EXHIBIT A: Attachment 1 - Project Narrative

A Multi-Stock Population Dynamics Framework for the Recovery of Sacramento River Chinook Salmon

1. Project purpose

The purpose of this project is to construct a multi-stock salmon population model and management strategy evaluation (MSE) tool that addresses the cross-linkages between water use and fishery ecosystem response. Recent federal court judgment concluded that insufficient evidence was provided for prescribing specific flow restrictions in two recent conservation measures. The inability to provide adequate evidence was a byproduct of not having the correct quantitative tools at hand. We propose to build these tools by furthering technological developments of previous analyses of Central Valley Chinook population dynamics. Specifically, our work will integrate multiple salmon populations together into a single model that can reconstruct historical population dynamics such that environmental conditions and water resource use can be used as predictors of biological response. Our goal is to integrate populations into a single model so that the effect of water management and fishery management policies can be examined in light of all populations and regulations simultaneously. This pertains to the biological interactions between the populations as well as the way in which fisheries impact individual populations depending on growth and maturation rate of each population. All analysis will be framed in the context of historical and proposed water use patterns.

Major scientific questions will be answered through several individual tasks. A breakdown of tasks is presented in detail in the *Approach and Scope of Work* section. The major questions and primary associated tasks are:

How are winter, spring and fall-run Chinook populations linked through habitat use, biology and management?

- Build a multi-stock population dynamics model with interactions between populations.
- Integrate hatchery production into populations.
- Estimate stock-specific parameters and between-population interaction parameters.
- Cross-linkages with fine-scale Delta sub-model.

What is the relationship between growth and maturation of a population, and vulnerability to fisheries?

- Build a growth sub-model sensitive to rearing biological and anthropogenic conditions such that survival in early ocean stages can be predicted as a function of size, and size is predicted from growing conditions in previous freshwater and ocean stages.
- Estimate maturation timing and size at run from empirical studies and fishery samples.
- Estimate the vulnerabilities of individual stocks to fishing effort.
- Build fishery harvest model sensitive to the relative vulnerabilities as a function of size and spatiotemporal distribution of fish stocks.
- Assess the value of life history diversity to Chinook harvest to providing socio-economic benefits through spreading of risk among different life history types.

What are the projected population trends with climate change projections?

- Assemble hydrological inputs from hypothesized scenarios and hydrology models that predict water distribution under future climate scenarios.
- Simulate population trends by incorporating uncertainty in original parameter estimate but using hydrology inputs as forcing variables.

What are the trade-offs between water resource rules, fish population persistence and fishery yield?

- Conduct stakeholder meetings to establish base units for the comparison of relative socioeconomic benefits that can be derived from resources, i.e., frame the trade-off in terms of potential unit of increased fishery yield to a unit of change in water resources.
- Use multi-stock model to predict the long-term population trends when alternative water use and fishery policies are applied.
- Develop a trade-off analysis methodology to perform a risk-weighted socioeconomic impact assessment of relative gains and losses of water use vs. fishery benefits at predicted sustainable population levels.

2. Background and Conceptual Models

Salmon populations in the Sacramento river are far below historical numbers (see Figure 2). Closures have been implemented to protect spring-run chinook (SRC), winter-run chinook (WRC), and recently even the fall-run chinook (FRC) which until 2005, had been considered a healthy stock and was the staple of the California salmon fishery. The FRC have been the most heavily subsidized with hatchery fish. The impact on commercial and recreational fisheries has been dramatic. A variety of reasons in both freshwater and marine environments have been cited as causes of the decline, but it appears that salmon have been subjected to something of a "perfect storm" of deleterious effects, both natural and anthropogenic.

