute to the species' jeopardy. The present Delta smelt and salmonids jeopardy findings are based on drought conditions and Project operations, as primary causes. The extent to which all other cooperative causes will continue to operate is unknown. There remains total uncertainty whether reduction in the threat of some predators will have more than minimal effect on the protected species.

Id. at *10.

20. The present situation is distinguishable. Here, Plaintiffs directly challenge imposition of one of the RPA Actions on the ground that it is scientifically unjustified. They have partially prevailed

on the merits of this challenge. CDFG has issued a consistency determination that incorporates the reasoning of the BiOp and its RPA:

> The Central Valley and California Delta system ... supports populations of delta smelt, which is distinguished as a threatened species under both the federal ESA and the California Endangered Species Act (CESA) (Fish & G. Code, § 2050 et seq.). Flow disruption, loss of habitat, and entrainment caused by Project related water export and management activities result in incidental take of delta smelt.
>
> Because the Project has the potential to take a species listed under ESA, the USBR, on behalf of DWR, consulted with the USFWS under Section 7 of the ESA. On December 15, 2008, USFWS issued a Biological Opinion (Ref. No. 81420-2008-F-1481-5), which includes an incidental take statement (hereafter, the BO). The BO describes the Project, including conservation measures developed to minimize impacts to delta smelt, and sets forth measures to mitigate any remaining impacts to delta smelt and its habitat. The measures in the BO include one "Reasonable and Prudent Alternative" with five components (RPAs) which must be implemented and adhered to. The RPA actions are to be implemented using an adaptive approach with specific defined constraints. The BO includes a detailed description of the adaptive process, its framework, and the rationale for each of the RPA components. On June 17, 2009, the Director of the Department of Fish and Game (DFG) received correspondence from Lester A. Snow, Director of DWR, requesting a determination from DFG that the BO and its incidental take statement are consistent with CESA pursuant to Fish and Game Code Section 2080.1.
>
> DETERMINATION
>
> DFG has determined that the BO, including all RPA requirements and the related incidental take statement, is consistent with CESA because the mitigation measures therein meet the conditions set forth in Fish and Game Code section 2081, subdivisions (b) and (c), for DFG to authorize incidental take of CESA listed species. This determination is limited to only those actions specifically identified and analyzed in the December 15, 2008 BO. Specifically, DFG finds that take of delta smelt will be

incidental to an otherwise lawful activity (i.e., SWP operations); the measures and RPAs identified in the BO to modify flow requirements and restore habitat will minimize and fully mitigate the impacts of the taking of delta smelt; and the Project, with the pre- scribed measures and RPAs in place, will not jeopardize the continued existence of the species. The avoidance, minimization, and mitigation measures in the BO include, but are not limited to, the following:

Minimization and Mitigation Measures

Avoidance and Minimization Actions: The BO requires SWP operational actions which are expected to provide flow conditions that reduce entrainment of delta smelt and retain necessary outflow and habitat to support all its life stages. Specific flow modification requirements are presented in RPA Components 1 and 2, including the information necessary to determine delta smelt risk. The requirements include a defined real time scientific evaluation process to develop timely flow augmentations to avoid situations that increase delta smelt risk.

Mitigation Measures: The BO includes two actions to increase the area of suitable delta smelt habitat in the estuary: 1) *Delta outflow augmentation in the fall following wet and above normal water years and*, 2) restoration of at least 8,000 acres of intertidal and associated subtidal habitat in the Delta and Suisun Marsh.

Reporting and Monitoring Actions: Conditions of the BO and respective RPAs require DWR to develop and follow specific monitoring programs to adaptively evaluate specific flow requirements and action triggers to achieve the RPA objectives. Participation in (including DFG among others), review of, and reporting requirements for these processes are all a condition of and detailed within the BO and RPAs. The BO outlines a monitoring and reporting process to determine specific operational actions set forth in RPA Components 1 and 2. RPA Components 3 and 4 include similar requirements for the design, monitoring, and adaptive management of fall flow actions to improve delta smelt habitat, as well as the implementation of required habitat restoration actions. RPA Component 5 ensures that information is gathered and reported appropriately.

