Appendix 5.G

Fish Life Cycle Models

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Acronyms and Abbreviations

°F	degrees Fahrenheit
AIC_c	Akaike's Information Criterion for small sample sizes
Bay-Delta	San Francisco Bay/Sacramento–San Joaquin River Delta
BDCP	Bay Delta Conservation Plan
BDEDT	Bay-Delta Ecosystem Diagnosis and Treatment
BiOp	biological opinion
CALFED	CALFED Bay-Delta Program
CDFW	California Department of Fish and Wildlife
cfs	cubic feet per second
CPOP	Chinook salmon population model for the Sacramento River basin
CVI	Central Valley Index
CVP	Central Valley Project
DCC	Delta Cross Channel
DPM	Delta Passage Model
DRERIP	Delta Regional Ecosystem Restoration Implementation Plan
EBC	existing biological conditions
ELT	early long-term
ESO	evaluated starting operations
FMWT	fall midwater trawl
HOS	high-outflow scenario
IBM	Individual Based Model
IEP	Interagency Ecological Program
IOS	Interactive Object-Oriented Simulation
LLT	late long-term
LOS	low-outflow scenario
m	meters
MAR	multivariate statistical autoregressive modeling
NMFS	National Marine Fisheries Service
NPB	nonphysical barrier
NRC	National Resources Council
OBAN	Oncorhynchus Bayesian Analysis
RBDD	Red Bluff Diversion Dam
Reclamation	Bureau of Reclamation
RM	River Mile
SLAM	Species Life-cycle Analysis Module
SLH	State-dependent life history
SRWQM	Sacramento River Water Quality Model
SWP	State Water Project
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WQCP	Water Quality Control Plan
YOY	young-of-the-year

Appendix 5.G
Fish Life Cycle Models

5.G.1 Introduction

This appendix describes the selection and application of two models used to evaluate the potential population-level effects of Bay Delta Conservation Plan (BDCP) covered activities on covered fish species. The models used in this analysis are both referred to as *life cycle models.* Life cycle models are used to estimate population responses based on performance of each life stage of the target fish species.

A number of life cycle models have been developed for the Bay-Delta environment that are in wide use for alternatives analysis and decision support. Several of the available life cycle models were recommended for consideration in this analysis. Sixteen models were screened for their applicability based on whether and how these models parameterize relevant ecosystem variables. The selected life cycle models needed to incorporate ecosystem variables that are likely to be measurably affected by the BDCP and can be characterized as quantitative model inputs that are representative of key aspects of the BDCP conservation strategy (Chapter 3, Section 3.4, *Conservation Measures*). The majority of models screened for this analysis did not meet these criteria. After careful evaluation, the following life cycle models were selected for use in this analysis:

- Oncorhynchus Bayesian Analysis (OBAN) for winter-run Chinook salmon.
- Interactive Object-Oriented Simulation (IOS) Model for winter-run Chinook salmon.

By virtue of the way that they are constructed and the ecological variables they consider, each of these models is capable of capturing only some of the effects of the BDCP. Therefore, the model results presented in this appendix provide an incomplete picture of the potential population-level effects of the BDCP on winter-run Chinook salmon. The models are fundamentally constrained in that they are based on species–habitat relationships that have been established for the existing configuration of the San Francisco Bay/Sacramento–San Joaquin River Delta (Bay-Delta) and therefore do not incorporate the substantial changes in the landscape proposed to occur with proposed habitat restoration. This is a critical limitation because large-scale habitat restoration is a core component of the BDCP that is intended to produce significant ecological benefits. Nevertheless, the life cycle models provide an additional tool for assessing effects from certain aspects of the BDCP, specifically the effects of *CM 1 Water Facilities and Operations*. When interpreted appropriately in conjunction with the other technical analyses used to support the BDCP, the life cycle model results provide a useful line of evidence informing the analysis of net effects presented in Section 5.5.

The remainder of this appendix is organized as follows: Section 5.G.2, *Overview of Life Cycle Models* provides an overview of life cycle models and their applications, with specific reference to the Bay-Delta environment, Section 5.G.3, *Models Available and in Development* describes the life cycle models considered for use in this appendix, Section 5.G.4, *Selection of Life Cycle Models,* describes the screening methods used to select or reject each of the models considered. Section 5.G.5, *Methods,* describes the structure and statistical and computational methodologies used in the OBAN and IOS models and the analysis methods used in this appendix. Section 5.G.6, *Results*, describes the OBAN and IOS modeling results. Section 5.G.7, *Conclusions,* provides a summary discussion and conclusions about the findings of this analysis and the utility of the OBAN and IOS model results for evaluating the effects of the BDCP. Section 5.G.8, *References,* provides references for the literature cited in this appendix.

5.G.1.1 Overview of Life Cycle Models

Over the past four decades, there has been an extensive body of scientific monitoring, experimentation, and analysis of environmental conditions in the Bay-Delta estuary, as well as monitoring of trends in the relative abundance of various fish and macroinvertebrate species that inhabit the estuary. Life cycle modeling has developed as an analytic tool and framework that can be used to organize scientific data into meaningful analyses, identify hypotheses regarding the response of a species and life stage to various environmental conditions, and serve as a technical foundation for identifying management actions that contribute to population-level responses for fish species. Life cycle models also provide a basis for identifying mechanisms and correlations among a variety of biotic and abiotic factors (covariates) and their effect on the survival, growth, abundance, and reproductive success of a species, not just one life stage. The key to applying predictive models is to identify these significant covariates. The associated biological response of a species to one or more covariates provides the basis for predicting and evaluating the response of a species to environmental changes. This approach also enables the identification of covariates that have the greatest population-level influence on the health and abundance of a species.

Life cycle models also provide for the means to identify and refine future monitoring and data collection activities as well as a framework for analysis of data collected over a range of past and current environmental conditions. The ability of life cycle models to investigate the interaction and importance of a variety of environmental factors, and to identify those conditions that produce the greatest response for the target species, provides a basis for identifying and critically evaluating potential effects of various management actions on the overall population dynamics of a species.

The development of life cycle models in recent years has included quantitative analyses of the level of uncertainty that a given environmental condition or management action will result in a predictable response by the species. One of the strongest benefits of the application of life cycle models to assessing the potential response of a species to a set of conditions lies in the integration of biological linkages among life stages. Life cycle models are able to integrate multiple variables such as changes in rates of growth, survival, density-dependent responses, stock-recruitment relationships, and other biological mechanisms. Each variable may have an individual or synergistic effect on species abundance, the probability of recovery or extinction, cost-benefit of various management actions designed to improve habitat value and availability, reduction of sources of mortality, and increased growth and reproductive success of a species.

Life cycle models are an important tool to predict a response of a species to a suite of management actions such as those proposed in the BDCP, although the applied life cycle models (IOS and OBAN) do not capture many of the BDCP conservation measures. These models also can identify the level of certainty in those predictions. Life cycle models provide a transparent and proven framework that can be critically reviewed and evaluated, and rerun with different assumptions.

The application of life cycle models as an important tool for assessing and managing Bay-Delta fish has been recognized by state and federal resource agencies, in independent scientific reviews by CALFED and the NRC (Rose et al. 2011), by water agencies and environmental organizations, and in state and federal litigation. Based on results of these reviews, the models have been refined and improved. For example, sensitivity analyses have been performed on many of the underlying assumptions and relationships, which help to establish confidence in the level of accuracy of the results.

The primary focus of many of the life cycle models has been on winter-run Chinook salmon, fall-run Chinook salmon, and delta smelt. New models not available for use in this analysis are being developed to address spring-run Chinook salmon and longfin smelt, and alternative models and refinements are focused on delta smelt.

The two life cycle models used in this analysis have not been used to predict changes in abundance of the target covered fish species. This is because of the uncertainty in various relationships inherent in population life cycle modeling, the propagation of errors and uncertainty within the models, and because the available models do not capture all aspects of the BDCP, including those assumed to be beneficial at population levels (i.e., restoration) or all other aspects of the environment in which the fish exist. Rather, the model results are considered more appropriate for relative comparisons in the response of a population under two or more potential future conditions. The BDCP effects analysis uses life cycle models to provide relative comparisons among the effects of alternatives (e.g., direction and relative magnitude of anticipated population response). These results should therefore not be interpreted as predictions of changes in population abundance.

5.G.1.2 Models Available and in Development

The approach for developing a life cycle-based population model typically is framed by a qualitative conceptual model of how various environmental factors positively and negatively affect the survival, growth, or abundance of a given fish species and life stage. Qualitative conceptual models have been developed for several of fish species and associated ecological processes in the Delta, the majority of which are summarized in the Delta Regional Ecosystem Restoration Implementation Plan (DRERIP). The foundational conceptual models can vary widely in terms of their structure and organization. For example, the hierarchal delta smelt conceptual model developed by Miller et al. (2012) represents an alternative approach to identifying factors, mechanisms, and linkages that could affect population dynamics for fish species such as delta smelt. Many of the basic processes and mechanisms identified in the species-specific conceptual models form the basis for developing quantitative life cycle models.