Historically both WRC and SRC used the upstream, higher altitude tributaries of the Sacramento River, but their current extents differ greatly and their lower abundances have lead to concern and listing by both state and federal agencies (Yoshiyama et al. 1998, 2000, Lindley et al. 2004). WRC and SRC were separated both temporally and geographically in their spawning habitat. Winter-run historically used the headwater springs, spawned in the early summer, emerged from the gravel in late summer, emigrated over the winter, and entered the ocean the following spring (Lindley et al. 2004). Development of eggs was dependent on relatively constant flow and cool temperatures of the spring fed streams. Currently, WRC are confined to spawning in the Sacramento River. SRC used the spring flows to reach the upper tributaries of the Sacramento in summer and waited out the summer in high elevation pools. Spawning commenced in the fall and juveniles emerged the following spring. Stream residency varied and could last over a year. Out-migration occurred in both spring and fall depending upon time of residency. There are currently several extant subpopulations of SRC. Lindley et al. (2004) suggest that there are four principle groupings that might form the basis of a meta-population structure: 1. Winter-run, 2. Butte Creek spring-run, 3. Deer and Mill Creek spring-run, 4. Fall-run, late fall-run and Feather/Yuba spring-run. Since several of these runs overlap in their usage of stream and mainstem habitat, it is reasonable to consider that they may compete for resources and therefore a modeling approach that accounts for these overlaps could improve the precision of population predictions. Additionally, variation in survival of one population can provide additional statistical ability to the estimation of environmental effects that influence both populations.

Over the past several decades, substantial resources have been devoted to the management of water resources, fisheries, and habitat in the San Francisco Bay-Sacramento River Delta (Bay-Delta) ecosystem in general, with particular attention being given to resident chinook salmon runs. There has been increasing concern for species in decline, with the listing of WRC and SRC in the Central Valley (CV) under both federal (Endangered Species Act, ESA) and state laws. The disappearance of FRC returns in 2008 led to a complete closure of salmon fisheries. Many studies have been conducted in attempts to explain sources of mortality in freshwater and in the ocean. Tagging studies have shown extremely low survival in freshwater. Wells et al. (2007) showed strong associations between survival and ocean climate indices, providing evidence for a linkage between survival and primary productivity.

Fish interact with natural and anthropogenic aspects of their environment and there can be significant variation in such externalities. Decisions regarding fisheries management, water management and research direction should account for all significant and predictable sources of variation in those externalities where they have a measurable effect on survival. What is lacking is an integrative model that can provide a level of detail in water resource management and fishery management that accounts for interactions between salmon populations, both in the wild as well implicitly captured in the mechanics of fisheries policy.

Although mathematical models of salmon species have been developed both at the individual (e.g., Kimmerer 2001, Jager and Rose 2003) and the population (e.g., Botsford and Brittnacher 1998) level, management and research direction have been based primarily on qualitative compilations of what is known about individual salmon runs. Management would benefit from models that more closely link environmental conditions to biological response. Lessard et al. (*submitted manuscript*) built upon the general principle that survival could be broken down into life history stages so that the relevant environmental factors in each stage could be factored into the estimation of the productivity and capacity parameters that predict density dependence in survival rates. A series of competing models were compared using a statistical modeling and population dynamics platform (OBAN), each reconstructing population dynamics and estimating the relative effects of environmental conditions in freshwater and ocean stages. The study found that temperature, flow and exports explained most of the variation in freshwater. Historically, gate positions of bypasses and cross channels have explained some of the variation in survival, however, water management agencies have responded to biological needs and have in recent years adjusted the timing and magnitude of water redirection activities to mitigate negative effects on salmon. Wind stress curl, a primary productivity surrogate (Wells et al. 2008), was the leading factor explaining variation in ocean survival, although indices such as the Pacific Decadal Oscillation (Mantua et al. 1997) and sea surface temperature also explained variation in ocean survival, although not throughout enough of the timeframe of the study to be statistically competitive in model selection.

For the population dynamics portion of the project, we propose to develop a multi-stock model of the three Central Valley chinook salmon species-at-risk (WRC, SRC and FRC) that incorporates mortality in all phases of salmon life history, and includes the effects of uncertainty in assessing population status. The approach involves several categories of models: (1) the population dynamics models, (2) the parameter estimation model, (3) the growth model, and (4) the fisheries management model that calibrates fishing effort to the predicted runs of the individual populations and the expected sizes of those fish.

The first step in our research will be to develop a conceptual model of the important life stages of each of the populations of winter, spring and fall runs. This will include assembling all the data available regarding growth, survival and reproductive rates in each stage. An important role of this task will be to inform CALFED and the Bay-Delta modeling community of the basis for our other tasks.

CV chinook salmon life cycle

A useful way of viewing the chinook salmon life cycle for management purposes is in terms of a complete mortality budget. Each individual female produces a certain number of eggs in the final stages of life and various sources of mortality compound throughout the life cycle.

