Impact of Altered in-Delta hydrodynamics: An Overview

Interior Delta Flows Worskshop
Delta Science Program of the Delta Stewardship Council

The Bay Institute

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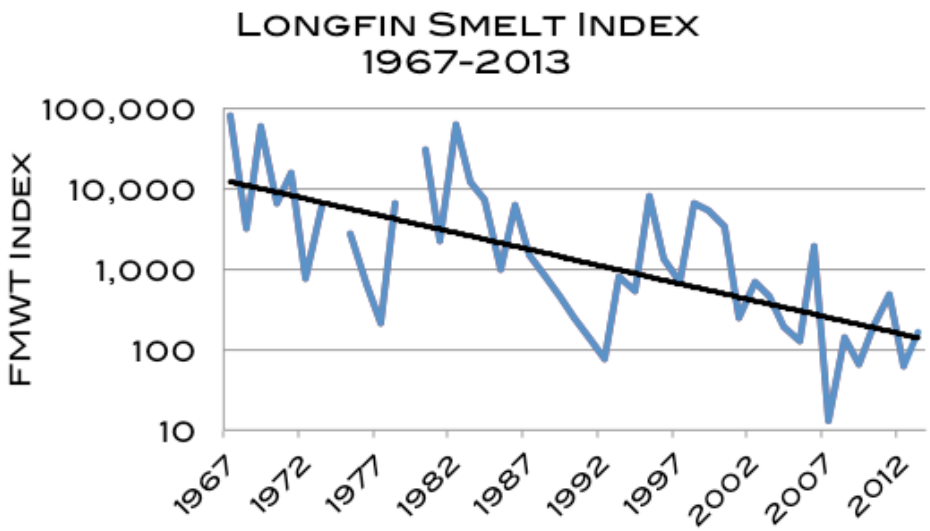
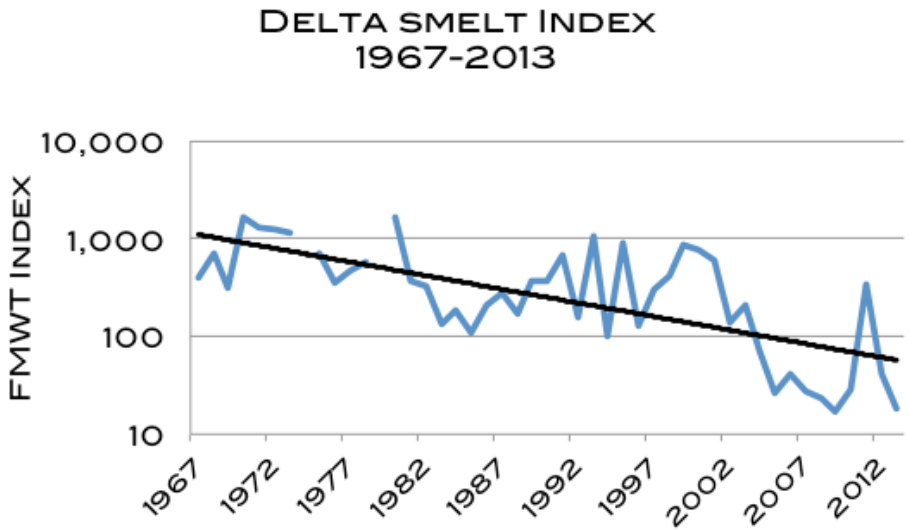
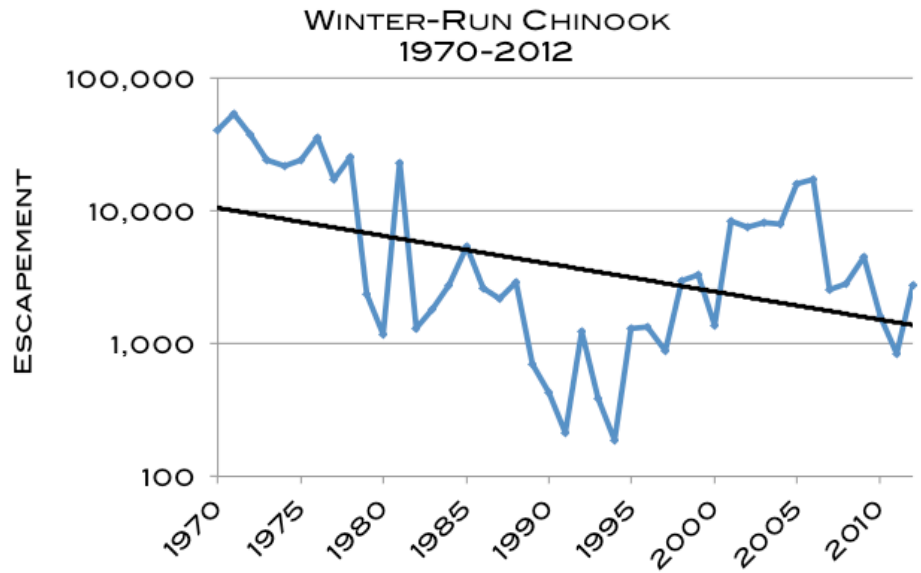
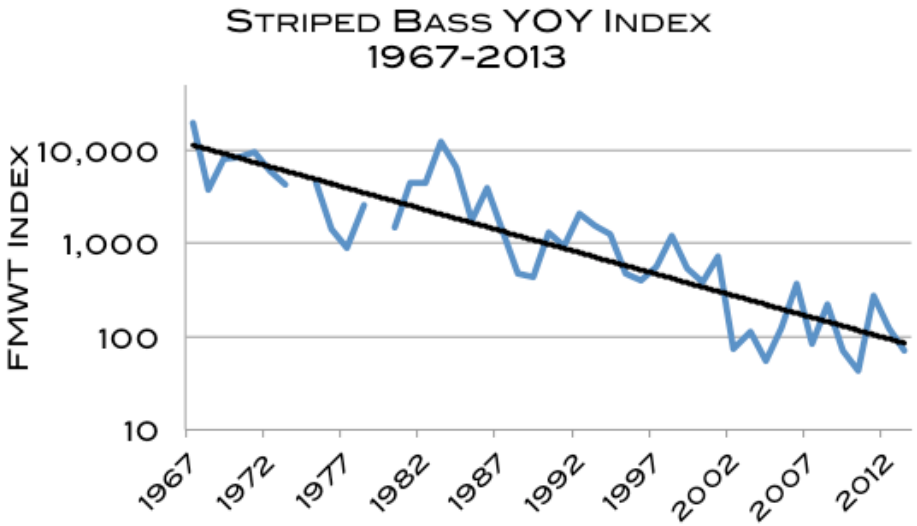
Decades of Steep Decline in Numerous Fisheries









Export: Direct Effects are Widespread and Large

(with strong mechanistic underpinnings)