A number of quantitative life cycle-based population models developed for Bay-Delta fish species, the majority of which fall into one of the following three general categories:

- **Mechanistic models** link studies and expert conclusions to create a causative model of the performance of a species in a defined environment. Survival between life stages is determined by specific mechanisms that are linked to create a hypothesis regarding how the system operates and responds to changes in the environment.
- **Statistical models** are based on observed statistical relationships between environmental conditions and species and/or life stage survival that may or may not reflect underlying biological mechanisms. These types of models define life stage survival by correlating a large number of habitat-specific, time-varying environmental covariates to indices of abundance or survival of individual life stages or the overall stock recruitment pattern. These models do not infer specific effect mechanisms between environmental parameters and survival. Environmental covariates are included or excluded from the final model based on their

statistical fit with historical data for species and life stage performance. Statistical relationships for individual life stages are then linked sequentially following a conceptual model to create of a life cycle model.

- **Dynamic programming models** consider how growth and variation in life histories of a species or life stage optimize fitness of the species over a wide range of potential environmental conditions.

These categories and the related models considered for use in this analysis are described in detail below. The models screened were fully functioning and readily available at the time of this analysis. Several other Bay-Delta life cycle models potentially useful for evaluating the BDCP are currently under development. Models were reviewed for their potential applicability are identified herein but are not described in detail because insufficient information was available.

5.G.1.3 Mechanistic Models

Mechanistic models track cohorts through space and time according to assumptions on survival and carrying capacity that are inferred from semi-deterministic relationships to environmental parameters. These models attempt to predict how variations in environmental properties of the habitats affect the survival among each life stage and ultimately population dynamics and abundance based on observed relationships between specific environmental parameters and survival. The models can be used to estimate how a population will respond to changes in the environment, under the assumption that none of the fundamental relationships between survival and the environmental variables will change under varying future conditions. For example, the life cycle model may reflect various life stages such as: spawner, egg, fry, multiple juvenile and smolt stages depending on rearing behavior (e.g., selection of river or Delta habitats), and ocean rearing. Each life stage has an initial abundance and based on survival functions, generates abundance estimates of entering the next life stage. Typically, functions describe the relationship between survival of fish life stages and habitat conditions. Different life stages may inhabit the same or different habitats and respond to a different set of environmental covariates.

Ten mechanistic life cycle models were considered for use in this analysis.

5.G.1.3.1 Shiraz

Shiraz uses a Beaverton-Holt mortality function in which life stage survival depends on specific relationships between environmental parameters (e.g., flow, temperature, sediment, riparian cover, road density) and survival. Each life stage has a carrying capacity that adjusts density-dependent survival. Maturation and spawning are set by coefficients allowing multiple spawning events. By relating habitat conditions and environmental covariates to survival, the model can be used to assess the relationship between actions or conditions and population dynamics. Measures are thus expressed in terms of an increase or decrease in life stage survival and carrying capacities, full life cycle or at specific life stages. Scheuerell et al. (2006) provided a general description of the application of the Shiraz model to assess conservation planning. The model has not been used extensively for covered fish inhabiting the Delta. There is no peer-reviewed application of the Shiraz model for conservation planning for Delta fish species.

5.G.1.3.2 Interactive Object-Oriented Simulation (IOS) Model

The IOS Model is used for comparing the relative impact of different flow, temperature, and water export scenarios on the winter-run Chinook salmon population. IOS is designed to compare relative survival rates under alternative operations and management scenarios. The model uses discrete life stages and migration routes of fish passing through the Delta using the Delta Passage Model (DPM), which contains significant relationships describing migration pathway selection and reach-specific smolt survival.

The IOS Model uses a systems dynamics modeling framework, a technique that is used for framing and understanding the behavior of complex systems over time (Costanza et al. 1998; Ford 1999). Survival and abundance estimates generated by IOS are not intended to predict future outcomes. Instead, IOS provides a simulation tool that can compare the effect of different water management options on winter-run Chinook salmon during different portions of their life cycle, with accompanying estimates of uncertainty. The IOS and DPM have been informally reviewed by state and federal resource agencies, water users, and the environmental community. A peer-reviewed account of IOS (and, by extension, DPM) and a sensitivity analysis of its parameters are provided by Zeug et al. (2012).

5.G.1.3.3 EACH

The EACH life cycle population model was developed as a mechanistic model of the San Joaquin River fall-run Chinook salmon population (EA Engineering, Science, and Technology 1991). The model used information on relationships between population metrics (e.g., juvenile salmon survival, adult escapement) and various environmental factors (e.g., river flow and temperature) as well as biological factors, such as spawner-recruit relationships, to estimate the effects of various factors on the salmon population. The model was developed using data collected primarily through the late 1980s. As a result of the complexity of the mechanisms and a lack of specific information to use in developing functional relationships, the model results were characterized by a high degree of uncertainty (EA Engineering, Science, and Technology 1991; Ligon pers. comm.). The EACH was informally reviewed by state and federal resource agencies, water users, and the environmental community, the application of EACH has not been formally peer reviewed or published in the scientific literature.

5.G.1.3.4 Chinook Salmon Population Model for the Sacramento River Basin (CPOP)

The Chinook salmon population model for the Sacramento River basin (CPOP) life cycle model was developed focusing on all four races of Chinook salmon inhabiting the Sacramento River. Like the EACH model, CPOP was constructed as a mechanistic model framework based on a conceptual model of the factors and processes that affect survival and abundance of Chinook salmon. The model then linked the abundance of salmon from one life stage to the next to assess population-level responses to environmental factors and sources of mortality. Development of many of the complex functional relationships within the model structure was hindered by a lack of information on factors such as sublethal temperature effects, abundance of young salmon, factors triggering migration, factors limiting juvenile rearing habitat, and survival of young salmon fry and smolts in the mainstem rivers and Delta and ocean rearing conditions and survival (Kimmerer et al. 2000). As a result of the complexity of the mechanisms and a lack of specific information to use in developing functional relationships, the model results were characterized by a high degree of uncertainty

(Kimmerer et al. 2000). The CPOP model has been informally reviewed by state and federal resource agencies, water users, and the environmental community. The application of CPOP has not been formally peer reviewed for published in the scientific literature, although Kimmerer et al. (2000) provide a discussion of the model development.

5.G.1.3.5 NMFS Central Valley Chinook Salmon Life Cycle Model

The National Marine Fisheries Service (NMFS) is developing a flexible life cycle model for Chinook salmon in the Central Valley of California, as described by Soykan et al. (2012). The model combines empirical data relating water temperature and flow levels to survival, with capacity estimates based on channel roughness, water depth, and velocity. These inputs are used to estimate life-stage- and river-reach-specific survival and capacity using a computational framework built on the R Statistical Software package. The initial versions of the model will focus on comparing salmon population dynamics given current, historical, and future scenarios (assuming BDCP-based changes in habitat and hydrology). Present limitations of the model include a lack of empirical data on survival and/or capacity for various life-stage/habitat-type combinations. Alternate methods are being explored to estimate these parameters, particularly fry survival in the Delta using modifications to the Particle Tracking Module of DSM-2. The flexible framework developed for the model means that new data (e.g., turbidity) and/or factors (e.g., hatchery fish) can be easily assimilated, and that diverse scenarios can be explored within a single modeling framework. However, even in its present form, the model provides a means to compare Chinook population dynamics under alternate scenarios and evaluate effects of specific management actions. The model formulation, structure, and assumptions are continuing to be developed and are not available for public review; the NMFS Central Valley Chinook Salmon Life Cycle Model has not been formally peer reviewed or published in the scientific literature.

5.G.1.3.6 California Department of Fish and Wildlife San Joaquin Fall-Run Chinook Salmon Population Model (SalSim and its Precursors)

The California Department of Fish and Wildlife (CDFW) (California Department of Fish and Game 2005) San Joaquin River Chinook salmon model evaluated various environmental covariates that have been identified as influencing abundance of adult fall-run Chinook salmon (escapement) in the San Joaquin River, such as ocean harvest, Delta exports and survival, abundance of spawners, and spring flow magnitude, duration and frequency. The statistical analysis showed that the non-flow-based parameters had little or no relationship to fall-run Chinook salmon abundance in the San Joaquin River, and that spring flow magnitude, duration, and frequency were a significant influence on San Joaquin River fall-run Chinook salmon abundance. The model used the significant relationship between Vernalis spring flow volume, duration, frequency, and the San Joaquin River fall-run Chinook salmon abundance to construct a simple regression-based spreadsheet San Joaquin River fall-run Chinook salmon population abundance prediction model. The model then was used to estimate the Vernalis spring flow objectives that could: (1) accomplish the 1995 Water Quality Control Plan (WQCP) Narrative Doubling Goal for fall-run Chinook salmon in the San Joaquin River (State Water Resources Control Board 1995); (2) improve the escaping salmon cohort replacement ratio; and (3) accomplish objectives 1 and 2 at the lowest water demand. The CDFW (California Department of Fish and Game 2005) model, a “simple salmon production model (V.1.0)” (Marston 2012), was first peer-reviewed in 2006. Preliminary model refinement and response to the peer review occurred in 2008, leading to intermediate versions of the model (V.1.5 and V.1.6). Advanced model refinement began in 2010.