Spawning and Eggs

Spawning adults produce eggs that incubate in the gravel and emerge as juveniles. Factors that may affect spawning include environmental attributes such as the quality and quantity of spawning habitat (which may be further defined as a function of river flow, water temperature, gravel size, etc.) and density dependent effects such as redd imposition. Data on WRC redds have been collected by

CDF&G by weekly aerial redd surveys (CDF&G 2004). Although there may be problems relating redd counts to egg production (e.g. detection of redds, variability in egg deposition rates, etc.), these data can serve as an index of egg deposition.

Eggs incubate and emerge from the gravel to rear in natal streams until migrating downstream. The factors affecting survival from incubation through the freshwater rearing stages may include redd dewatering, water temperature, rearing habitat quantity and quality (a function of stream flow, water temperature, pool availability, woody debris, etc.). Juvenile counts of WRC have been collected at rotary screw traps at Red Bluff Diversion Dam and they may be used to quantify the number of juveniles leaving the upper Sacramento traveling toward the Delta.

Juvenile rearing

Juveniles migrate down the Sacramento River, either remaining in the Sacramento or becoming diverted through the Delta Cross Channel (DCC) and into the North fork of the San Joaquin River. In either case, juveniles migrate through the Sacramento-San Joaquin River Delta (Delta) past Chipps Island and into San Francisco Bay.

There have been some efforts to estimate how environmental conditions (salinity, turbidity, water temperature, river flow) and water management decisions (exports and DCC position) affect survival of out-migrating hatchery chinook salmon (Brandes and McLain 2001, Newman and Rice 2002, Newman 2003). Newman and Rice (2002) analyzed the fate of migrating fall-run hatchery chinook released at various points in the Delta and collected as juveniles in a trawl at Chipps Island or as adults in the marine catch. Newman (2003) also used paired releases of fall-run hatchery chinook juveniles at the entry to the Delta (near Sacramento) and at the exit of the Delta (near Benicia). Brandes and McLain (2001) consolidated the release studies to date and examined the environmental factors that might affect survival through the Delta. The results of these studies indicated that survival was negatively correlated with water temperature, positively correlated with Sacramento River flow, negatively correlated with exports, negatively correlated with DCC gate position, positively correlated with salinity, and negatively correlated with turbidity. The same relationships were found reconstructing WRC trends using the OBAN model (Lessard et al. *submitted manuscript*).

It would appear that this phase of the life cycle has been analyzed quite effectively, however the survival rates of out-migrating juveniles have not considered population interactions.

Ocean

Smolts entering the ocean probably have a survival rate ranging from 0.01 to 0.1 (based loosely on survivals from coho salmon). Factors such as primary productivity, upwelling, predator abundance, temperature and size at ocean entry contribute to mortality. Since the 1970s, there has been increasing interest in the influence of ocean conditions on Pacific salmon abundance at two different time scales, inter-annual variability, and more recently decadal change (see reviews in Botsford et al. 1989, Pearcy 1992, Botsford and Lawrence 2002 and Botsford et al. 2003). For CV chinook salmon at the inter-annual scale, examination of the combined influence of upwelling, ocean temperature and sea level identified a dependence of abundance on warm/cool conditions (i.e., El Niño/La Niña) during the year of entry and the year of return (Kope and Botsford 1990). The study also identified a dependence on flows in the Sacramento River, and noted the potential confounding effects of common drivers of precipitation (hence flows) and ocean conditions.

In the 1990s a mode of variability in surface pressure fields (winds and temperatures) in the northeast Pacific that shifted in the mid-1970s was identified. The Pacific Decadal Oscillation, or PDO (Mantua et al. 1997), was associated with opposite changes in salmon abundance in the Gulf of Alaska and the California Current (Beamish and Bouillon 1993; Francis and Hare 1994; Francis et al. 1998). Since the 1990s when research efforts such as the NSF/NOAA-funded GLOBEC North East Pacific program began to focus on determining the causal links between the atmosphere, ocean physics, biological productivity and salmon abundance, a more comprehensive understanding of both physical and biological changes has evolved (e.g., Strub and James 2000, McGowan et al. 1998, Batchelder et al. 2003). In addition to these retrospective analyses of the changes in the mid-1970s, considerable attention has been focused on the more recent shift from warm to cool conditions in the late 1990s. The PDO also seemed to change at that time, but closer examination has shown that the modes of variability in pressure fields in the northeast Pacific are more complex than could be described as a simple return to an earlier state (Bond et al. 2003). Much about the ocean remains unknown, and ocean conditions are often blamed for poor salmon survival (Lindley 2009).