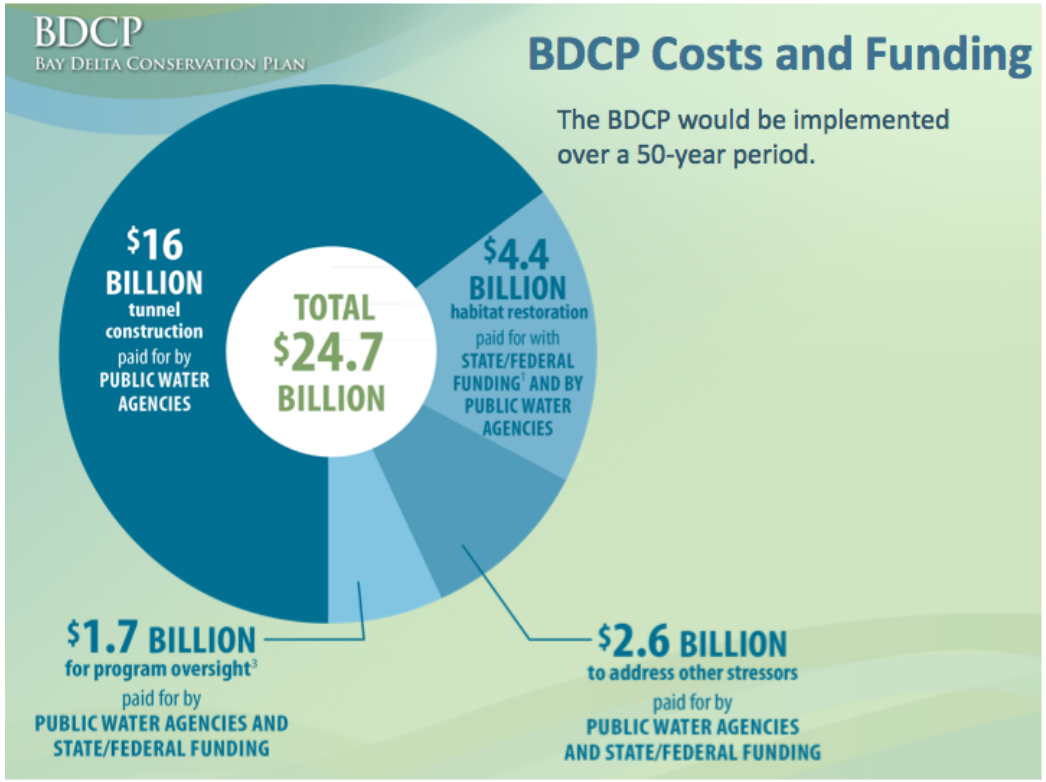
- On average, every year, 10,000,000's – 100,000,000's of fish are entrained by South Delta exports
- A substantial fraction of Delta primary productivity (not to mention higher trophic levels) is exported from the Delta via South Delta exports

Selected Fish Species	1993-2011 Annual Salvage	
	Average	Maximum
American shad	1,022,700	2,510,184
Bluegill	127,133	394,952
Channel catfish	45,799	131,484
Chinook salmon (winter run) Chinook salmon (spring run) Chinook salmon (fall run) Chinook salmon (late-fall run)	51,955	183,890
Delta smelt	29,918	154,820
Green sturgeon	58	363
Inland silverside	62,838	142,652
Largemouth bass	54,180	234,198
Longfin	6,228	97,686
Prickly sculpin	76,403	274,691
Steelhead (Rainbow trout)	5,278	18,580
Redear sunfish	1,609	5,611
Riffle sculpin	155	798
Sacramento sucker	3,443	27,362
Sacramento splittail	1,201,585	8,989,639
Striped bass	1,773,079	13,451,203
Threadfin shad	3,823,099	9,046,050
White catfish	296,543	941,972
White sturgeon	151	873
Yellowfin goby	193,399	1,189,962

Average yearly salvage total: 9,237,444

Bay Delta Conservation Plan

California DWR HCP-NCCP Proposal



New Diversion "will implement flow management changes to address the following flow-related issues for fish.

- Reverse flows in Old River and Middle River
- Entrainment, salvage, and predation effects on native fish species due to south Delta intakes.
- Delta Cross Channel effects on fish migration."