Ongoing efforts to refine, revise, and, update the CDFW fall-run Chinook salmon model were presented to the State Water Resources Control Board in November 2012 during the third workshop of the Comprehensive Review of the 2006 *Water Quality Control Plan for the San Francisco Bay/Sacramento–San Joaquin Delta Estuary* (excluding San Joaquin River Flows and Southern Delta Salinity) - Water Quality Control Planning Phase (Marston 2012). Version 2.0 of the model is a full life cycle model called SalSim and includes inputs related to the south Delta, San Joaquin River, and tributary flows. Included in the model are eight modules, of which the Juvenile Delta Module is the most pertinent to potential BDCP effects in the Plan Area. The Juvenile Delta Module includes survival factors related to inflow to the Delta, water temperature entering the Delta, water export, striped bass abundance, and Head of Old River Barrier status. The SalSim model was peer-reviewed in 2012. Current work involves preparing a response to the peer review and finishing remaining tasks such as final computer programming, final model calibration/validation, and completion of model documentation. The SalSim life cycle model for San Joaquin River fall Chinook salmon is scheduled to be released in January 2013.

5.G.1.3.7 Individual-Based Delta Smelt Model

As part of a CALFED-funded project, Rose and others are in the process of developing an individual-based population life cycle model for delta smelt. The model tracks delta smelt through their life cycle on the same spatial grid as the DSM2 hydrodynamics model (Rose et al. 2012). Daily water temperature, salinity, and the densities of six zooplankton prey types are represented on the spatial grid. The model follows the reproduction, growth, mortality, and movement of individuals over their entire life cycle. Reproduction is evaluated daily and egg cohorts are tracked until hatching. New model individuals are introduced as individual yolk-sac larvae and tracked through a series of life stages. Growth of feeding stages is based on bioenergetics and zooplankton densities. Mortality includes a stage-specific constant rate, starvation, and entrainment. Movement of individuals is by particle tracking for the larval stages and behavioral algorithms for juveniles and adults. Simulations exploring the role of south Delta entrainment and food in the population decline were presented by Rose et al. (2012), who found that the effect of entrainment on simulated delta smelt population growth rate was between 50% of and equal to the effects of food, leading to the conclusion that both food and entrainment were important to the population decline of delta smelt. The model has been submitted for peer review, which is ongoing (Rose pers. comm.).

5.G.1.3.8 Bay-Delta Ecosystem Diagnosis & Treatment Model (BDEDT)

The Bay-Delta Ecosystem Diagnosis & Treatment model (BDEDT) is being developed to address habitat potential for delta smelt (Schwartz 2012). BDEDT is based on the Ecosystem Diagnosis & Treatment model framework that has been used previously in the Pacific Northwest and California, primarily for salmonids (Blair et al. 2009). EDT is a modeling framework to evaluate the potential of habitat to support fish species in terms of population performance. Habitat along multiple life-history pathways is evaluated in terms of a multiple-stage Beverton-Holt production model (Beverton and Holt 1957; Moussalli and Hilborn 1986) to produce spatially explicit estimates of fish population performance in terms of productivity, capacity, equilibrium abundance, and life history diversity. Habitat is evaluated in EDT along life history trajectories that evaluate life stage performance in different time-space strata with differing environmental conditions; life stage performance is then integrated across the life history to characterize habitat potential along that pathway. Population-level performance is computed by integrating performance from each successful trajectory. BDEDT uses the DSM2 network to define time-space strata (reaches) and potential life history pathways. This allows DSM2 data to be directly ported to BDEDT. The effect of habitat conditions along these pathways on productivity and capacity are evaluated by applying life-stage-specific rules to conditions in each reach, e.g., survival of delta smelt juveniles in relation to water temperature and density in tidal marsh habitat in Cache Slough. BDEDT compares alternative habitat conditions (i.e., management actions) in terms of limiting factors and performance of delta smelt life stages and the population. Such comparisons provide a basis for prioritizing restoration areas and actions and for tracking restoration progress. The model allows comparison of alternative life history configurations and variation. The BDEDT model has not been published or peer-reviewed. However, the EDT modeling has been extensively peer reviewed with respect to salmonids (Blair et al. 2009). An EDT model is being developed for spring-run Chinook to guide actions under the San Joaquin River Restoration Program.

5.G.1.3.9 Individual-Based Model for Longfin Smelt

Loboschefsky et al. (2012) presented information on the development of an individual-based population life-cycle model to integrate field and laboratory data into a quantitative measure of the impact of multiple stressors on longfin smelt population dynamics. Constitutive relationships utilized in the model for the egg and larval life-stages included movement and mortality. Eggs were modeled with low probabilities of movement (i.e., longfin smelt eggs typical adhere to a surface once laid) while larvae were assumed to be passively moving particles with their motions controlled by hydrodynamic forces. DSM2 was used as the hydrodynamic model to guide the transport of larvae. Mortality of eggs and larvae were modeled as functions of water temperature. Constitutive relationships utilized in the Individual Based Model (IBM) for the post-larval through the adult life-stages included movement, growth, mortality, and fecundity. Movement was modeled utilizing a two-dimensional biased Gaussian run and tumble approach, where the bias reflects habitat suitability (i.e., food availability, salinity, water temperature, and depth). Growth was modeled through a bioenergetics approach, life-stage specific mortality was modeled following decay rate expressions, and fecundity was modeled based upon empirical relationships between longfin smelt size and egg production. The model formulation, structure, and assumptions are continuing to be developed and are not available for public review. Consequently, the individual-based model for longfin smelt population dynamics (Loboschefsky et al. 2012) has not been formally peer reviewed or published in the scientific literature.

5.G.1.3.10 Splittail V5

Splittail V5 was described by Moyle et al. (2004) in a peer-reviewed publication and is a model based on the known life cycle of the splittail. The model assumes that the environmental conditions most strongly driving abundance are the amount and duration of flows in rivers in the February–May period because these flows affect success of spawning and rearing in the flooded areas of rivers tributary to the San Francisco Estuary. The basic structural relationships of the model represent a modified Leslie matrix formulation, based on age-size groups. The model allows changes to default parameter values to be made for vital attributes, behavioral switches, and rainfall-flood drivers. Examples of these include the probability that water on floodplains will be low, fraction of females spawning in a wet year, and surviving fraction of young-of-the-year (YOY) moving down the estuary in wet years. Losses of young-of-the-year and adult splittail in the model are implicit and do not specify mortality sources such as entrainment at the State Water Project (SWP)/Central Valley

Project (CVP) south Delta export facilities. Moyle et al. (2004) did not experiment with the model extensively but did note that a number of tentative conclusions were supported. These included the findings that very high population growth could result from conditions favoring spawning over multiple years, that the population appears to be able to persist through long droughts because of at least a few splittail spawning every year, and the relative insensitivity of the model to low survival rates used in the model. Moyle et al. (2004) suggested that the confidence in future use of the model could be improved by better measurements of various population parameters, including differences in survival between floodplains and river margins, as well as the degree of site fidelity in relation to reproduction and the need to model the population as discrete subpopulations. Moyle et al. (2004) noted that an application of the model to assess the consequences of the loss of young-of-the-year splittail to the south Delta export facilities, for example, would require the model to be sectored into spatial segments because presumably splittail from different watersheds (e.g., Sacramento River, San Joaquin River) would have different susceptibility to entrainment.

Agency review of earlier drafts of the BDCP effects analysis suggested that this model should have been used to investigate effects of the BDCP on the splittail population. However, as discussed below, the model is not considered appropriate for evaluating effects of specific covered activities, although the conclusions derived from results of the model and presented in the review paper provided useful information on splittail population biology that was used in considering certain general BDCP effects, such as risk of extinction (Section 5.5).

The Moyle et al. (2004) population model is designed to explore factors that limit the splittail population, based on current knowledge of the species. The model explores the effects of environmental factors by assuming that these factors influence splittail life cycle parameters, such as mortality rates and reproductive effort, and by investigating how changes in the life cycle parameters affect population abundance and structure. However, the effects of environmental factors on the actual values of these parameters are poorly known. As the authors state, "while the model can be made to simulate population dynamics that mimic the natural situation, actual numbers for mortality and survival rates are lacking for the most part, so it is hard to distinguish among various sources of mortality." This limitation, which simply reflects how little is known about splittail biology, limits the utility of the model for evaluating potential effects of implementing specific covered activities on the population.

A specific example helps illustrate the limitations of the splittail model for BDCP effects analysis. *CM2 Yolo Bypass Fisheries Enhancement*, has considerable potential to result in substantial increases of inundated floodplain habitat for splittail spawning and rearing of larvae and young juveniles. Based on historical observations, increases in spawning and rearing habitat would be expected to result in increased abundance of YOY splittail, but the specific quantitative relationship between habitat availability and splittail abundance is unknown. The splittail model includes several life cycle parameters that vary with water-year type, based on the understanding that availability of inundated floodplain habitat is related to water-year type. For instance, the model gives several parameters, such as reproductive effort and survival of YOY hatched on the floodplain, one of three values depending on which of three water-year types (dry, normal, wet) is selected (Moyle et al. 2004). However, the actual (or even approximate) values of these parameters for a given level of inundated floodplain availability, not to mention for a given water-year type, are unknown, so the model allows only a general exploration of potential effects. It is expected that both reproductive effort and YOY survival would take on higher values with implementation of CM2, which would lead to an increase in year class abundance, but such a gross effects analysis does not require use of a life cycle model.