Upstream migration

After one to four years at sea winter-run adults return through the Bay and Delta to migrate up the Sacramento River. Factors affecting the number of adults migrating to spawning grounds include straying due to flow regimes in the Delta, passage of diversion dams, harvest in the freshwater fishery, etc. Spawner abundance has been estimated for winter-run chinook from 1970 to 2008 from counts of adults passing Red Bluff Diversion Dam. The operation of Red Bluff Diversion Dam has changed the precision of the spawning escapement estimates over this time period however. Prior to 1990, all returning spawners passed via a counting ladder. Since 1990 the gates of the diversion dam have been opened to enhance upstream survival of winter-run, which has reduced the precision of the estimates (Botsford and Brittnacher 1998). Spatial distribution, age, and sex composition of spawners may be inferred from carcass counts, which have been conducted since 1996 by CDF&G (CDF&G 2004).

3. Approach and Scope of Work

Our work will be broken into distinct tasks (see Table 1). We will build upon an approach that was the product of a project funded under the 2004 PSP "A Statistical Model of Central Valley Chinook Incorporating Uncertainty". The approach was to couple environmental effects with productivities and capacities via Beverton-Holt survival functions at various life-history stages in the Sacramento river and in the ocean. The software and model OBAN provided the means to make the cross-linkage between water supply and condition, and biological response. This was done for a single salmon run from the egg deposition stage through to escapement and involved dividing the life history into approximately 9 stages where environmental information was available. The model was statistically fit to population abundance data at various stages of life history using maximum likelihood techniques. The statistical fitting resulted in estimates of the magnitudes of the effects of various environmental factors on the productivities and capacities of life history stages. The product was a model that could reconstruct historical population trends from 1967 to 2008 from initial escapements of Sacramento winter run chinook in 1967-1971 and attribute variation in survival and abundance to changes in fresh water and ocean conditions. Appendix A provides a technical description of the WRC model fitting with OBAN.

We propose a strategy whereby we use the same basic philosophy of linking environmental conditions and water management patterns to productivities and survivals, but we do so with multiple populations so that interactions between populations are accounted for in the model. Each population would be accounted for separately, but the in some cases the populations would interact in terms of habitat use and competition, thus causing variation in survival attributable to population interactions. Additionally, a synergistic population model will allow for more detailed implementation of harvest rules sensitive to the needs of mixed-stock fisheries.

Modeling strategy

Our approach will integrate population models of spring, fall and winter run in a single model. Populations will be separately accounted for in the model so that population specific predicted abundances can be compared to empirical data. This will have the benefit of reducing the variation in estimates of stage specific parameters because the estimated rates will need to explain the observed abundances of more than once population throughout for the time-frame modeled. This differs from a single population model in two ways: 1. by representing the interactions between abundance, and 2. by the fact that observations from prior stages or both populations will also be accounted for statistically, forcing the model to estimate rates that explain two previous abundances surviving to states later observed. From a model structure point of view, more is better and explaining more that one population reduces the range of admitted variability in parameter estimates (and hence in the range of forecasted population trends). This will alleviate one of the chief concerns of using models to forecast future population trends under alternate management strategies, i.e., that large amounts of variability in estimates lead to highly variable forecasts.

Bayesian approach to uncertainty

Accounting for uncertainty is a central feature of our modeling approach. The effect of environmental, anthropogenic, and density related factors cannot be known with certainty (e.g. Minns and Moore 2003, Peters et al. 2001), therefore we will incorporate uncertainty into the modeling approach. Multiple hypotheses have been put forth to explain the population declines of natural stocks of chinook salmon, for example loss of freshwater habitat, high harvest rates, and competition with hatchery fish (Nehlsen et al. 1991). In addition, salmon migrating through the Delta may face additional factors that affect survival such as entrainment in water pumping stations or diversion into irrigation canals (Brandes and McLain 2001, Baker and Morhardt 2001). The relative importance of these factors can only be tested by constructing a model (Greene and Beechie 2004). Further, the degree to which this model reflects reality can only be addressed by comparing the model predictions to observed data. The model is indefensible if it is not tied to data, because many other parameter sets can be used to produce the same results if that set of parameters facilitates a particular agenda. Confronting models with data does not remove the possibility of arbitrary interpretations, however it does provide a transparent method for testing what we think we know about the mechanisms to what we have observed (Hilborn and Mangel 1997).