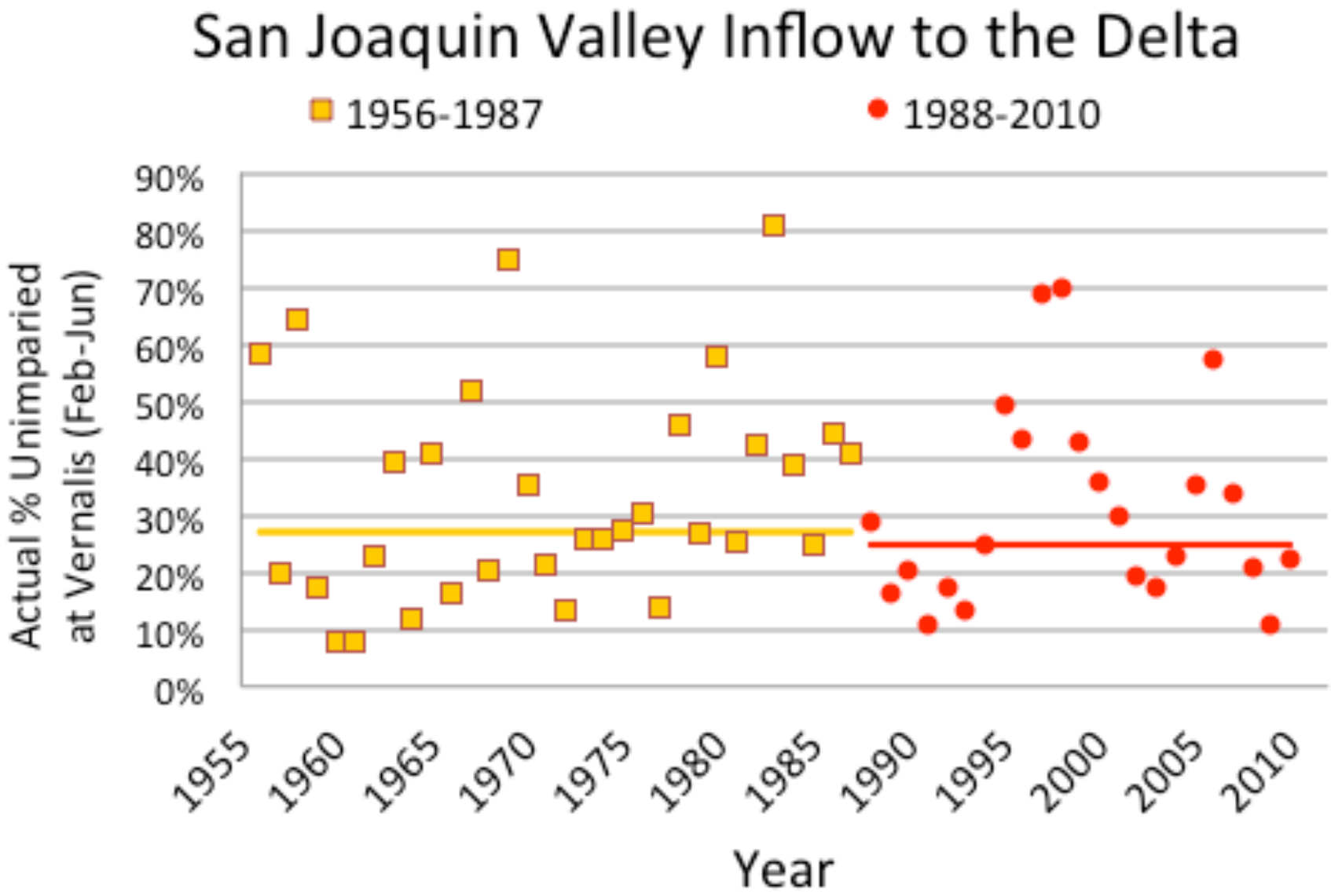
BDCP Conservation Strategy --Page 3.4.1

Altered Delta Hydrodynamics

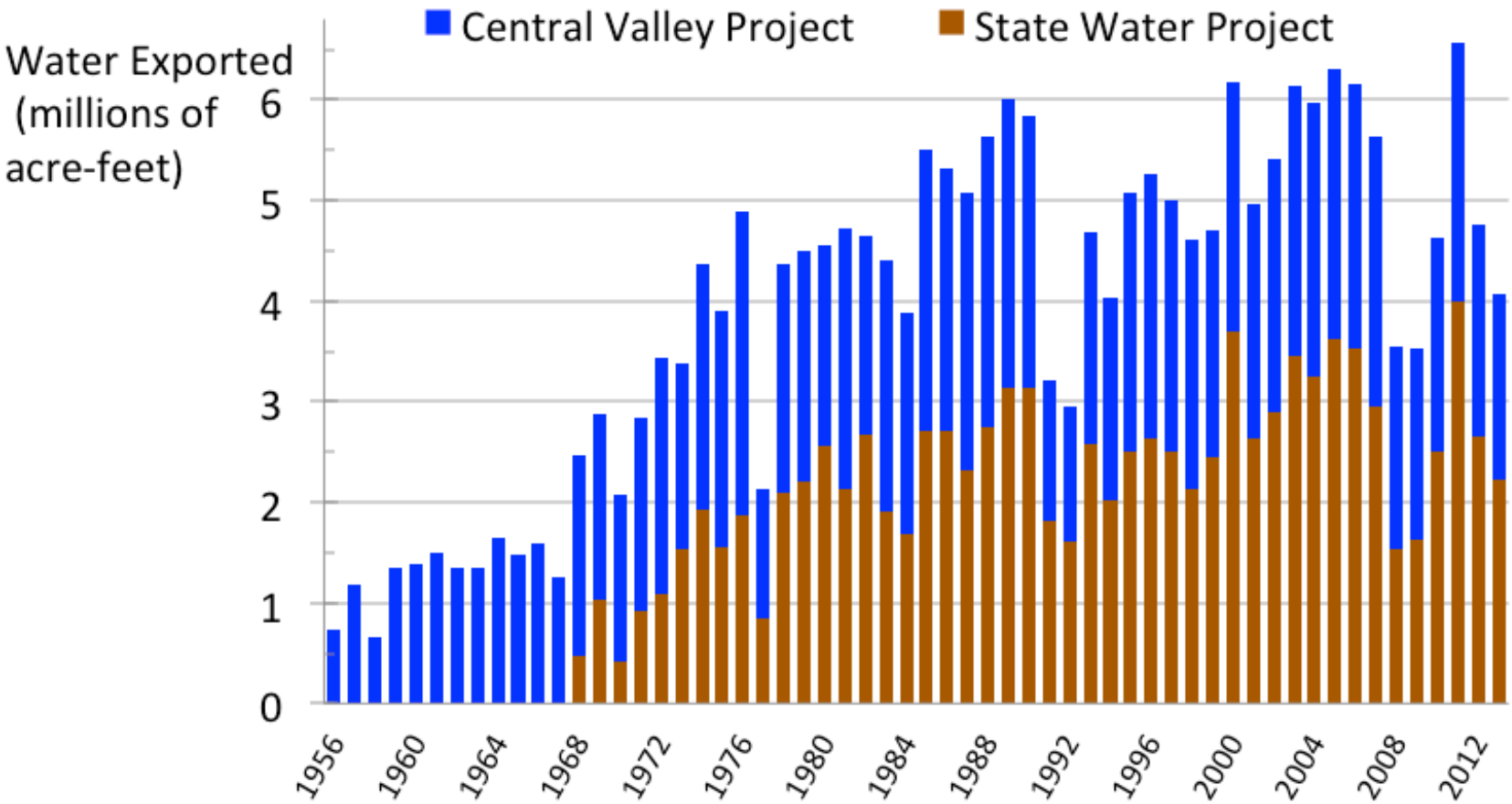
- Arise from reduced inflows **and** increased exports **and** current Delta geometry

- Negative effects include:
  - Direct mortality ("salvage")
  - Pre-screen mortality
  - Altered hydrology alters behavioral cues (leading to increased in-delta mortality)
  - Low dissolved oxygen
  - Impacts to system-wide productivity (direct and indirect)