***

> Based on this consistency determination, DWR does not need to obtain authorization from DFG under CESA for incidental take of delta smelt that occurs in connection with the Project, provided DWR implements the Project as described in the BO, and complies with the measures, RPAs and other conditions described in the BO. However, if the Project as described in the BO, including the mitigation measures therein, changes after the date of the BO, or if the USFWS amends or replaces the BO, including any of the RPAs, DWR will need to obtain from DFG a new consistency determination (in accordance with Fish and Game Code section 2080.1) or a separate incidental take permit (in accordance with Fish and Game Code section 2081).

Ex. 1004 at 1300-301. This Consistency Determination is made under the authority of California Fish and Game Code § 2081, which sets forth the requirements for obtaining a take permit under CESA. Although these requirements are not identical to those of the ESA, *e.g.*, § 2081 requires that take be "minimized and fully mitigated," a federal judicial finding that an RPA is scientifically unjustified significantly undermines the basis for the Consistency Determination. This is sufficient for purposes of standing. The principles of judicial economy would not be served if Plaintiffs were required to prosecute both cases simultaneously in parallel cases in order to obtain evidence from the state court that a parallel injunction would likely result from a federal injunction against the Fall X2 action. Adopting Defendants' rule would effectively bar standing in many cases involving species dually listed under the ESA and parallel state statutes, contrary to Congressional intent that ESA challenges be subject to broad judicial review. *See* 16 U.S.C. § 1540(g).

D. Success on the Merits.

(1) Success on NEPA Claims.

21. Plaintiffs have already succeeded on their NEPA claim. *See* Doc. 399.

22. NEPA insures that federal agencies "make informed decisions and 'contemplate the environmental impacts of [their] actions.'" *Ocean Mammal Inst. v. Gates*, 546 F. Supp. 2d 960, 971 (D. Hi. 2008) (quoting *Idaho Sporting Cong. v. Thomas*, 137 F.3d 1146, 1149 (9th Cir. 1998)).

23. "NEPA emphasizes the importance of coherent and comprehensive up-front environmental analysis to insure informed decision-making to the end that the agency will not act on incomplete information, only to regret its decision after it is too late to correct." *Ctr. for Biological Diversity v. U.S. Forest Serv.*, 349 F.3d 1157, 1166 (9th Cir. 2003).

24. Federal Defendants' violations of NEPA prevented the required reasonable evaluation, analysis, "hard look at," and disclosure of the harms of implementing the 2008 Smelt BiOp RPA Actions to human health and safety, the human environment, and other environmental values.

(2) Success on the ESA Claim Regarding the Fall X2 Action.

25. The 12/14/10 MSJ Decision rejected some of Plaintiffs' challenges to the BiOp's rationale for the Fall X2 action, but found that the BiOp's X2 analysis was flawed in two critical respects. *San*

Luis v. Salazar, 760 F. Supp. 2d at 922. The MSJ Decision marginally upheld the BiOp's reliance on the Feyrer (2007) and Feyrer (2008) studies as justification for imposing some controls on Fall X2, but found that the BiOp "fail[ed] to explain why it is essential to maintain X2 at 74 km and 81 km respectively, as opposed to any other specific location." *Id.* at 922-23.

E. Requirements for Injunctive Relief.

26. In order to establish entitlement to injunctive relief, Plaintiffs must establish:

> (1) that [they will] suffer[] an irreparable injury;
>
> (2) that remedies available at law, such as monetary damages, are inadequate to compensate for that injury;
>
> (3) that, considering the balance of hardships between the plaintiff and defendant, a remedy in equity is warranted; and
>
> (4) that the public interest would not be disserved by a permanent injunction.

Sierra Forest Legacy, --- F.3d ---, 2011 WL 2041149 at *16.

(1) Irreparable Harm.

a. General Requirements for Proving Irreparable Harm.

27. Plaintiffs bear the burden of showing that "irreparable injury is likely in the absence of an injunction." *Winter*, 555 U.S. at 22. Attenuated, conjectural, or speculative injuries will not suffice. *Caribbean Marine Servs. Co. v. Baldrige*, 844 F.2d 668, 674-75 (9th Cir. 1988) (finding that declarations which merely speculate about imminent threat of harm are insufficient for purposes of

injunctive relief).