We propose using Bayesian methods to incorporate uncertainty into the estimation of model parameters. Bayes theorem is

$$p(\beta \mid y) = \frac{p(\beta) p(y \mid \beta)}{p(y)} \quad , \qquad (1)$$

where y are the data, $p(y|\beta)$ is the posterior distribution, $p(y)$ is the sum (or integral) over all values of β if β is discrete (or continuous), $p(y|\beta)$ is the likelihood function, and β is the vector of coefficients that we would like to estimate. In words, Bayes theorem says that the posterior distribution is proportional to the prior times the likelihood and normalized to scale to 100% probability space (Gelman et al. 1995). The numerical implementation of this method is Markov Chain Monte Carlo (MCMC) simulation, which simulates a probability distribution that is very useful to produce probabilistic "what if" scenario analysis. Examples are Population Viability Analyses (PVA) or any desired certainty estimate of a predicted future scenario.

Calibration, validation and uncertainty

Calibration is a term generally reserved for hand-tuning models and validation is a term generally used to described the qualitative examination of model outputs to ensure that predictions are reasonable and within boundaries of biologically feasible behavior. We will perform the calibration statistically using parameter estimation. The basic approach involves estimating of model parameters with statistical comparison to time series of data. Validation will be done in several ways. First will be retrospective analysis, that is fitting the model up to year t and projection forward using the estimated parameters and known covariates forward from year t+1. This method is commonly employed as a validation method for population dynamics analysis. Second is analysis of residuals. If the residuals have anomalies it suggests assumptions may be incorrect.

The Bayesian framework provides a standard approach for expressing uncertainty both of the estimated parameters, and in any forward projections. The project will involve parallel comparisons of models that are founded on different complexities and which conflate comparison pure statistical selection. We will both compare and combine models. We will use the Akaike Information Criterion weights to express degrees of belief in different model formulations. These two approaches are derived from different theoretical bases, but in the work done in OBAN thus far suggest the come to similar conclusions about uncertainty.

Task 1: Project Management

Project management activities will include budget verification, data acquisition and handling, report preparation, project oversight and outreach. Management will be allocated with approximately 50% of PI time and 10% of project coordinator time.

Tasks 2-5: Integrated Population Model

Task 2 ***Building sub-population structure***. This involves the construction of the population dynamics models, independent of statistical fitting. We will recycle much of the architecture of the OBAN model to integrate the sub-populations. We will construct life cycle models of each population such that survival from one life history stage to another involves a BH survival function. At this point, the number of life history stages to be modeled is not known. A good guess would be approximately 7-9 freshwater stages, an early ocean stage, and a yearly stage for ocean residence years, making it approximately 12. The number of stages in freshwater and marine environments will depend on the space/time overlaps of the populations (see Figures 3 and 5). It will also depend on the data available to fit the models to intermediate population predictions. The number of stages will be relative to the number of stages where populations overlap as well as the availability of data to which the model can be fit. For instance, escapements are available for all stocks, but not for precisely the same time periods, which will mean that some populations will be absent for parts of the timeframe simulated for a particular stage and time (see Figure 5). Additionally, juvenile data was collected for some stocks in some years and not in others. Ultimately, we will model any stage that has data.

We propose to model the life cycle of all stocks that have distinct spatial and temporal migration patterns (see Figure 3). The break-down into stages will be determined by the precise geographic points at which populations mix. For instance, the WRC spawn mainly in the Sacramento river above Bend Bridge and fry emerge and make their way down stream. At bifurcations in the river where the tributaries meet the Sacramento, we would define a new stage and declare that the populations join a common pool for the purpose of competing for resources if they are present in the same reach of the river at the same time. Their individual numbers would still be accounted for separately, but their abundances would be combined for density dependent survival purposes. This multi-stock life cycle model will involve constructing the stage-by-stage models of each population and building the linkage between the stages so that pooled abundances can be calculated at any relevant. This will in effect treat each population as a sub-population with spatio-temporal linkage to the topology of the river.

Our strategy will be to use the distinctions outlined in Lindley (2004) with two more population distinctions: 1. Winter-run (WRC), 2. Butte Creek spring-run (BCSR), 3. Deer and Mill Creek spring-run (DMSR), 4. Fall-run (FRC), 5. late fall-run (LFR), and 6. Feather/Yuba spring-run (FYSR). We will construct a temporal map of the life cycle of each stock and attribute each stock to an approximate river mile in a given month. With a map of the spatio-temporal location of each stock, we can advance the life stage of each abundance with density dependent survival, but allocate stocks into common abundance pools when they occupy the same habitat at the same time.