Extremely Low (but Relatively Stable) Inflows to the Delta

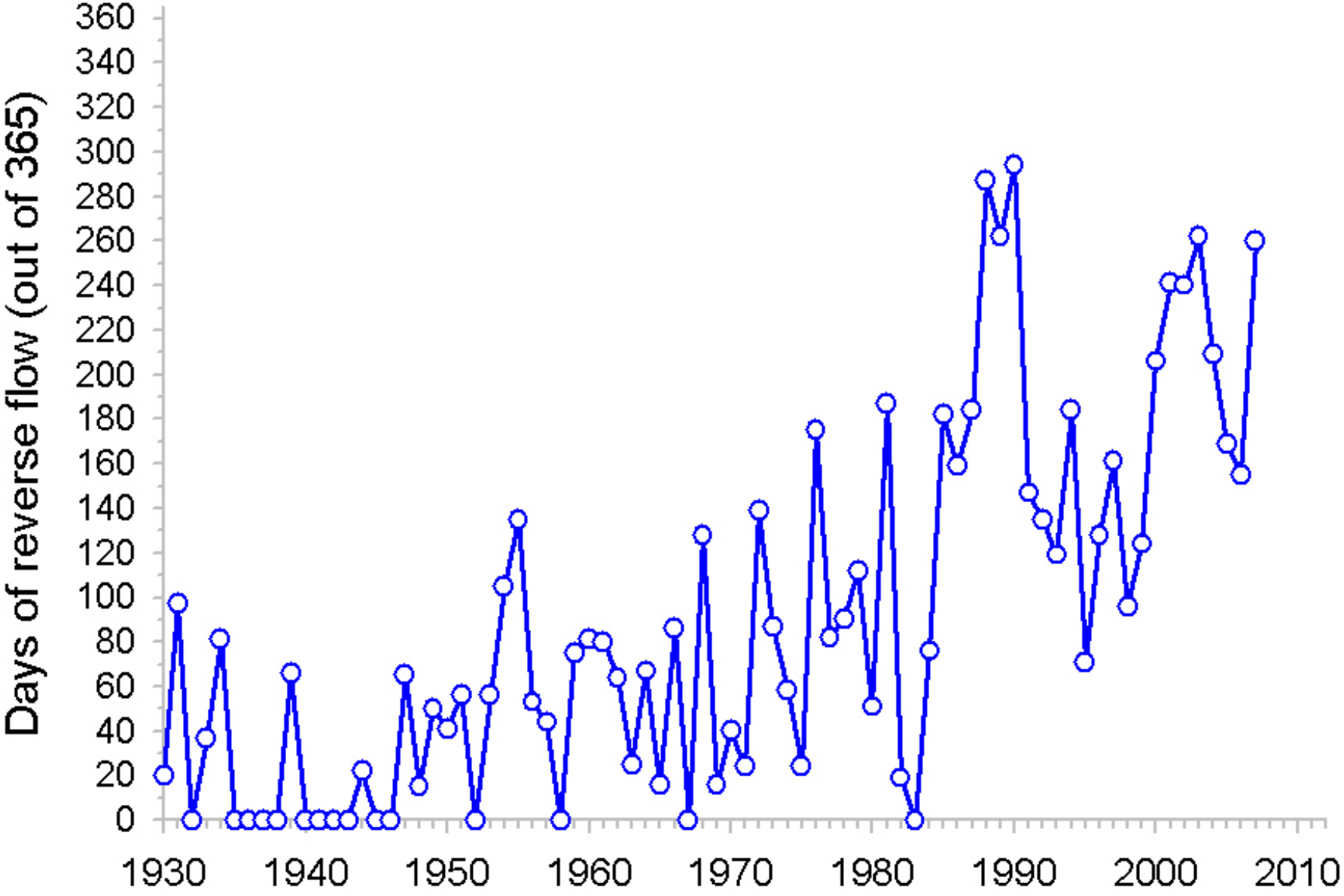


Increasing Direct Export from the Delta



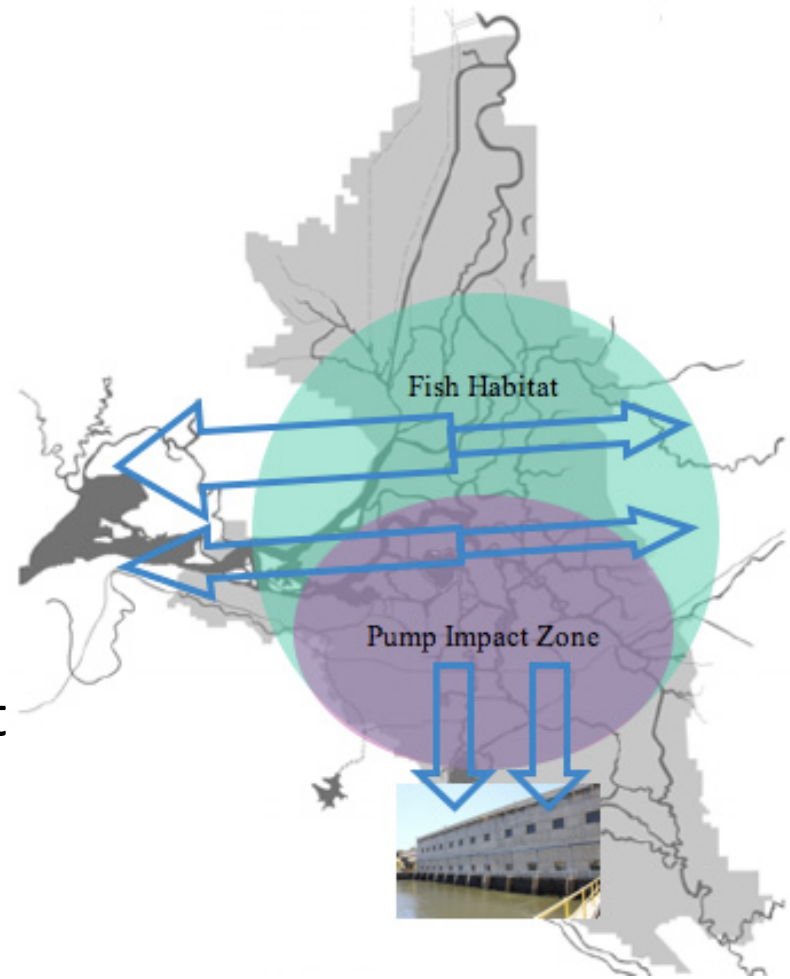
"… both exports and Delta outflow changed systematically during this period [1956–2003] … The Delta effect … increased over time, at the expense of outflow to San Francisco Bay. The trend in Delta effect is due to a trend in water exports from the Delta, as opposed to within-Delta depletion ... The long-term increase in exports, from approximately 5% to 30% of Delta inflow, is obvious…" [Cloern and Jassby 2012]

Increasingly Adverse Hydrodynamics



General Conceptual Model

- Altered hydrodynamics result from the interaction of inflows to the Delta, direct exports, and the Delta's current geometry
  - including gates and barriers
- Biological effects are the product of species behavior, distribution, and altered hydrodynamics at a given time
- Altered hydrodynamics effect different species (and life stages) differently
  - magnitude of effects may change from year to year



A single metric or one that tracks a single mechanism will not provide widespread benefit