28. The Court of Appeals recently confirmed that the likelihood of irreparable harm -- as opposed to the mere possibility of it -- remains an unyielding threshold requirement prior to the issuance of injunctive relief. *Alliance for the Wild Rockies v. Cottrell*, 632 F.3d 1127, 1131 (9th Cir. 2011). Although the *Alliance for the Wild Rockies* panel affirmed other parts of the "sliding scale" approach not reached in Winter and not at issue here, the panel also confirmed the irreducible requirement that "under *Winter*, plaintiffs must establish that irreparable harm is likely, not just possible." *Id*. Under controlling Supreme Court and Ninth Circuit precedent, a district court need not reach the remaining factors of the injunctive relief test if a moving party has not shown that irreparable harm is likely.

29. In general, "the test for determining if equitable relief is appropriate is whether an injunction is necessary to effectuate the congressional purpose behind the statute." *Biodiversity Legal Found. v. Badgley*, 309 F.3d 1166, 1177 (9th Cir. 2002).

30. In addition, before any injunctive relief can issue, Plaintiffs must also show that the relief they seek is "narrowly tailored" to remedy the specific violations at issue and is not likely to result in irreparable harm to an ESA-listed species. *Nat'l Wildlife Fed'n v. NMFS*, 422 F.3d 782, 796, 800 (9th Cir. 2005); *see also Pac. Coast Fed'n of Fisherman's Ass'ns v. Gutierrez*, 606 F.

Supp. 2d 1195, 1203 (E.D. Cal. 2008) (noting that during periods of interim relief in ESA context "only 'non jeopardizing' actions may continue"); *Natural Res. Def. Council v. Kempthorne*, 2007 WL 4462395, at *21 (E.D. Cal. Dec. 14, 2007) (holding that "[a]ny interim remedial prescriptions must (1) not cause jeopardy ... [or]; (2) adversely modify its critical habitat").

b. Injunctive Relief in ESA Cases.

31. Previous rulings in this case have discussed the balancing of the equities in ESA and NEPA cases:

> The Supreme Court held in *TVA v. Hill*, 437 U.S. 153, 194 (1978), that Congress struck the balance in favor of affording endangered species the highest of priorities. In adopting the ESA, Congress intended to "halt and reverse the trend toward species' extinction, whatever the cost." *Id*. at 184 (emphasis added). *TVA v. Hill* continues to be viable. *See Home Builders*, 551 U.S. at 669-71; *see also Oakland Cannabis Buyers' Co-op.*, 532 U.S. 496-97; *Amoco Prod. Co. v. Village of Gambell*, 480 U.S. 531, 543 n.9 (1987).
>
> *Winter* does not modify or discuss the *TVA v. Hill* standard. Although *Winter* altered the Ninth Circuit's general preliminary injunctive relief standard by making that standard more rigorous, *Winter* did not address, nor change, the approach to the balancing of economic hardships where endangered species and their critical habitat are jeopardized. *See Biodiversity Legal Found. v. Badgley*, 309 F.3d 1166, 1169 (9th Cir. 2002) (Congress removed the courts' traditional equitable discretion to balance parties' competing interests in ESA injunction proceedings); *Nat'l Wildlife Fed'n v. Burlington N. R.R., Inc.*, 23 F.3d 1508, 1510-11 (9th Cir. 1994)(same).
>
> Prior decisions involving the coordinated projects' operations found that *TVA v. Hill* and related Ninth Circuit authorities foreclose the district court's traditional discretion to balance economic equities under the ESA. There is no such bar in NEPA injunction proceedings.

> Plaintiffs have advanced a human welfare exception and contend that unlike any of the prior cases, this case juxtaposes species' survival against human welfare, requiring a balancing of the BiOp's threats of harm to humans, health, safety, and protection of affected communities. No case, including TVA v. Hill, which concerned the competing economic interest in the operation of a hydro-electric project and prohibited federal courts from balancing the loss of funds spent on that project against the loss of an endangered species, expressly addresses whether the ESA precludes balancing of harms to humans and the human environment under the circumstances presented here.
>
> This case involves both harm to threatened species and to humans and their environment. Congress has not nor does *TVA v. Hill* elevate species protection over the health and safety of humans.

Consolidated Delta Smelt Cases, 717 F. Supp. 2d at 1068-69.