Predation on juvenile chinook is an area of major concern, with changes in the predator community, and the changes in vulnerability of chinook to predation caused by flow, water exports, and turbidity all considered potential factors affecting chinook recovery. Within the OBAN approach we never specifically model predation, but at each life history stage in the model survival is calculated. This survival includes both predation and other forms of mortality. When we evaluate if survival through a life stage is related to (or explained by) the abundance of potential predators, or the flow, exports or turbidity, we are implicitly evaluating the impact of predation. For instance, if the striped bass index explains some of the changes in survival when applied at the time of downstream migration, the model implicitly is saying that striped bass predation is important. Since we do not have any direct estimates of predation rates, we must infer the predation impact through the impact on total survival.

Task 3 Integrate hatchery production into dynamics. Similar to the way in which non-hatchery populations are modeled, this sub-model will have a stage-to-stage BH survival function, but the key difference will be to properly integrate the hatchery population with the wild populations. This task will involve a careful review of the biology and migratory patterns of hatchery fish. We will make use of historical coded wire tag (CWT) studies to provide an estimate of survivals. Hatchery smolt production will differ from wild production mainly in the fact that juveniles will not be subject to density dependent rules.

Task 4 Estimate stock-specific parameters and between-population interaction parameters. Once the population models are fully integrated, model fitting and parameter estimation will take place. In preparation for this, Task 3 will entail assembly of all abundance data and environmental data, and preparation of likelihood objective functions. Since the estimation of parameters will involve an iterative process of including and excluding interaction effects, environmental effect coefficients, we will use a model selection approach to identify the most parsimonious model.

Task 5 Cross-linkages with Delta survival sub-model: A recent project has been initiated as part of the Bay Delta Conservation Process (BDCP) that will construct a life-history model for WRC, BCSR, DMSR, and FRC focused on the Delta. The model will be constructed using the Shiraz (Scheuerell et al. 2006) life-cycle modeling framework and the project will be lead by NMFS. The goal of this effort is to develop a fine-scale understanding of factors affecting capacity and productivity (the Shiraz model also uses Beverton-Holt transition functions) in the Delta.

The Shiraz model being developed for the BDCP process provides a unique opportunity to link the OBAN type models proposed here to a model that is targeted on a specific area of high management interest. Current applications of the winter run OBAN model to BDCP alternatives has proved problematic as the winter-run OBAN model treats the Delta as one homogeneous region. This assumption has not been supported by evaluation of route-specific survival rates for Chinook traversing through the Delta (e.g., Perry et al. 2010). We will develop the methodology to cross-link the patterns in survival from modifications of the Delta physical habitat, SVP and CWP operations, and BDCP conservation measures into the multi-stock model. Given our goal of evaluating trade-offs between water management and fishery management on the population dynamics of CV Chinook stocks, this task will provide a method for evaluating the full life cycle effects of BDCP related actions.

There are at least two approaches that we will explore for incorporating more detail regarding chinook life history in the Delta that will blend the BDCP work with the OBAN work. The first approach will be to break the life history within OBAN into smaller spatial/temporal stages, and model the proportion of fish that enter the delta, and the survival of those that enter the delta and those that do not. This will involve, at a minimum, two additional parameters, the proportion that enter, and the survival difference between those that enter and those that do not. As in the rest of the OBAN framework, the values of these parameters will be initially set at "best estimates", but then we will attempt to estimate these parameters as a function of the environmental variables such as flow, OMR, water withdrawals, whether the delta cross channel is open etc. We can also include as additional data the estimated movement proportions and survival rates from the acoustic tagging report in Perry et al. 2010 and other acoustic tagging data. We will explore different levels of complexity in the life stage involving passage through the delta. We anticipate that the acoustic data will be highly informative (for the years it is available) of proportions taking different migration routes and the survival of fish taking those routes. At the extreme the migration model might be as complex as the model used in Perry et al. 2010. Using the same model comparison methods used throughout the OBAN process, AIC and Bayesian equivalents, we can explore the benefits of making the internal migration model more complex.