5.G.1.4 Statistical Models

Statistical models (e.g., OBAN and various delta smelt models by Mac Nally et al. [2010]; Thomson et al. [2010]; Maunder and Deriso [2011]; and Miller et al. [2012]) are based on a statistically identified set of environmental covariates that provide the best explanation of historical population performance. These statistical relationships are then used to predict future population response to alteration of these covariates based on projected future conditions. Statistical models assume that covariant relationships between environmental variables and historical population performance will remained unchanged in the future. A total of six statistical life cycle models were considered for this analysis.

5.G.1.4.1 Oncorhynchus Bayesian Analysis (OBAN) Winter-Run and Spring-Run Chinook Salmon

OBAN is a statistical life cycle model based on a Beverton-Holt stock-recruitment function developed for all life stages of Sacramento River winter-run and Central Valley spring-run Chinook salmon. Separate model modules and covariate relationships have been developed for each species. OBAN defines the transition from one life stage to the next in terms of survival and carrying capacity. Unlike the mechanistic models, OBAN does not consider the timing of movement between stages or habitats. Survival and carrying capacity parameters are determined by a set of time-varying covariates that are statistically fitted to a Beverton-Holt stock-recruitment relationship using historical spawner and recruit data.

The OBAN model was among the life cycle models reviewed as part of the salmonid integrated model workshop. Rose et al. (2011) evaluated a number of life cycle models and offered recommendations and guidance on development of a salmonid life cycle model that could be used to assess and evaluate various alterative management or conservation strategies. The peer review panel comments did not focus on OBAN or other salmonid lifecycle models explicitly (e.g., IOS, OBAN, etc.) but rather provided general guidance to NMFS on the attributes of life cycle models that would be most useful in evaluating management actions (Rose et al. 2011). Therefore, while OBANs potential has not been formally peer reviewed or published in the scientific literature, it has gained acceptance as a potentially useful tool for characterizing winter-run and spring-run Chinook salmon population dynamics.

5.G.1.4.2 State-Space Multistage Delta Smelt Life Cycle Model (Maunder and Deriso 2011)

The delta smelt life cycle model developed by Maunder and Deriso (2011) is a state-space multistage model that includes consideration of density-dependent survival among life stages. In addition to density dependence, the model uses a set of environmental covariates to assess the differences in survival and population abundance of delta smelt. The model was developed by identifying a range of potential covariates and then ranking covariates two variables at a time to select that combination of environmental factors that produced the strongest predictions of impacts on the delta smelt population. Results of the model indicated that in addition to density-dependent survival, water temperature, food availability, and predators were identified as the most important factors affecting different life stages of delta smelt. These factors explained recent declining trends in delta smelt abundance and can be used to assess the expected response of the delta smelt population to environmental changes captured by the covariates included in the model. The model does not explicitly include management actions such as the restoration of intertidal or shallow subtidal habitat. The model formulation has been peer reviewed and published in the scientific literature (Maunder and Deriso 2011).

5.G.1.4.3 Multivariate Autoregressive Modeling (Mac Nally et al. 2010)

Mac Nally and coauthors (2010) developed a multivariate statistical autoregressive modeling (MAR) for four Delta pelagic fish species, including delta smelt and longfin smelt. The approach to developing the model was to assemble extensive datasets on various covariates that could then be analyzed statistically to assess relationships with indices of abundance for various life stages of the target fish species. Fifty-four relationships were tested, of which 28 were significantly related to the indices of abundance. The model was found to be robust regarding stock-recruitment relationships. The authors recommend that further refinement be done using a state-space construct for model development (e.g., Maunder and Deriso [2011]). The model is not truly a life cycle model but rather focuses on year to year changes in abundance at the same life stage (represented by fall midwater trawl [FMWT] abundance indices) explained by factors that could occur at various life stages during or between consecutive fall periods. The model has been formally peer reviewed and published in the scientific literature (Mac Nally et al. 2010)

5.G.1.4.4 Bayesian Change Point Model (Thomson et al. 2010)

Thomson and coauthors (2010) used a Bayesian change point statistic model to assess step changes in the indices of abundance for four Delta pelagic fish species, including delta smelt and longfin smelt. Results of Bayesian modeling and regression analysis were used to assess relationships between trends in fish abundance and environmental covariates to determine whether the changes in environmental covariates observed over the past 4 decades detected and accounted for observed changes in indices of fish abundance. Various abiotic variables such as water clarity, X2 position, and the volume of fresh water exported from the system were associated with changes in population indices in the early 2000s, but none statistically explained the trends in abundance after 2000. As with the MAR model (Mac Nally et al. 2010), the Bayesian change point model is not truly a life cycle model but rather examines changes affecting the same life stage (represented by FMWT abundance). The model has been formally peer reviewed and published in the scientific literature (Thomson et al. 2010).

5.G.1.4.5 Delta Smelt Survival Regression (Miller et al. 2012)

Miller et al. (2012) developed multiple regressions that examined statistical associations between survival of delta smelt from one life stage or generation to the next (fall-to-summer, summer-to-fall, and fall-to-fall) in relation to a suite of covariates. A conceptual model based on a hierarchy of effects was used to assemble several dozen biotic and abiotic data sets for covariates thought to have a plausible direct or indirect effect on delta smelt. The Multivariate Autoregressive Modeling and Bayesian Change Point Models of Mac Nally et al. (2010) and Thomson et al. (2010) also consider changes in delta smelt abundance from fall to fall. Miller et al.'s (2012) model of fall-to-fall survival found strong evidence for density dependence (as expressed by previous year's fall abundance and fall abundance from two years previous) and evidence that the density of delta smelt zooplankton prey were the most important environmental factors from 1972 to 2006 in determining delta smelt survival derived from indices of delta smelt abundance as reflected in various CDFW fishery surveys. The best-fit regression model for fall-to-summer survival included density-dependent terms (previous year's fall abundance and fall abundance from two years previous), two food covariates, and proportional entrainment at the south Delta export pumping plants. The best-fit regression model for summer-to-fall survival included abundance in July as a density-dependent term and a food covariate. As with other models based on the existing configuration of the Plan Area such as the state-space multistage delta smelt model (Maunder and Deriso 2011), the Miller et al. (2012) delta smelt statistical model does not explicitly include management actions such as the restoration of intertidal or shallow subtidal habitat. The model formulation has been peer reviewed and published in the scientific literature (Miller et al. 2012).

5.G.1.4.6 Hierarchical Spatial-Temporal Modeling of Delta Smelt Population Dynamics (Newman et al.)

Newman et al. (2012) presented information on a spatially explicit, hierarchical state-space model that is being formulated and fit to predict delta smelt population dynamics. The model is being developed primarily to provide resource managers a tool for assessing and predicting the effects of various management actions, particularly actions aimed at restoring the population, on the population dynamics. The model uses delta smelt catch data from various surveys (20-mm trawl, summer tow net, fall midwater trawl, Spring Kodiak trawl, Bay trawling, and Chipps Island trawling), data for other biota, and physical data from multiple sources in an integrated manner to estimate the parameters of the model. Management actions can be translated into changes in model input variables or covariates, which in turn affect model processes such as survival. Alternatively, management actions can be translated more directly as changes in a model process, e.g., survival is adjusted up or down by some specified amount. The tool is intended to be of direct relevance for quantitatively evaluating how different actions might affect the survival of delta smelt and potential for recovery. The model formulation, structure, and assumptions are continuing to be developed and are not available for public review. Consequently, the hierarchical spatial-temporal modeling of delta smelt population dynamics (Newman et al. 2012) has not been formally peer reviewed or published in the scientific literature.

5.G.1.5 Dynamic Programming Models

State-dependent life history (SLH) models offer a different framework from those of the other models reviewed (Satterthwaite et al. 2009, 2010). Instead of predicting survival under specified habitat conditions, SLH evaluates the fitness of steelhead in response to a range of alternative life history strategies (e.g., 1-year versus 2-year freshwater rearing, seasonal timing of migration, remaining resident in fresh water [rainbow trout] or anadromous with ocean rearing, etc.). SLH models address: (1) whether strategies currently displayed are optimal; (2) whether evolutionary changes are expected in response to the simulated environmental conditions; and (3) what evolutionary changes would be expected under future environmental conditions. Life stage variations (smolts, residents) are evaluated based on growth trajectories. The model simulates life history strategies that provide optimum fitness. Dynamic programming life cycle models have not been used extensively for Bay-Delta covered fish species but have been applied in peer-reviewed, published studies elsewhere in California (steelhead in the American/Mokelumne Rivers and central California) (Satterthwaite et al. 2009, 2010).

5.G.1.6 Selection of Life Cycle Models

The various life cycle models described in the previous section were evaluated for their potential utility for characterizing the effects of the BDCP on covered fish species. The results of the independent scientific review of Bay-Delta fishery life cycle models (Rose et al. 2011; others) provided useful guidance and criteria for evaluating and selecting appropriate models for use in this analysis. Table 5.G-1 provides a summary of life cycle models considered in relation to key relevant criteria determining their applicability. These criteria include a model framework that allows for useful characterization of the Plan Area, inclusion of environmental covariates affected or potentially affected by the BDCP, and status and availability of the model at the time of this analysis (i.e., whether completed or not).