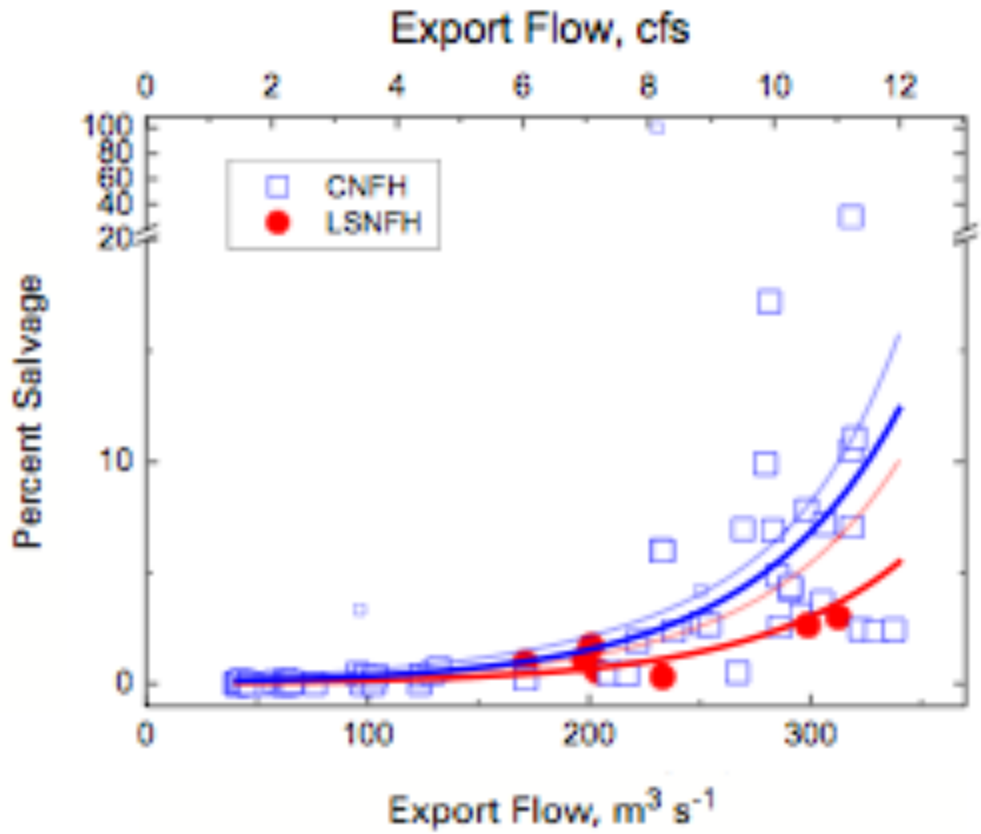
General Conceptual Model

Delta flow factors affect different attributes of viability for different species

Viability Attribute	Flow Criteria: Delta outflows	San Joaquin River Delta Inflows	Sacramento River Delta Inflows	Delta Hydrodynamics
Abundance	**longfin smelt** **bay shrimp** **delta smelt** starry flounder Sacramento splittail striped bass American shad Eurytemora affinis (spring) *habitat abundance for estuarine species*	**fall run Chinook salmon** spring run Chinook salmon *Abundance of and transport to accessible cold-water riverine habitats and communities*	Sacramento fall-run Chinook salmon Sacramento winter-run Chinook salmon	**SJR Chinook salmon** **Sacramento River Chinook salmon** **Delta smelt** *abundance of habitat for smelt species in the south Delta*
Spatial Extent	**longfin smelt** **Delta smelt** **striped bass YOY** starry flounder bay shrimp *transport both seaward and landward (e.g. gravitational circulation)*	**fall run Chinook salmon** **spring run Chinook salmon** steelhead white sturgeon green sturgeon Sacramento splittail longfin smelt Delta smelt *Distribution of productive cold-water riverine habitats and communities*	**fall run Chinook salmon** **Sacramento splittail** **spring run Chinook salmon** **winter run Chinook salmon** **late-fall run Chinook salmon** white sturgeon green sturgeon American Shad striped bass *increased distribution of floodplain habitats*	longfin smelt Delta smelt fall run Chinook salmon (SJR) spring run Chinook salmon (SJR) *Spatial distribution of spawning and rearing habitats in the South Delta*
Diversity	*increased occurrence of juveniles seaward for freshwater spawners and landwards for marine spawners*	**fall run Chinook salmon** spring run Chinook salmon white sturgeon steelhead *Diversity of riverine hydrographs and habitats in the Central Valley*	fall run Chinook salmon spring run Chinook salmon winter run Chinook salmon late fall run Chinook salmon *increased availability of floodplain habitats*	**Delta smelt**
Productivity/ Stability	**longfin smelt** **bay shrimp**	**fall run Chinook salmon**	**fall run Chinook salmon** **Sacramento splittail** spring run Chinook salmon winter run Chinook salmon late-fall run Chinook salmon white sturgeon green sturgeon American Shad striped bass *increased production and transport of materials off of floodplains to river and tidal habitats*	**longfin smelt** **Delta smelt** **SJR Chinook salmon**

Entrainment Effects

- Loss of Productivity/Resilience
  - Entrainment ("salvage") of winter run Chinook salmon increases with export flow (Kimmerer 2008)
  - Through-Delta survival of San Joaquin basin Chinook salmon ~5% (NMFS 2013)