The second approach will be to use results from the BDCP modelling directly as inputs to OBAN. Thus, if the BDCP analysis provides estimates of within delta survival as a function of environmental variables, we can use those as "known" relationships.

We anticipate the two approaches to analysis of delta survival will proceed in parallel and the advantages and disadvantages of each method will be evaluated as the project proceeds.

Tasks 6-10: Growth and maturation

The purpose of this task is to take advantage of two pieces of information that distinguish between stocks to harvest selectively: 1. size as determined by growth characteristics and 2. distribution of sizes as proportional to abundance at age of return (i.e., as determined from a maturation schedule). This will provide insight into the relative natural survival and vulnerability to fishing. Openings and closures of mixed stock fisheries are designed to select for some stocks and not others. This is achieved through spatial and temporal fishing restrictions, and through size limits in retainable catch. When salmon stocks originate from the same river, timing and size are the only distinguishing characteristics. Pre-terminal fisheries can also be managed with time and space consideration if migratory patterns are distinctive. But, if stocks are mixed spatial and temporally and can only be distinguished by size, fishery rules would need to select for size to target one stock over another.

Task 6 Growth model. One of the variables that we will track in the model will be the size of juveniles entering the ocean. Since smaller fish are more vulnerable to predation than larger fish, we will model the maximum survival rate as a function of size at the time of ocean entry. Size and growth will be estimated from rearing conditions. A growth sub-model will be developed to estimate size at ocean entry. The model will be based on data available from tagging studies.

Task 7 Maturation and size estimation. Each stock matures at such a rate as to produce relative abundances of ages of adult returns. The age structure can be used to back-calculate those maturation rates. In turn, the number of maturing fish of a given age will contribute a relative number of a given size class to the total abundance of adult fish returning of a particular stock. A sub-model will be constructed to calculate this aspect of the population dynamic predictions.

**** Tasks 8 and 9 eliminated from proposal**

Task 10 Value of life history diversity to Chinook harvest.

Diversity of Chinook salmon population structure can provide socio-economic benefits through spreading of risk among different life history types. Recent evaluations of fall-run Chinook indicate that the covariability among fall-run stocks in the Central Valley has been increasing; thus, fall-run abundances tend to move in unison. In contrast, late-fall, winter, and spring-run have somewhat distinct patterns in abundance (Lindley et al. 2009). This may be due in part to the large proportion of fall-run Chinook of hatchery origin in the Cental Valley (Barnett-Johnson 2007). Historically, the abundance of Central Valley salmon was dominated by spring-run Chinook in most years (Fisher 1994), suggesting that there are other components of the Central Valley Chinook assemblage that could provide harvest opportunities. We will evaluate the socio-economic value of diversification of the Chinook assemblage in the Central Valley by evaluating the risk adjusted return of salmon harvest (i.e., more weight given to consistent harvest opportunities and less weight given to highly variable harvest opportunities).

Tasks 11 & 12: Population Viability Analysis with climate projections

The result of model fitting procedures in Task 4 is a list of estimates of biological parameters (see Figure 4 (a)) and coefficients that explain the magnitudes of the effects of environmental change on population survival. These can be used to predict population trends as long as certain starting conditions and certain environmental conditions are supplied (see Figure 4(b)). We will explore the effects of a suite of hydrological inputs that reflect alternate water use strategies. The water use strategies will be implemented as alternative inputs that will be expressed in the same units as the original data sources. For example, if the model estimated the relationship between flow and survival using water flow at river mile 100 as the average of minimum daily flows, alternative strategies must supply this number. This is not unique to hydrology. The full suite of environmental conditions that were used to "condition" the model must be represented for forecasting. In some cases these may be supplied from adjunct models that produce flow, temperature, exports, ocean conditions, etc… In other cases, they may be speculative in nature. For example, if river temperatures are expected to rise by one degree Celsius over the next 20 years, this increment could be added to the mean expected temperature gradually over a 20-year simulation. In this manner, supplied in advance with a set operating parameters, the model can predict the outcomes of a variety of scenarios defined by management inputs. We propose to assemble where possible, model outputs from climate models (ocean temperatures, PDO, etc…), water flow and exports (to provide analogues of aggregate statistics used to fit the model), gate and channel openings and closures, and fishing policies. We will implement climate change by imposing predicted climate change patterns into the climate inputs. At the time of writing, these appear to be reflected in oceanographic models, air temperature models and precipitation models. We do not intend to model such measures directly, but rather seek to either use existing model outputs or calibrate historical numbers such that they represent the change intended. It is expected that effects such as higher rainfall and lower snowpack will be reflected in hydrological variables such as river temperature in spring and summer, as well as flow patterns.