32. *TVA v. Hill* itself involved more than just pure economic interests. The Supreme Court's description of the project at issue in that case includes non-economic human interests on both sides of the equation:

> In this area of the Little Tennessee River the Tennessee Valley Authority, a wholly owned public corporation of the United States, began constructing the Tellico Dam and Reservoir Project in 1967, shortly after Congress appropriated initial funds for its development. Tellico is a multipurpose regional development project designed principally to stimulate shoreline development, <u>generate sufficient electric current to heat 20,000 homes, and provide flatwater recreation and flood control, as well as improve economic conditions in "an area characterized by underutilization of human resources and outmigration of young people</u>." Hearings on Public Works for Power and Energy Research Appropriation Bill, 1977, before a Subcommittee of the House Committee on Appropriations, 94th Cong., 2d Sess., pt. 5, p. 261 (1976). Of particular relevance to this case is one aspect of the project, a dam which TVA determined to place on the Little Tennessee, a short distance from where the river's waters meet with the Big Tennessee. When fully operational, the dam would

> impound water covering some 16,500 acres-much of which represents valuable and productive farmland-thereby converting the river's shallow, fast-flowing waters into a deep reservoir over 30 miles in length.

TVA v. Hill, 437 U.S. at 157. But, the Supreme Court never discussed how these non-economic impacts factored into the balance of the equities, perhaps because the impact of enjoining Tellico's construction was to prevent benefits that would flow from the construction of the dam. Here, by contrast, it is alleged that imposition of the Fall X2 Action will affirmatively harm human communities through the reduction of water supplies and by reducing water supply security in future years. If such harms cannot be considered in the balance in an ESA case, it is difficult to envision how a resource-dependent plaintiff would ever obtain injunctive relief in an ESA case.

33. Even if an injunction may not issue under the ESA based on economic harm, there is no such restriction in a NEPA case. A court may not issue an injunction under NEPA that would cause a violation of other statutory requirements, such as those found in section 7 of the ESA. *See United States v. Oakland Cannabis Buyers' Coop.*, 532 U.S. 483, 497 (2001) ("A district court cannot, for example, override Congress' policy choice, articulated in a statute, as to what behavior should be prohibited."). Nor should an injunction issue under NEPA when enjoining government action would result in more harm to the environment than denying injunctive relief. *Save Our Ecosystems v. Clarke*, 747 F.2d 1240, 1250 (9th Cir. 1984); *Am.*

Motorcyclist Ass'n v. Watt, 714 F.2d 962, 966 (9th Cir. 1983) (holding public interest does not favor granting an injunction where "government action allegedly in violation of NEPA might actually jeopardize natural resources"); *Alpine Lakes Prot. Soc'y v. Schlapfer*, 518 F.2d 1089, 1090 (9th Cir. 1975) (denying injunctive relief in NEPA case where more harm could occur to forest from disease if injunction was granted). However, where the evidence indicates that the ESA will not be violated by injunctive relief issued under NEPA, the presence of a NEPA claim permits consideration of economic harm evidence.

c. Showing of Irreparable Harm.

34. Although the showing of irreparable harm made here is subject to uncertainty, it is not "speculative."

35. The CVP will likely not experience any water supply impact as a result of the Fall X2 Action. However, it is more likely than not that SWP Contractors will suffer some water supply impact in 2012 if the Fall X2 Action is implemented starting in September 2011.

36. Mr. Leahigh's most up-to-date estimates, which incorporate recent conditions, indicate that any storage losses due to implementation of the Fall X2 Action in 2011 will likely be recovered. However, it is more likely than not that the SWP will suffer a 300,000 AF export impact, as only in a wet year would this impact be reduced or eliminated.

37. Even though 2011 has been a "really good water year," in

which much of the storage deficits caused by the 2007-2010 drought have been made up, prudent water management calls for the storage of water in good years to guard against future dry periods. SWP Contractors fared relatively well, as compared to CVP Contractors, during the last drought period, largely due to local surface and groundwater storage reserves.

38. A 300,000 AF export impact would reduce SWP Contractors' ability to put additional water into storage programs to prepare for future dry years. SWP Contractors have sufficient storage available to take advantage of any additional water that may be delivered if the Fall X2 Action is modified or enjoined. Although the impact of reduced deliveries resulting from the Fall X2 Action may be delayed, this does not render them "speculative."