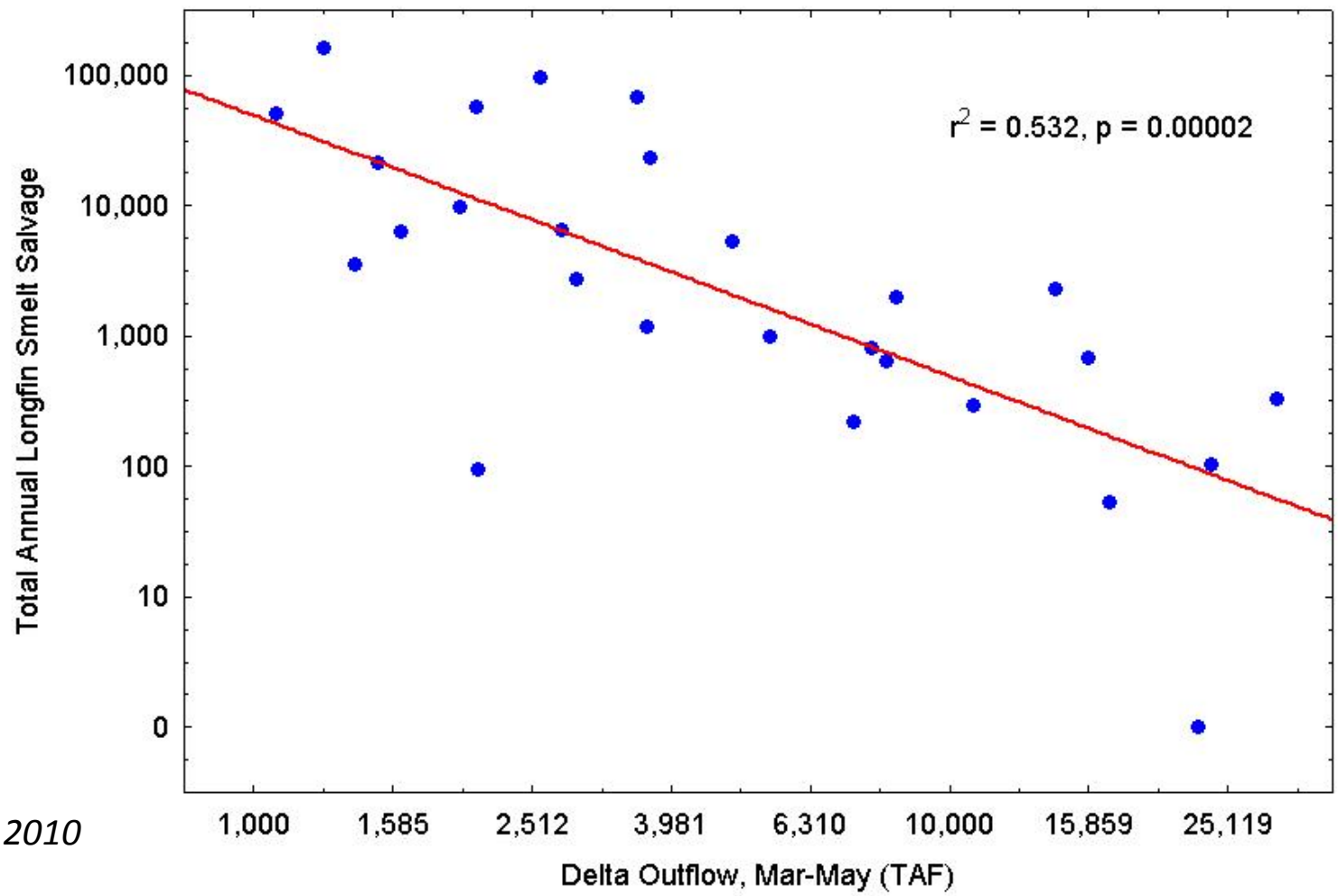


Copied from Kimmerer 2008

"…this level of additional mortality at the export facilities may place constraints on the rate of recovery of the listed winter- and spring-run stocks…" [Kimmerer 2008]

Entrainment Effects

- Loss of Productivity/Resilience
  - Entrainment of longfin smelt increases when population is already impacted by low outflow (i.e. when it is dry)

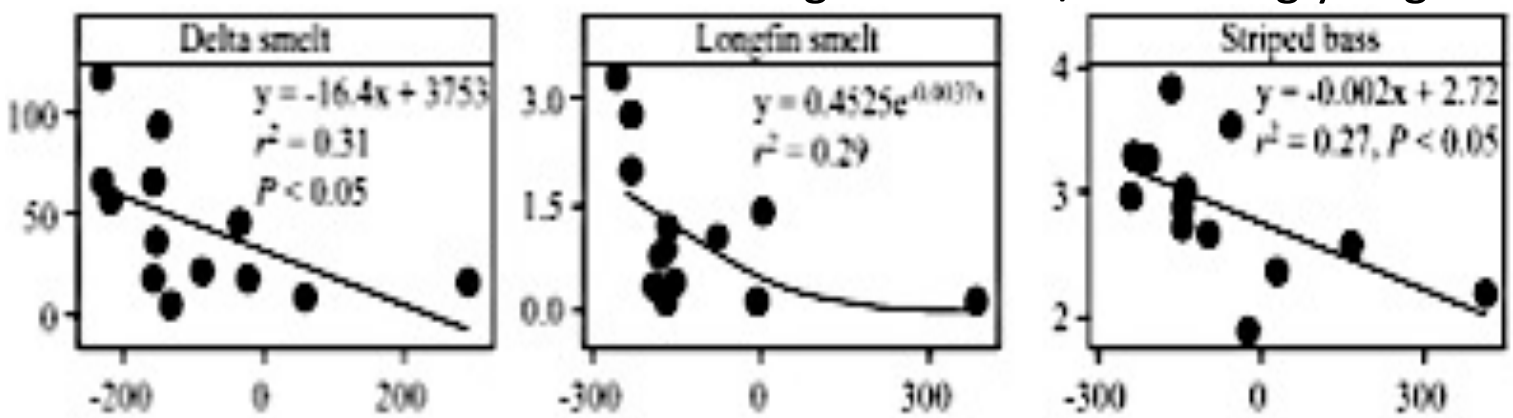


Copied from Rosenfield 2010

Entrainment: Productivity/Resilience

OMR as a Metric of Entrainment Effects

- For management purposes OMR is measured as a multi-day average (e.g. 14d, 5d)
- At this scale, conceptual models of "net flow" as a driver are supported for pelagic **and** migratory species
  - Entrainment increases with increasing diversions/increasingly negative OMR



Copied from Grimaldo et al. 2009

- Little conceptual support for the model of salmon orientation that relies on "instantaneous" flows (e.g. OMR on 15-minute time step)

"Our study suggests that entrainment of pelagic species can be effectively reduced by manipulating system hydrodynamics." *[Grimaldo et al 2009]*

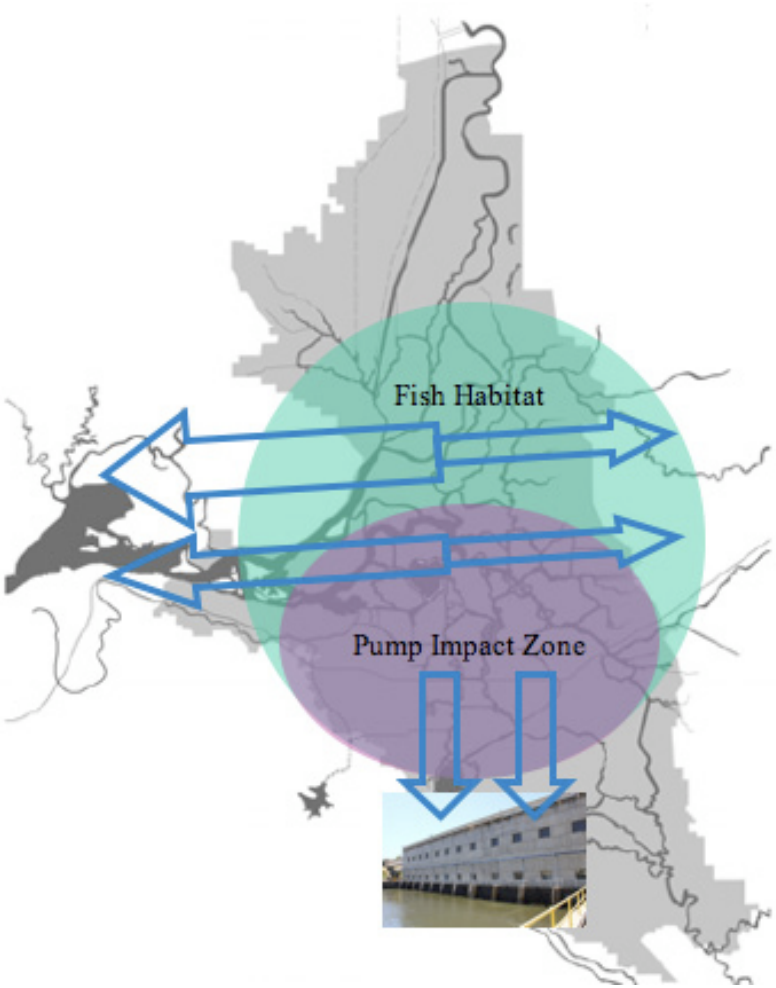
Entrainment Effects

- Loss of Productivity/Resilience
  - San Joaquin River Fall run Chinook straying