We propose to conduct a Population Viability Analysis (PVA) while incorporating uncertainty in the parameter values and model structure using the multi-stock model. We will use a threshold of 100 spawners (Botsford and Brittnacher 1998) to represent quasi-extinction, because depensatory mechanisms (e.g. Allee effects, Allee 1931) can cause populations to decrease rapidly after crossing such thresholds. Like Botsford and Brittnacher (1998), we will compare the number of spawners of each stock predicted by the multi-stock model in a given year to this threshold to identify cohort extinction events. When all cohorts fall below 100 spawners, the population has reached quasi-extinction. Using the Monte Carlo approach described in the multi-stock model section, statements about the probability of extinction can be made in light of age at spawning and other uncertainties in the life history of fall, winter and spring-run chinook.

The specific quantitative values that define delisting criteria have varied depending on species. A probability of extinction less than 0.1 in the next 50 years was used by Botsford and Brittnacher (1998) for winter-run chinook in the Sacramento River. Botsford and Brittnacher (1998) used an ad hoc model to account for parameter uncertainty and measurement error in determining the number of samples needed to determine that a population of winter-run chinook that had met the delisting criteria. They concluded that winter-run chinook in the Sacramento could be subject to delisting if more than 10,000 spawners were counted (with measurement error less than 25%) consecutively for 13 years.

Task 11 Assemble hydrological and environmental inputs: This task will entail a thorough review of historical water use policies, projected demands, and proposed water use actions. Where models have been developed, and where these models are capable of producing quantitative predictions of conditions in the same units as the Operating Model (OM), we will make use of these. Where such model inputs are not available, we will quantify the expected change in water use such that the projected use is relative to historical.

A number of other projects associated with the Delta Science Program, and other agencies are producing hydrologic simulations of future scenarios both of water management actions and of climate impacts. We can incorporate these scenarios directly in our models through the flow, temperature and turbidity co-variates in our models. For instance, in the winter chinook OBAN modelling we found temperature and flow at different places and life stages explained variability in survival. In our analysis thus far we used historical records of these variables. Using future scenarios of water management policies we can take the outputs of these scenarios, and treat them as inputs into OBAN. Thus we found that the spawning ground temperature was an important factor in egg to fry survival for winter chinook. If some future scenarios show increased temperatures of the flow coming out of Shasta Dam, the results from our winter chinook modelling would show that future trends in winter chinook abundance would be more negative than a future scenario with cooler temperatures emanating from Shasta Dam. We do not need to link the OBAN models to the hydrologic simulations, we can simply take their outputs and treat them as inputs.

Task 12 Simulate population trends with uncertainty: With hydrological and environmental variables in place, the OM can be used to predict population trends. The estimated parameter set from Task 4 exists not only as a set of maximum likelihood estimates, but also as a set of random draws from the joint posterior produced by MCMC simulations. Beyond simulating population trends under management alternatives, we can also predict the range of variability in those trends. By drawing parameter values randomly from the posteriors, we can simulate trends thousands of times and from a single set of environmental and hydrological inputs. A comparison of simulated trends across a range of alternative inputs provides a measure of relative performance of management alternatives. We will establish comparative measures of the performance of management options. These will involve tabulating population numbers, fishery yield and measures of water usage. The final evaluation of the performance of management options will depend on the priorities identified during the definition of the comparative measures.

Task 14: Population projection and recovery

A central goal is to determine how water management activities will affect the recovery of at-risk species. Management activities must be compared to quantitative criteria of recovery to reveal how effective each management action will be. Typical approaches to evaluating recovery include calculating the probability of extinction and the probability of delisting under different management actions (including no action). The multi-stock model and the parameter distributions from the retrospective analysis can be used to evaluate recovery goals. For each water use scenario, and for each assumed environmental input, a population trend can be simulated (for a given set of fishery management rules).

**** Tasks 13 and 15 Eliminated from proposal**

Task 14 Use multi-stock model to predict the long-term population trends. The model runs will look to optimize for population recovery under a variety of management inputs. The model will predict expected abundance by integrating across uncertainty. The result will be a probability that a given minimum target will be met.