39. Although it is likely that San Luis Reservoir will fill this year, which has the potential to cause SWP Contractors to lose SWP Carryover storage held there, the record suggests that the SWP Contractors will modify delivery schedules to minimize or eliminate any such losses.

40. Metropolitan, the largest SWP Contractor, which serves primarily domestic users in Southern California, holds approximately half of the total SWP Table A entitlement. Because Metropolitan's current storage levels are at historic levels, it is unlikely that Metropolitan will be required to reduce deliveries to its member agencies in 2012 as a result of any reduced exports in 2011 due to

the Fall X2 Action. However, it is undisputed that any reductions in deliveries to Metropolitan will reduce its overall ability to store water to prepare for future dry years. Reduced water supply reliability for domestic uses in the service area of the largest SWP Contractor is not a purely economic harm.

41. KCWA will likewise be impacted in its ability to store water for future years. Due to cropping patterns (predominantly permanent trees and vines) in KCWA service areas, a loss of a given volume of water to KCWA is likely to result in an equal volume of water being pumped from the KCWA portion of the San Joaquin Valley Groundwater basin that otherwise would not be extracted.

42. In addition to affecting the SWP Contractors' ability to store water for future dry periods, reduced exports resulting from the Fall X2 Action will directly impact the environment by making it more difficult for Contractors to recharge historically depleted groundwater basins. This can have resulting impacts to groundwater quality. As users draw down groundwater levels, this increases the likelihood that they will have to rely on poor quality groundwater. Increased groundwater pumping will also likely result in increased energy use.

43. Evidence gathered during the recent drought period, ending in 2010, suggests that water supply reductions have resulting economic impacts to the agricultural industry, by reducing the ability of farmers to access credit and provide employment. Reduced

employment has the potential to adversely impact agricultural communities. However, the evidence does not clearly demonstrate the extent to which implementation of the Fall X2 Action in 2011 will cause such economic and sociological impacts in the foreseeable future.

44. Modifying the Fall X2 Action will substantially decrease the water supply impact of the action.

(a) Positioning X2 at kilometer 79, as opposed to kilometer 74, would have a likely water supply impact of 90,000 AF, reducing the impact by 210,000 AF in most water year types.

(b) Positioning X2 at kilometer 80, as compared to kilometer 74, would have a likely water supply impact of 80,000 AF, reducing the impact by 220,000 AF in most water year types.

(2) Monetary Compensation Inadequate.

45. No party has addressed the issue of whether monetary compensation could adequately compensate Plaintiffs for the harm they may suffer as a result of the Fall X2 Action. It has never been suggested that Federal Defendants could be subject to money damages for any harm imposed by implementation of an action required by an ESA biological opinion. *See, e.g., O'Neill v. United States*, 50 F.3d 677, 682-87 (9th Cir. 1995) (finding language in CVP water service contracts absolves federal government of liability for reduced water deliveries). There are no claims in this lawsuit that could even arguably subject the State of California to monetary damages.

(3) Balancing of the Equities.

46. According to the recently-decided *Sierra Forest Legacy*, in a post-judgment injunctive relief proceeding, a court is not bound by the deferential standard applicable in APA cases:

> Although the federal government is undoubtedly permitted to follow its own experts when making a decision, federal experts are not always entitled to deference outside of administrative action....
>
> ... It is reasonable that courts would defer to particular experts when the government has unique expertise, in fields such as national security or the internal functioning of the military. However, *Winter* applied no such deference concerning the possibility that sonar testing would irreparably harm whales. *See id.* at 383-84. Ecology is not a field within the unique expertise of the federal government.
>
> If the federal government's experts were always entitled to deference concerning the equities of an injunction, relief against federal government policies would be nearly unattainable, as government experts will likely attest that the public interest favors the federal government's preferred policy, regardless of procedural failures.

--- F.3d ---, 2011 WL 2041149, *18-*19 (citations omitted).

47. Therefore, the Court must independently weigh the evidence to determine whether, on balance, the record justifies imposing the Fall X2 Action.