On the basis of this screening procedure, the IOS winter-run Chinook salmon and its associated Delta Passage Model (DPM) component, and the OBAN winter-run Chinook salmon life cycle models were selected for use in this analysis. The remaining models were excluded for a variety of reasons. Some (EACH, CPOP) were out of date and therefore not relevant or inconsistent with new information. Several models were duplicative, incomplete or currently in review and unavailable (e.g., Newman et al. delta smelt model, delta smelt individual-based model, CDFW San Joaquin River Fall-Run Chinook salmon population model, NMFS Central Valley salmonid life-cycle model). Some models were rejected because they required inputs that cannot be characterized with certainty, such as the various delta smelt statistical models (Mac Nally et al. 2010; Thomson et al. 2010; Maunder and Deriso 2011; Miller et al. 2012) that have significant uncertainty for inputs describing food availability.

Some or all of the rejected models may be completed or modified for applicability in the future. Should these models become available within a suitable time frame they could be incorporated into subsequent iterations of the BDCP effects analysis.

Additional details on the structure, assumptions, analytical approach, and results of the effects analysis by the IOS and OBAN life cycle models are presented below.

Table 5.G-1. Fish Life Cycle Models Considered for Selection for BDCP Effects Analysis

Model	Covered Fish Species Addressed	Includes Plan Area?	Includes Study Area?	Includes Covariates that BDCP May Affect?	Completed/ Available?	Peer-Reviewed?	Key Reference(s)	Selected for BDCP Effects Analysis (If not, why)?
Mechanistic Models								
SHIRAZ	Chinook salmon	No	No	Yes	Not for BDCP covered species	Yes	Scheuerell et al. 2006	No (Not yet developed for Central Valley salmonids)
Interactive Object-Oriented Simulation (IOS) Model	Winter-run Chinook salmon	Yes	Yes	Yes	Yes	Yes	Zeug et al. 2012	Yes
EACH	Chinook salmon (San Joaquin River fall-run)	Yes	Yes	Yes	Yes	No, only informal review	EA Engineering, Science, and Technology 1991	No (Complex mechanisms, much uncertainty, based on old data, superseded by other models)
Chinook salmon population model for the Sacramento River basin (CPOP)	Winter-run, spring-run, fall-run, and late fall–run Chinook salmon	Yes	Yes	Yes	Yes	No	Kimmerer et al. 2000	No (Complex mechanisms, lack of specific information to use in developing functional relationships, results characterized by high uncertainty)
NMFS Central Valley Chinook Salmon Life Cycle Model	Winter-run, spring-run, fall-run, and late fall–run Chinook salmon	Yes	Yes	Yes	No	No	Soykan et al. 2012	No (Not yet complete)
California Department of Fish and Wildlife San Joaquin Fall-Run Chinook Salmon Population Model (SalSim)	Chinook salmon (San Joaquin River fall-run)	Yes	Yes	Yes	Yes	Yes	California Department of Fish and Game 2005; Marston 2012	No (Not yet complete)
Individual-Based Model for Delta Smelt	Delta smelt	Yes	Yes	Yes	No	In review	Rose et al. 2012	No (Not yet complete)
Bay-Delta Ecosystem Diagnosis and Treatment	Delta smelt	Yes	Yes	Yes	No	No	Schwartz 2012; Blair et al. 2009	No (Not yet complete)
Individual-Based Model for Longfin Smelt	Longfin smelt	Yes	Yes	Yes	No	No	Loboschefsky et al. 2012	No (Not yet complete)
Splittail V5	Sacramento Splittail	Yes	Yes	Yes	Yes	Yes	Moyle et al. 2004	No (Lack of specificity in covariates [e.g., mortality], spatial segmentation necessary to capture entrainment effects, little information available on proportional entrainment, and need to refine model to account for differences in floodplain inundation)
Statistical Models								
Oncorhynchus Bayesian Analysis (OBAN)	Winter-run and spring-run Chinook salmon	Yes	Yes	Yes	Yes	No, only informal review	Hendrix 2008	Yes for winter-run Chinook salmon (spring-run Chinook salmon model includes ocean covariates that are not affected by BDCP or for which there is a lack of information on changes related to BDCP, i.e., striped bass catch-per-unit-effort)
State-Space Multistage Delta Smelt Life Cycle Model	Delta smelt	Yes	Yes	Yes	Yes	Yes	Maunder and Deriso 2011	No (Lack of information to develop model inputs for factors such as zooplankton abundance)
Multivariate Autoregressive Model	Delta smelt and longfin smelt	Yes	Yes	Yes	Yes	Yes	Mac Nally et al. 2010	No (Lack of information to develop model inputs for factors such as zooplankton abundance)
Bayesian Change Point Model	Delta smelt and longfin smelt	Yes	Yes	Yes	Yes	Yes	Thomson et al. 2010	No (Lack of information to develop model inputs for factors such as zooplankton abundance)
Delta Smelt Survival Regression	Delta Smelt	Yes	Yes	Yes	Yes	Yes	Miller et al. 2012	No (Lack of information to develop model inputs for factors such as zooplankton abundance)
Hierarchical Spatial-Temporal Modeling of Delta Smelt Population Dynamics	Delta smelt	Yes	Yes	Yes	No	No	Newman et al. 2012	No (Not yet complete)
Dynamic Programming Models								
State-Dependent Life-History Models	Steelhead	No	Yes	Yes	Yes	Yes	Satterthwaite et al. 2009, 2010	No (not best suited for effects analysis, outcome may not be most informative for management purposes)

5.G.2 Methods

The following sections describe the underlying computational methodologies used in the OBAN and IOS models, and the specific model outputs developed for the purpose of this analysis.

5.G.2.1 Model Scenarios

A common set of BDCP operational scenarios was used in both the OBAN and IOS modeling analyses. These are summarized in Table 5.G-2. Comparisons were made between the existing biological conditions 2 (EBC2), the ESO, HOS, and LOS scenario in the early long-term (ELT) and late long-term (LLT).

Each of these scenarios incorporates the projected beneficial effects of *CM2 Yolo Bypass Fisheries Enhancement*. Four additional ESO scenarios were developed to consider the effects of two specific project elements over the ELT and LLT time frames: the beneficial effects of *CM 16 Nonphysical Barriers* on juvenile survival; and the detrimental effects of juvenile entrainment at the North Delta Intakes.

As noted previously, these scenarios do not consider several of the BDCP conservation measures, including the broad scale effects of *CM4 Tidal Natural Communities Restoration* and *CM 5 Seasonally Inundated Floodplain Restoration*.

Modeling scenarios were compared in terms of IOS and OBAN abundance predictions over each time interval as well as the predicted survival rates during individual life stages. Life-stage survival rates in the upper Sacramento River where spawning, incubation and early rearing occurs, and during juvenile passage through the Delta (through-Delta survival) provide useful metrics for a relative comparison of the potential effects of each scenario.

Table 5.G-2. Analytical Conditions of the Modeled Scenarios

Condition		Description
Existing Biological Conditions	EBC1	Current operations, based on the USFWS (2008) and NMFS (2009) BiOps, excluding management of outflows to achieve the Fall X2 provisions of the USFWS (2008) BiOp.
	EBC2	Current operations based on the USFWS (2008) and NMFS (2009) BiOps, including management of outflows to achieve the Fall X2 provisions of the USFWS (2008) BiOp.
Projected Future Conditions without the BDCP	EBC2_ELT	EBC2 projected into year 15 (2025) accounting for climate change conditions expected at that time.
	EBC2_LLT	EBC2 projected into year 50 (2060) accounting for climate changes conditions expected at that time.
Projected Future Conditions with the BDCP[a]	ESO_ELT	Evaluated staring operations in year 15; assumes the new intake facility is operational but restoration actions are not fully implemented.
	ESO_LLT	Evaluated staring operations in year 50; assumes the new intake facility is operational and restoration actions are fully implemented.
	HOS_ELT	High-outflow operations (high-outflow outcomes of decision tree for management of spring and fall outflow) in year 15; assumes the new intake facility is operational but restoration actions are not fully implemented.
	HOS_LLT	High-outflow operations (high-outflow outcomes of decision tree for management of spring and fall outflow) in year 50; assumes the new intake facility is operational and restoration actions are fully implemented.
	LOS_ELT	Low-outflow operations (low-outflow outcomes of decision tree for management of spring and fall outflow) in year 15; assumes the new intake facility is operational but restoration actions are not fully implemented.
	LOS_ELT	Low-outflow operations (low-outflow outcomes of decision tree for management of spring and fall outflow) in year 50; assumes the new intake facility is operational and restoration actions are fully implemented.
	ESO_33_ELT[b]	Evaluated starting operations in year 15 incorporating the effects of *CM 16 Nonphysical Barriers*; assumes that 67% of migrating juvenile salmonids that would otherwise enter the Georgiana Slough are directed down a more favorable survival pathway (IOS only).
	ESO_33_LLT[b]	Evaluated starting operations in year 50 incorporating the effects of *CM 16 Nonphysical Barriers*; assumes that 67% of migrating juvenile salmonids that would otherwise enter the Georgiana Slough are directed down a more favorable survival pathway (IOS only).
	ESO_95_LLT[b]	Evaluated starting operations in year 15 incorporating an assumed 5% mortality rate for juvenile salmonids passing the North Delta Intakes (IOS only).
	ESO_95_LLT[b]	Evaluated starting operations in year 50 incorporating an assumed 5% mortality rate for juvenile salmonids passing the North Delta Intakes (IOS only).