SJR salmon stray rates were negatively correlated with the average magnitude of [fall] pulse flows … and positively correlated with mean Delta export rates… Whether SJR-reduced pulse flow or elevated exports causes increased stray rates is unclear. … empirical data indicates that little if any pulse flow leaves the Delta when south Delta exports are elevated… [Marsten et al. 2012]

Entrainment Effects

- Loss of Productivity/Resilience
- Range Constriction
  - Consistent mortality + altered Delta hydrodynamic conditions may restrict range of fishes including:
    - Delta smelt;
    - longfin smelt;
    - San Joaquin salmonids
  - Range restriction increases susceptibility to catastrophic events



Entrainment Effects: Abundance

- Loss of Productivity/Resilience
- Range Constriction
- Abundance Effects
  - Delta smelt

    (e.g. Bennett 2005; Kimmerer 2008 & 2011 Mac Nally et al. 2010; Thomson et al. 2010; Rose et al. 2013)

"...a loss [of Delta smelt] *to export pumping on the order reported by Kimmerer (2008) can be simultaneously nearly undetectable in regression analysis, and devastating to the population. This also illustrates how inappropriate statistical significance is in deciding whether an effect is biologically relevant."* [Kimmerer 2011]

Delta Smelt Abundance Decline of 1995–2005

- No single factor explains entire decline
- Entrainment/Exports are among the most important factors

Authors	Finding
Rose et al 2013	• Growth of juveniles in the fall–winter, temperature, **and hydrodynamics** clearly had the strongest effects [on population growth] • Figure 8 from Maunder and Deriso (2011) … agrees with our analysis, showing higher entrainment mortality during the same years as in our simulation; however, we would term their Figure 8 results as providing **more than "some" support for a negative effect** of adult entrainment.
Maunder and Deriso 2011	• [Our model] did not include exports, but included explicit estimates of entrainment. We found some **support for adult entrainment**, … • The coefficients are similar magnitudes for most covariates except those for water clarity and, particularly, **adult entrainment, which had much larger effects** **
Thomson et al 2010	• **Export flows** in winter and spring were negatively associated with abundance of delta smelt and threadfin shad • …at the estuary scale, abiotic factors (water clarity, X2, **exports**) may have more influence … than do biotic variables.
Mac Nally et al. 2010	• …there is evidence of potential effects of **water exports** on delta smelt and threadfin shad

Delta Smelt Abundance

High Entrainment Losses Persist Under BDCP

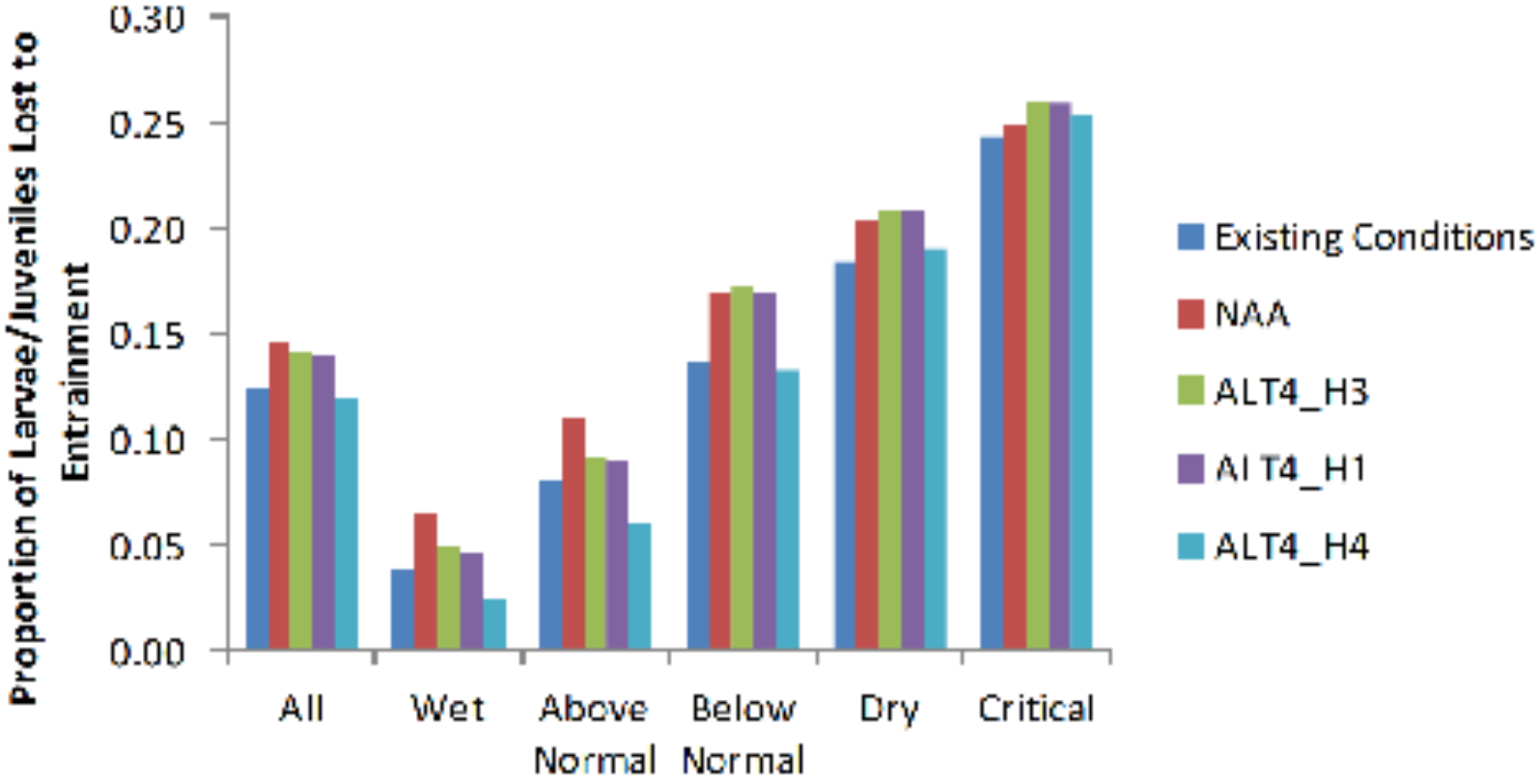
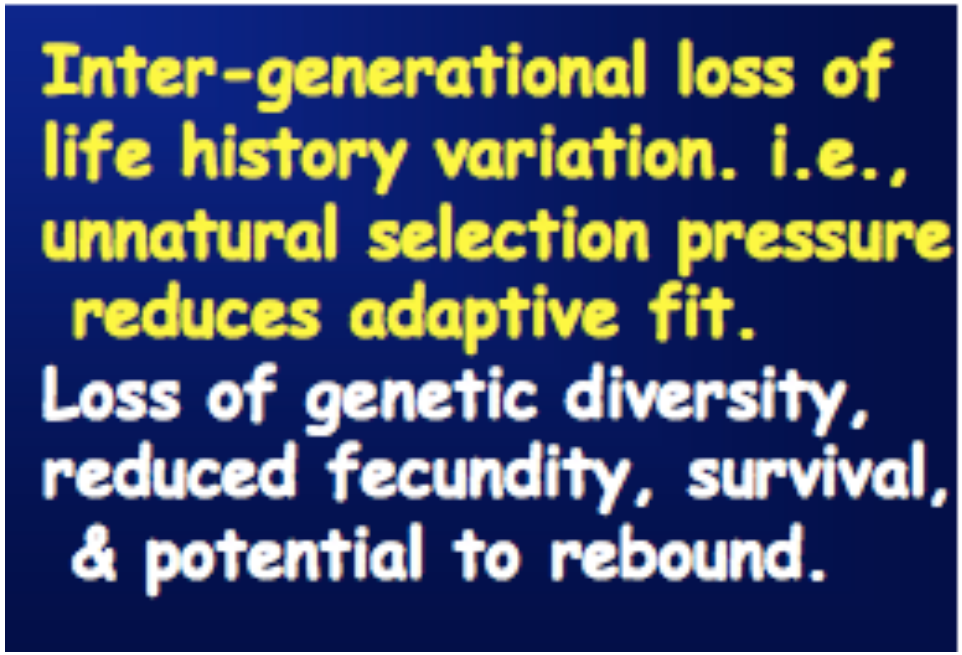