48. The smelt has been listed as a threatened species under the ESA, and FWS has determined that uplisting to endangered status is "warranted but precluded" by other, higher-priority listing activities.

49. Although abundance indices have shown slight improvements since 2009, the species is still imperiled. Abundance indices are

still at or near historic lows. The species' overall situation is not altered by the discovery in recent years of "new" populations of delta smelt in the Cache Slough Complex.

50. Although smelt occupy a wide range of salinities, the movement of the "centroid" (i.e., the center of the distribution) of the delta smelt population is correlated with the movement of X2. While the breadth (i.e., overall spread of the population from east to west) of the distribution does not appear to change as X2 shifts, X2 is a reliable proxy for the center of the smelt population.

51. The Fall X2 Action is designed to address a purported shift to the east of the average location of X2, as well as a decrease in the variability of the average position of X2. The BiOp concludes, based on a review of data from 1967 forward, that these changes were caused by project operations. Plaintiffs' argue that an analysis of a broader set of data, starting in 1930, demonstrates that no easterly shift has occurred and variability has in fact increased over time. However, Defendants' alternative analyses of the longer data set indicate that Plaintiffs' results are not dispositive.

52. The Fall X2 Action is also designed to redistribute the centroid of the smelt population into Suisun Bay, a more biologically productive and turbid area of the Delta in which smelt are likely to have increased opportunities to feed, rear, and shelter.

53. To support moving X2 (and therefore the centroid of the smelt population) to Suisun Bay, the BiOp, as well as subsequent

analyses issued by Federal Defendants, relies almost exclusively on Mr. Feyrer's work to develop an abiotic habitat index, which evaluates the availability of suitable abiotic habitat in various locations of the Delta according to the position of X2. Based on this work, the BiOp concluded that, as X2 shifts to the west, greater areas of suitable habitat become available to the smelt.

54. This trend is depicted in Figure B-17, which shows an "s" shaped curve, with two asymptotes at approximately 74 kilometers and 81 kilometers. These asymptotes represent the outer boundaries of the part of the curve that changes most rapidly, suggesting that gains and losses in habitat area occur less rapidly outside these bounds. These bounds correspond to the Fall X2 Action's 74 km and 81 km requirements in wet and above normal years.

55. Mr. Feyrer and his co-authors found a statistically significant correlation between the habitat index in the Fall and the subsequent year's FMWT. Specifically, Feyrer (2011) found that the habitat index variables of salinity and turbidity explain 25% of the variation in delta smelt abundance.

56. These results are the subject of considerable, legitimate criticism, on the following grounds: (1) the analysis used data from the FMWT in both axes, thereby guaranteeing some form of statistical significance; (2) the authors' failed to account for statistical uncertainty throughout their analyses; and (3) the admitted limitation of the analysis to abiotic factors only.

57. In addition, the recent discovery of relatively large smelt populations outside the areas that were the primary focus of Feyrer's work suggest that additional units of habitat may need to be added to the "s" shaped curve depicted in Figure B-17. This may shift the asymptotes of the curve slightly to the right, which could justify different kilometer requirements for the Fall X2 Action.

58. The Feyrer (2011) analysis of the relationship between the habitat index and abundance, as well as its precursor Feyrer (2007), did not utilize life cycle modeling, a methodologically superior way to quantitatively measure the impact of one environmental variable on a species population growth. The Feyrer (2008) manuscript employed a life cycle model to evaluate whether the habitat index was correlated with abundance, and concluded that the fall habitat index had a statistically significant impact on subsequent smelt abundance. This life cycle model was omitted from the published version of that manuscript, which became Feyrer (2011).

59. Plaintiffs presented the results of three subsequent life cycle modeling efforts. Although all three life cycle models employed different methods and data sets, all concluded that the position of X2 in the fall was not related to subsequent delta smelt abundance. All found different combinations of other factors drove abundance the following year. For example, the Maunder & Deriso model concluded that food abundance in spring, spring water temperature, and fall predation are important factors.

60. While each model, and in particular the Maunder & Deriso model that was the focus of Plaintiffs' presentation, have weaknesses, the overall trend in this research cannot be ignored. These three recent statistical approaches do not demonstrate a link between the position of X2 and delta smelt population growth.