[a] The decision-tree process, described in Section 3.4.1.4.4, *Decisions Trees*, provides a mechanism for selection of one of four potential operational outcomes for *CM1 Water Facilities and Operation*: evaluated starting operations, high outflow scenario, low outflow scenario.

[b] The ESO_33 and ESO_95 scenarios are used only in the IOS sensitivity analysis.

USFWS = U.S. Fish and Wildlife Service.

NMFS = National Marine Fisheries Service.

BiOp = biological opinion.

5.G.2.2 Oncorhynchus Bayesian Analysis (OBAN) Model (Winter-Run Chinook Salmon)

OBAN is a model that uses statistical relationships between historical patterns in winter-run Chinook salmon abundance and a number of other parameters that covary with abundance to predict future population abundance. The model was developed by first determining which of a suite of parameters (e.g., water temperature, harvest, exports, striped bass abundance, offshore upwelling) covaried with historical abundance data. The set of parameters, called covariates, that provided the best model fit was retained for the full model. The model then uses predicted future values of these parameters, primarily from CALSIM and Sacramento River Water Quality Model (SRWQM) outputs, to predict future patterns in Chinook salmon population abundance. The OBAN model incorporates uncertainty by estimating the influence of covariates on population abundance in a Bayesian estimation framework. The uncertainty then is incorporated into model output through Monte Carlo simulations (1,000 simulations per model run). The OBAN model was among the life cycle models reviewed as part of the salmonid integrated model workshop (Rose et al. 2011) which evaluated a number of life cycle models and offered a set of recommendations and guidance on development of a salmonid life cycle model that could be used to assess and evaluate various alterative management strategies for the Bay-Delta. The peer review panel offered a number of suggestions on the formulation of a life cycle salmonid model that could be used effectively to identify and evaluate alternative management actions or conservation strategies. The peer review panel comments did not focus on OBAN or other salmonid life cycle models explicitly (e.g., IOS, OBAN, etc.) but rather provided general guidance to NMFS on the attributes of life cycle models that would be most useful in evaluating management actions (Rose et al. 2011).

Specifically, the OBAN model:

- Estimates model coefficients by fitting predictions of the population dynamics model to observed indices of abundance.
- Evaluates the importance of covariates that may explain dynamic vital rates (e.g., the influence of thermal mortality in reducing alevin survival rates in spawning reaches).
- Accounts for mortality during all phases of the Chinook salmon life history, including environmental and anthropogenic factors.
- Incorporates uncertainty in the estimation of model coefficients by fitting in a Bayesian framework.

An OBAN model is also available for spring-run Chinook salmon. The covariates in the model include striped bass catch-per-unit efforts of adult striped bass (which affects Delta survival of juveniles); average wind stress curl, a measure of coastal productivity (which affects survival of juveniles in the ocean); and average April–June sea level height (which also affects ocean survival of juveniles). Because these covariates either are not affected by the BDCP (curl and sea level height) or may be affected by the BDCP but in unpredictable ways (e.g., striped bass catch-per-unit-effort), the spring-run OBAN model was not included in the BDCP effects analysis.

5.G.2.2.1 Model Structure

The winter-run Chinook salmon OBAN model is composed of several life history stages (Figure 5.G-1).

- Alevin—incubation in the gravel below Keswick Dam.
- Fry—rearing above Red Bluff Diversion Dam (RBDD).
- Delta—from RBDD to Chipps Island.
- Bay—from Chipps Island to the Golden Gate.
- Gulf of Farallones.
- Ocean 1—first year in the ocean, returning to spawn as 2-year-olds.
- Ocean 2—second year in the ocean, returning to spawn as 3-year-olds.
- Ocean 3—third and final year in the ocean, returning to spawn as 4-year-olds.
- Escapement—composed of all spawners on the spawning ground.

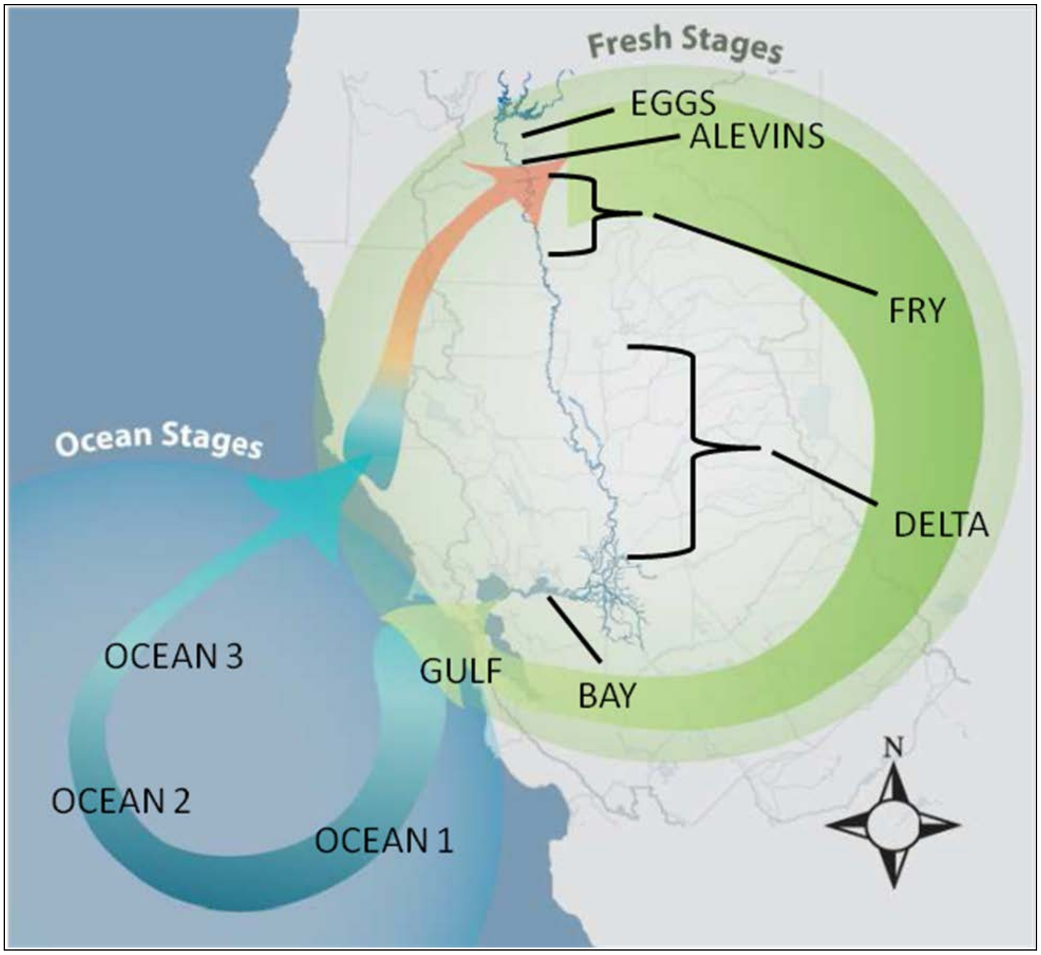


Figure 5.G-1. Winter-Run Chinook Salmon Life History Stages Used in the OBAN Model

The winter-run Chinook salmon OBAN model has been developed from the conceptual life cycle model of winter-run and coded into Windows-based software with graphic output capability. The Bayesian estimation of model coefficients was coded into WinBUGS (Spiegelhalter et al. 2002). The software finds a statistical “best fit” to empirical trends by matching model predictions to empirically observed juvenile and adult abundances. The model is capable of fitting any number of abundance data sources and estimating any number of coefficient values to find the best statistical prediction.

The transition between life history stages occurs with a Beverton-Holt recruitment function:

$$N_{i,j+1} = N_{i,j} \times \frac{p_{i,j}}{1 + \frac{p_{i,j} N_{i,j}}{K_{i,j}}}$$

where $N_{i,j}$ is the abundance for spawning stock i at life history stage j, $p_{i,j}$ is the productivity in the absence of density dependence for spawning stock i at stage j, $K_{i,j}$ is the carrying capacity for spawning stock i at stage j.

Only one spawning stock is assumed for the winter-run model. The two parameters of the Beverton-Holt transition equation are $p_{i,j}$ and $K_{i,j}$, which can be user-defined constants, estimated parameters fixed across all years, or dynamic, i.e., $p_{i,j,t}$ and $K_{i,j,t}$ can be modeled as changing in each year t. Note that density dependence can be effectively removed from the formulation by setting $K_{i,j}$ to a very large value relative to $p_{i,j}$ and $N_{i,j}$.

In the case of dynamic productivity ($p_{i,j,t}$) and capacity ($K_{i,j,t}$), parameter values, the values of the productivities and capacities in a given year, are modeled from a set of time-varying covariates. By using this formulation, the influence of anthropogenic and environmental factors on specific life history stages was evaluated. Each productivity parameter can be influenced by independent covariates acting simultaneously on the life history stage to drive demographic rates. The $X_{j,t}$ are environmental variables that represent water conditions such as temperature or flow, biotic factors such as predator abundance and food abundance, or anthropogenic factors such as water export levels or harvest rates.