Figure 11-4-1
Average Annual Estimated Proportion of the Larval/Juvenile Delta Smelt Population Lost to Entrainment at the SWP/CVP South Delta Facilities for Alternative 4 (Scenarios H3, H1, and H4), Based on the Proportional Entrainment Regression

But are Responsive to Hydrological Conditions + Operations

Entrainment Effects

- Loss of Productivity/Resilience
- Range Constriction
- Abundance Effects
- Life History Diversity Erosion
  - Life history impacts indicated for Delta smelt (Bennett 2005)
  - Similar impact would be expected for many native species including longfin smelt and Chinook salmon

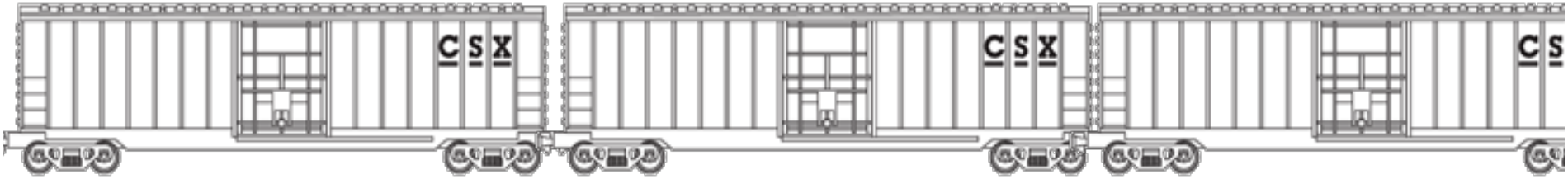


Slide reprinted with permission, B. Bennett 2012

Entrainment Effects

- Loss of Productivity/Resilience
- Range Constriction
- Abundance Effects
- Life History Diversity Erosion
- Loss of Productivity (system-wide)

"Water export from the Sacramento-San Joaquin Delta is a direct source of mortality to fish… and export plus within-Delta depletion alters system energetics of an already low-productivity ecosystem by removing phytoplankton biomass equivalent to 30% of Delta primary production." [Cloern and Jassby, *2012 citing Jassby 2002*].

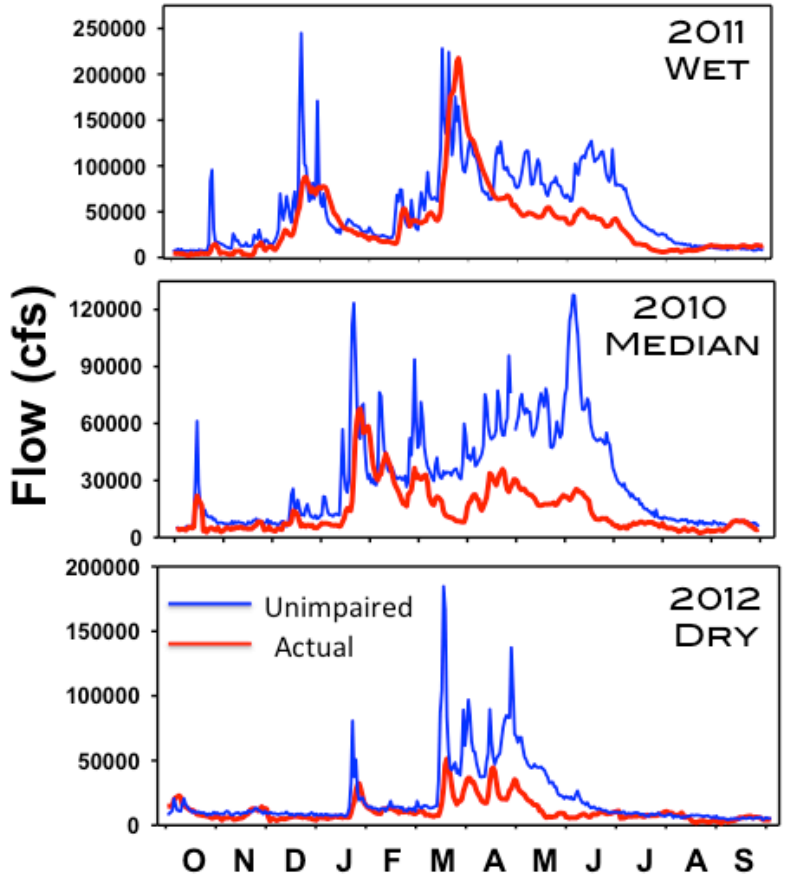


~three 50' boxcars worth of water (& food) exported every second

Additional Impacts of Altered Hydrodynamics

[*It's more than just entrainment*]

- Export restrictions in the WQCP have led CVP/SWP to shift exports **and** Delta inflow towards the summer and fall
  - Alters hydrograph shape
- Cross Channel Gate Operation
  - Alters distribution/entrainment susceptibility
- Low DO in the south Delta
  - Forms migration barrier that constricts geographic range
- Favors invasive species



… the Delta [has] shifted into a different assemblage of dominant organisms … [which] *reflects an altered physical environment in which the Delta has become simplified into a channelized conveyance system to support export of fresh water from and through the Estuary during summer and to reduce freshwater outflows at other times of year.* [Moyle et al. 2010]

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