61. The results of the three recent life cycle models find some corroboration in the work of Dr. Hanson, who found no relationship between Fall X2 and delta smelt survival in the fall, reproductive success the following year, or food availability.

62. Overall, the record reveals no support for a direct link between X2 and smelt abundance. There is some support for the BiOp's conclusion that the habitat index is correlated with smelt abundance, but the overall value of this finding is undermined by, among other things, the fact that it considers only abiotic habitat factors.

63. The record also reveals almost no biological support for the use of the 74 km and 81 km markers for the Fall X2 Action. While those locations correspond with existing monitoring stations, this is not biological support for requiring X2 to be positioned at these locations.

64. The locations also correspond with the asymptotes of the curve depicted in Figure B-17, suggesting that 74 km is the western edge beyond which the increase in habitat surface area begins to slow. This is not a reasonable biological justification for positioning X2 at 74 km either.

(a) First, while this curve generally reflects the geography of the delta and the fact that more habitat (measured by surface area) is available to the smelt as X2 moves westward, the exact position of the curve may need to be revised to account for additional habitat that appears to exist in the Cache Slough Complex. Moving the curve will change the location of the asymptotes.

(b) Second, Defendants do not explain why it is important to push X2 to the asymptote. Pushing it beyond 74 km may not achieve much, but this does not justify 74 km per se, as opposed to 75 km or 76 km. These are not just academic debates. The record indicates that every kilometer that X2 must be pushed to the west requires substantial amounts of water.

65. Finally, Defendants' suggestion that a 74 km requirement is justified because that represents the average of where X2 was located historically in wet years is not persuasive. The lack of a correlation between the position of X2 and the species' abundance suggests that other factors, besides the location of X2 are controlling the species' abundance today. Particularly in the absence of NEPA compliance, the costs of returning habitat to pre-Project conditions must be considered.[17]

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[17] The ESA contains independent requirements that FWS evaluate whether Project operations are likely to (1) jeopardize the continued existence and recovery of the species and/or (2) adversely modify the species critical habitat. The adverse modification threshold is exceeded when the proposed action adversely affects the critical habitat's PCEs, or their management, in a manner likely to appreciably diminish or preclude the role of the designated critical habitat in the conservation of the species. Defendants argue that the Fall X2 Action should be upheld because it independently addresses adverse modification of critical habitat.

66. There is some record support, however, for not permitting X2 to shift east of the confluence of the Sacramento San Joaquin Rivers. It is undisputed that because of the geography of the estuary, if X2 is located upstream of the confluence, the habitat index decreases dramatically. The National Research Council's report reviewing the BiOp's RPA reported that the lowest smelt abundances all occurred when the habitat-area index was less than 6,000 hectares, which could mean that, while it is not the only cause of smelt population collapses, "reduced habitat area is a necessary condition for the worst population collapses." Ex. 12 at 53. Mr. Feyrer suggests that 80 km is a reasonable demarcation line above which the habitat is "a lot smaller." 7-29-11 Tr. at 125:23-126:9.

67. While the evidence for imposing any form of X2 control this fall is not strong, the imperiled status of the species cautions against entirely abandoning the Fall X2 Action.

68. In addition, the balance of the harms shifts dramatically if the Fall X2 Action is modified. As discussed above:

(a) Positioning X2 at kilometer 79, as opposed to kilometer 74, would have a likely water supply impact of 90,000 AF, reducing the impact by 210,000 AF in most water year types.

(b) Positioning X2 at kilometer 80, as compared to kilometer 74, would have a likely water supply impact of 80,000 AF, reducing the impact by 220,000 AF in most water year types.

But, the BiOp provides no independent critical habitat justification for requiring X2 to be maintained at 74 km in wet years.

(4) Public Interest.