The dynamic productivities use a logit transformation, which causes the productivities to remain between 0 and 1. This interval is the sample space for the survival of all stages from alevin to spawner:

$$\operatorname{logit}(p_{i,j,t}) = \beta_{0,i,j} + \beta_{1,i,j} X_{1,i,t} + \beta_{2,i,j} X_{2,i,t} + \cdots + \beta_{5,i,j} X_{5,i,t}$$

$$p_{i,j,t} = \frac{\exp(\beta_{0,i,j} + \beta_{1,i,j} X_{1,i,t} + \beta_{2,i,j} X_{2,i,t} + \cdots + \beta_{5,i,j} X_{5,i,t})}{1 + \exp(\beta_{0,i,j} + \beta_{1,i,j} X_{1,i,t} + \beta_{2,i,j} X_{2,i,t} + \cdots + \beta_{5,i,j} X_{5,i,t})}$$

The dynamic capacities uses a log transformation, which causes the capacities to remain between 0 and infinity. This interval is the sample space for the abundance for all stages from alevin to spawner:

$$\ln(K_{i,j,t}) = \beta_{0,i,j} + \beta_{1,i,j} X_{1,i,t} + \beta_{2,i,j} X_{2,i,t} + \cdots + \beta_{5,i,j} X_{5,i,t}$$

The estimation of $p_{i,j,t}$ and $K_{i,j,t}$ involves estimating the β parameters. If no environmental effect is being estimated, only β_0 is estimated and the remaining β values are set to 0. If $p_{i,j}$ and $K_{i,j}$ are not estimated, but rather set as constants, then β_0 is selected such that p or K equates to the desired rate, i.e., $\beta_0 = \ln(p/(1-p))$ or $\beta_0 = \ln(K)$.

The model has the ability to estimate as few or as many of the parameters as desired. The Akaike Information Criterion (AIC) (Burnham and Anderson 2002) was applied to evaluate the utility of adding additional parameters evaluating model complexity in a maximum likelihood framework. Estimating a fixed rate involves one additional parameter (β_0), and estimating relationships to a covariate involves adding a β parameter for each additional covariate.

5.G.2.2.2 Time Step

OBAN operates at an annual time step. Model inputs (covariates) are composed of daily, weekly, or monthly values. To fit within the annual time step for OBAN model outputs, some manipulation of the CALSIM outputs (for YOLO, FLMIN, and EXPT [see explanation under *Covariates*]) and SRWQM output (for STEMP) is required. These metrics are effectively converted from daily, weekly, or monthly covariate values into annual values that then are used in the model at the annual time step. Although extreme values of some covariates (e.g., flow, water temperature, and exports) are lost by averaging the data at a larger time step, the relationships between these covariates and population size were developed using this time step during model development and, therefore, should still reflect their biological significance.

5.G.2.2.3 Model Inputs

Data on the distribution of winter-run spawners are available through carcass surveys that have been conducted since 1996 (Snider et al. 1997; Snider et al. 1998; Snider et al. 1999; Snider et al. 2000; Snider et al. 2001; Snider et al. 2002; U.S. Fish and Wildlife Service 2007). Age and gender of spawning winter-run Chinook salmon are provided by carcass surveys for fish that spawn above River Mile (RM) 275 (California Department of Fish and Game 2004). Aerial redd surveys have been conducted that provide an assessment of the distribution of redds below RBDD (California Department of Fish and Game 2004). Counts at RBDD have been used to estimate winter-run escapement since 1967; however, since 2001, annual escapement estimates have been calculated using a Jolly-Seber estimator derived from carcass count data (California Department of Fish and Game 2004). Despite some changes in operations of RBDD that affect the precision of spawner escapement estimates (Botsford and Brittnacher 1998), RBDD counts provide a continuous time series of winter-run estimates. Prior to 1987, all returning spawners passed via a counting ladder at RBDD, but, from 1987 onward, the gates of the diversion dam have been opened to enhance upstream survival of winter-run Chinook salmon and likely improve access to areas above RBDD. The current operation of RBDD makes counts of winter-run Chinook salmon after closing the gates on May 15. On average, 15% of the winter run passed RBDD by May 15, but the specific percentage in a given year was as low as 3% or as high as 48% (Snider et al. 2000). Egg abundance is calculated by assuming that each adult spawner produces 2,000 eggs (Williams 2006).

Juvenile production indices taken from Poytress (2007) were used for 1995 through 1999 and 2002 through 2007. Maturation rates were taken from an analysis of 1998, 1999, and 2000 coded wire tag data (Grover et al. 2004).

CALSIM and SRWQM modeling outputs were used to provide predicted physical conditions for OBAN under each model scenario. The parameters from each model are described further under *Modeling Process*.

5.G.2.2.4 Covariates

Through maximum likelihood and Bayesian estimation to minimize deviations between predicted and observed winter-run Chinook salmon abundance estimates, the following covariates were retained in the model, and their coefficients were estimated:

- **STEMP:** July through September mean daily water temperature (degrees Fahrenheit [°F]) in the Sacramento River at Bend Bridge. This covariate affects survival of the alevin life history stage.
- **FLMIN:** August through November minimum monthly flow rate (cubic feet per second [cfs]) in the Sacramento River at Bend Bridge (U.S. Geological Survey [USGS] Gage 11377100 data). This covariate affects survival of the fry life history stage.
- **EXPT:** Total water exports in the south Delta (CVP and SWP) during December through June, derived by taking average daily export rate (cfs), multiplying by the number of days in the month, and then summing over December–June (Interagency Ecological Program [IEP] Dayflow data). This covariate affects survival in the Delta life history stage.
- **YOLO:** Number of days during December through March with minimum flows of 100 cfs over the Fremont Weir (December of the brood year and January–March of the year following) (Bureau of Reclamation data). The 100 cfs minimum flow threshold was chosen to distinguish days with an actual inundation event from the rest of the days with year-round 100 cfs flows into the bypass to maintain positive flows for adult fish passage under the ESO. Although this flow rate is much lower than the flow rate needed for juveniles salmonids to gain survival benefits in the Yolo Bypass (~4,000 cfs) (Sommer pers. comm.), the parameter used to fit the data is number of days of flooding, and not flow rate during flooding. This covariate affects survival in the Delta life history stage.
- **DCC:** Proportion of time (days per year) that the Delta Cross Channel (DCC) gates were open between December and March (December of the brood year and January–March of the year following) (Bureau of Reclamation data). This covariate affects survival in the Delta life history stage.
- **CURL:** a wind stress curl index that is correlated with coastal productivity off California (Chelton 1982) (Pascals per meter) (Pacific Fisheries Environmental Laboratory, Pacific Grove data). Persistent longshore equatorward wind stress during spring and summer forces surface waters offshore via Eckman transport drawing nutrient-rich water to the euphotic zone to replace surface waters pushed offshore (Rykaczewski and Checkley 2008). Once nutrient-rich water reaches the euphotic zone, primary productivity increases. Positive effects of the CURL index on Chinook salmon growth and maturation have been observed (Wells et al. 2007). This covariate affects survival in the Gulf life history stage.

Harvest: Ocean harvest of Ocean 2 and Ocean 3 individuals (Ocean 1 are assumed to be too small to be vulnerable to the fishery) as the proportion of the total Ocean 2 and Ocean 3 individuals available for harvest. The harvest rate index was constructed by using the CDFW ocean and recreational fishing regulations. Until 1987, there was little regulation of the Central Valley Chinook salmon fishery and estimates of the mortality rate on winter-run Chinook salmon in the ocean fishery were approximately 0.7 of the mortality rate experienced by fall-run Chinook salmon. The harvest rate of fall-run Chinook salmon is calculated annually as the Central Valley Index (CVI) by calculating the proportion of the fall run that were captured in the fishery (harvested/(harvested + escaped)). In 1989, winter-run Chinook salmon were listed as threatened, and the following year the ocean fishery regulations were shifted to open 2 weeks later (National Marine Fisheries Service 1997). It was assumed that this had an effect on the winter-run harvest mortality and reduced the impact to 0.5 of the CVI. In 1994, winter-run were listed as endangered, and in 1997, a biological opinion (BiOp) was released by NMFS (1997) initiating a delayed opening of the ocean fishery from mid-March to mid-April and eventually to late April in 2001. Using coded wire tagged winter-run Chinook salmon from 1998 through 2000 cohorts, Grover and coauthors (2004) estimated ocean harvest rates of 0.22. The effect of the fishery, however, is not the same for Ocean 2 and Ocean 3 stages. The rates described above were generated for the Ocean 2 stage.