69. It is undeniable that "that CVP water not pumped for diversion to the San Luis Unit flows through the Delta and out to the ocean." *San Luis & Delta-Mendota Water Auth. v. Locke*, 2010 W.L. 500455, *8 (E.D. Cal. Feb. 5, 2010). Preservation of such water for beneficial use "is in the public interest, and protection of human health, safety and the affected communities also serves the public interest." *Id.*

70. The public interest is also implicated in this case because the actions sought to be enjoined are ones that are taken by the United States government in its responsibility to implement and to enforce the ESA and NEPA, both of which are public interest statutes

VII. CONCLUSION

1. Plaintiffs have succeeded on the merits of their NEPA claim.

(a) NEPA requires that the responsible agency take a hard look at the environmental consequences of its actions, *Robertson v. Methow Valley Citizen's Counsel*, 490 U.S. 332, 350 (1989), obligating federal agencies to prepare an environmental impact statement ("EIS") for all "major federal actions significantly affecting the quality of the human environment." 42 U.S.C. § 4332(2)(C). This has not been done.

(b) Federal Defendants are required to evaluate the impact of the coordinated operations of the CVP and SWP, which constitutes

major federal action. The evidence establishes significant detrimental effects visited on the quality of the human environment by implementation of the BiOp's RPA Actions, which impose substantial restrictions on the water supply to California, solely to protect the delta smelt.

(c) Where required, an EIS is intended to disclose environmental effects of a proposed action and consider alternative courses of action. *Id.* Here, by erroneously by-passing NEPA, Federal Defendants completely abdicated their responsibility to consider reasonable alternatives to the Fall X2 Action that would not only protect the species, but would also minimize the adverse impact on humans and the human environment. The result is the issuance and implementation of a one-sided, single purpose RPA that inflicts drastic consequences on California water users, a situation NEPA prohibits.

2. Plaintiffs have also succeeded in part on the merits of their ESA challenge to the Fall X2 Action. This required de novo review of the available evidence to determine if equity permits injunctive relief:

(a) Plaintiffs have established the likelihood of irreparable harm. Imposition of the Fall X2 Action as it is currently planned will likely cause a negative 300,000 AF water supply impact to SWP contractors. This will impact long-term water supply reliability for both domestic and agricultural users. There

will be further impacts to groundwater recharge programs, with resulting direct environmental impacts to groundwater levels, groundwater quality, and energy use. Water supply reductions will cause economic impacts to farmers and may have socioeconomic impacts on agricultural communities, although the magnitude of any such economic and/or socioeconomic impacts given the "very good" water year in 2011 is unclear.

(b) The scientific evidence in support of imposing any Fall X2 action is manifestly equivocal. There is essentially no biological evidence to support the necessity of the specific 74 km requirement set to be triggered in this "wet" water year. The agencies still "don't get it." They continue to believe their "right to be mistaken" excuses precise and competent scientific analysis for actions they know will wreak havoc on California's water supply.

(c) In balancing hardships, the record arguably supports a requirement that X2 not be allowed to shift east of the confluence of the Sacramento San Joaquin Rivers. Positioning X2 at 80 km or 79 km accomplishes this goal. It also serves the population data collection objective of the Action's adaptive management plan. The competing balance is the continuing imperiled status of the protected species, which counsels against doing nothing at all.

(d) Limiting the Fall X2 Action will significantly reduce the water supply impact. Positioning X2 at kilometer 79 will have a probable water supply impact of 90,000 AF, reducing the impact by

210,000 AF. Positioning X2 at kilometer 80 would equate to a probable water supply impact of 80,000 AF, reducing the impact by 220,000 AF in most water year types.

(e) Balancing the imperiled status of the species, the equivocal and highly disputed support for the X2 action, and the even weaker and unjustified support for positioning X2 at 74 km, against the substantial and damaging water supply impact of doing so, limiting the X2 position to 80 km or 79 km achieves equity. Between these two targets, assuming the truth of Federal Defendants' scientific theories, positioning X2 at 79 km will provide substantial additional protection above and beyond an 80 km X2 for a relatively insignificant additional water cost of 10,000 AF. This is only 5 km further upstream than the BiOp's wet year requirements, yet imposes a far less draconian water supply cost.

The BiOp's Fall X2 Action shall be enjoined to prevent implementation of the 74 km X2 target. No Fall X2 action setting the X2 target west of 79 km shall be implemented. All other requirements of the Action, including the timing of the Action and the mechanisms for its measurement, shall remain unchanged.

Plaintiffs shall submit a form of injunction consistent with these findings of fact and conclusions of law within five days following electronic service.

SO ORDERED
Dated: August 31, 2011

/s/ Oliver W. Wanger
United States District Judge