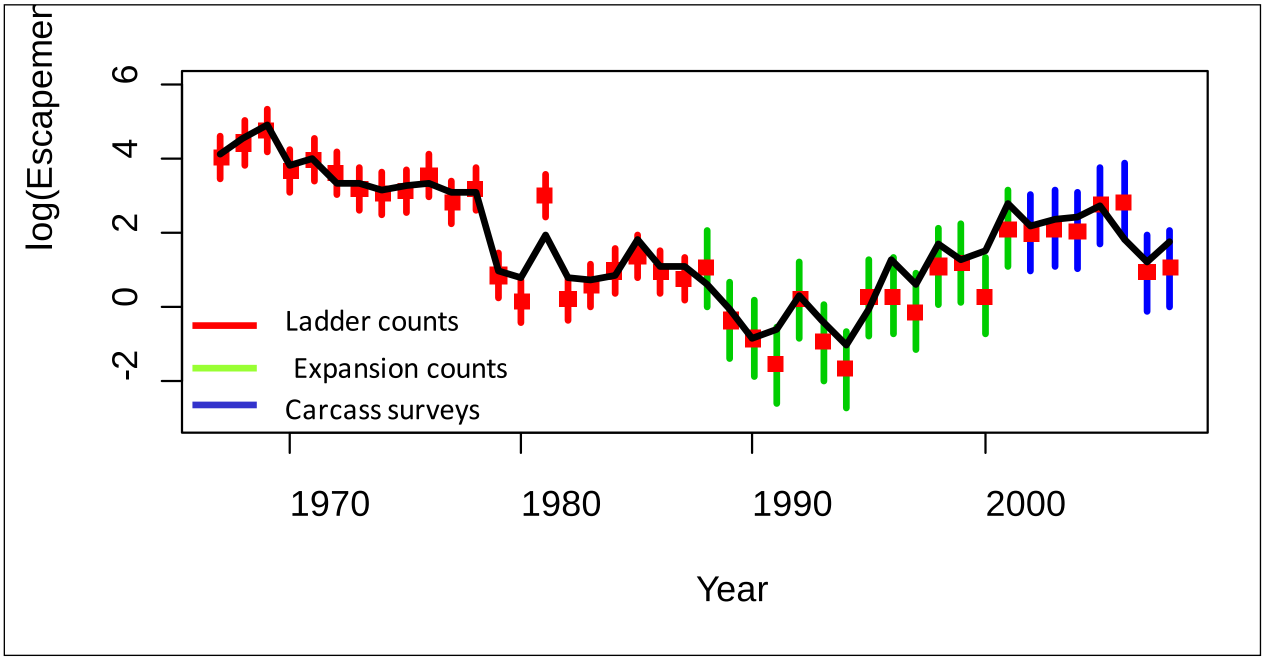
Ocean 2 and Ocean 3 fish are not captured at the same rate. Most winter-run Chinook salmon return to spawn as 3-year-olds (after the Ocean 2 stage); however, Ocean 3 fish are more likely to be captured in the commercial fishery because of their larger size. Grover and coauthors (2004) found that harvest-related mortality of Ocean 3 winter-run Chinook salmon was 2.5 to 3.7 times the rate of Ocean 2 fish. For OBAN, it assumed that the harvest rates experienced by Ocean 3 stage winter-run were 2.7 times the harvest rates experienced by Ocean 2 stage. To ensure that harvest rate could not surpass 1, a logistic regression approach was used to incorporate harvest rate.

Harvest also occurs in the Sacramento River, and the best available published rates were used. Between 1967 and 1975, estimates of winter-run harvest in the recreational river fishery varied from 0.04 to 0.14 (Hallock and Fisher 1985). For OBAN, it was assumed that the in-river fishery harvest rates were 0.09 from 1975 to 1982, which was the average of the Hallock and Fisher (1985) estimates. NMFS (1997) published in-river harvest rates from 1983 to 1990 that varied between 0.013 and 0.087. For OBAN, it was assumed that the in-river harvest was constant at 0.05 from 1991 to 2007. The 0.05 river harvest rate was used in combination with the 0.22 ocean harvest rate to equal the average harvest impact rate identified by Grover and coauthors (2004) for the 1998, 1999, and 2000 cohorts.

Figure 5.G-2 shows the mean prediction of winter-run escapement. All predicted values were within the range of survey error with the exception of 1981.

Additional covariates that were analyzed but not used in the full model because of weak relationships with winter-run population size include those following.

- **FLMAX:** Maximum monthly average flow (cfs) during August through November in the Sacramento River at Bend Bridge (USGS Gage 11377100 data).
- **BASS:** Catch per unit vessel of adult striped bass via recreational party boat surveys (CDFW data).
- **SLH:** Average April to June sea level height (meters [m]) at Presidio (University of Hawaii Sea Level Center, San Francisco data).
- **UPW:** Upwelling at the Gulf of Farallones from April to June (Pacific Fisheries Environmental Laboratory, Pacific Grove data).
- **PDO:** Pacific Decadal Oscillation index from October to March of the following year (University of Washington, Joint Institute for the Study of the Atmosphere and Ocean data).
- **SST:** Sea surface temperature from July to February of the following year (°C) (Scripps Institute of Oceanography data).



Horizontal bars indicate the measurement error in each of the three survey types.

Figure 5.G-2. Mean Prediction (Black Line) of Winter-Run OBAN Model to Winter-Run Escapement Data, Which Was Collected Via Ladder Counts, Expansion Counts, and Carcass Surveys

5.G.2.2.5 Modeling Process

To simulate winter-run Chinook salmon population dynamics under each of the model scenarios, predicted covariate data were required for each model scenario. These covariates were produced for each model scenario through flow (CALSIM) and water quality models (SRWQM). Harvest rate and CURL do not differ between model scenarios. In addition, DCC position does not differ between model scenarios because gates remain closed during the entire December to March period of winter-run Chinook salmon presence in the Delta. All covariates were normalized by subtracting the mean and dividing by the standard deviation of empirical data used to fit OBAN to empirical population data.

Figure 5.G-3 through Figure 5.G-8 present input conditions to OBAN that were derived from other models for a series of historical water-year conditions.

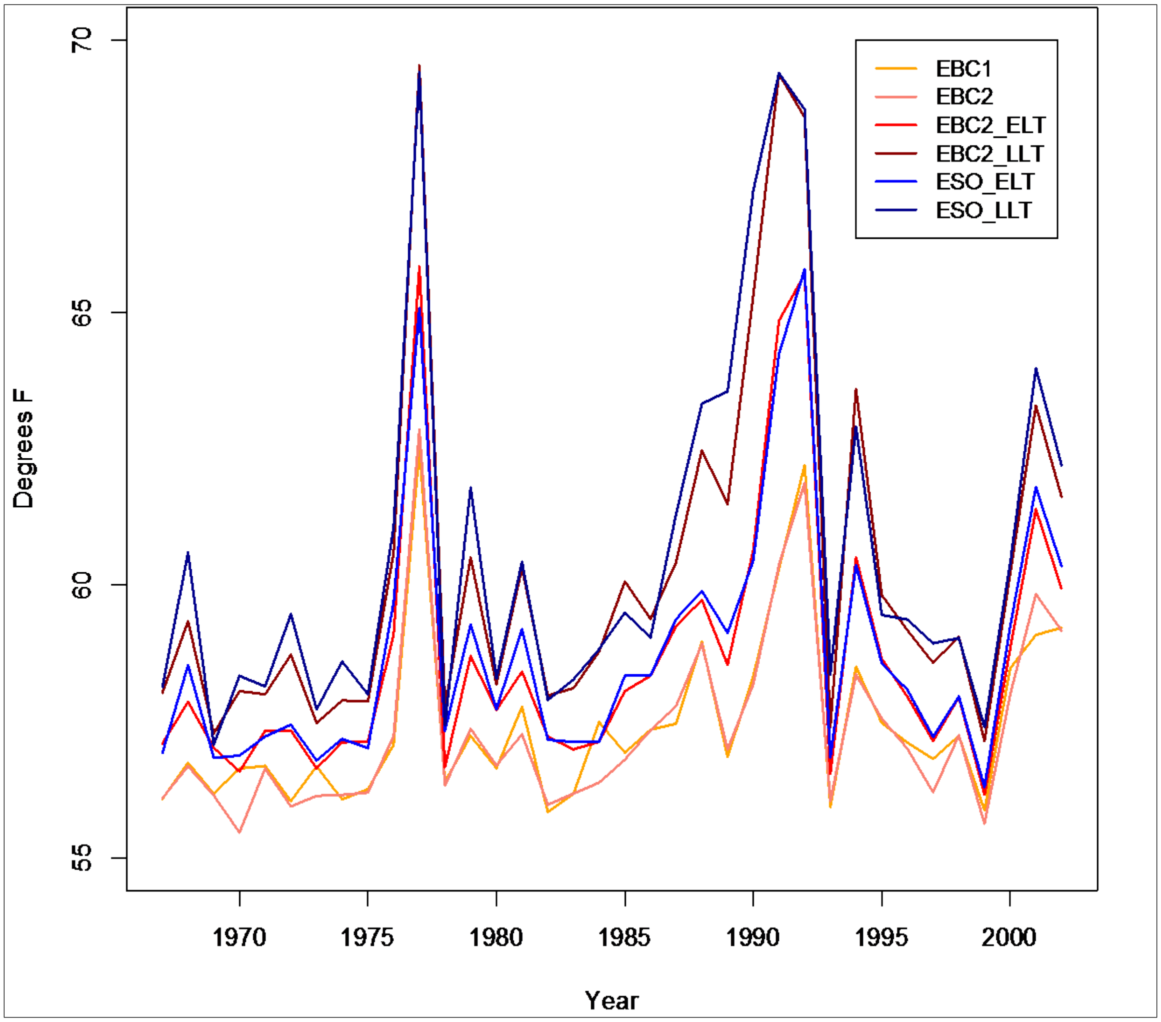
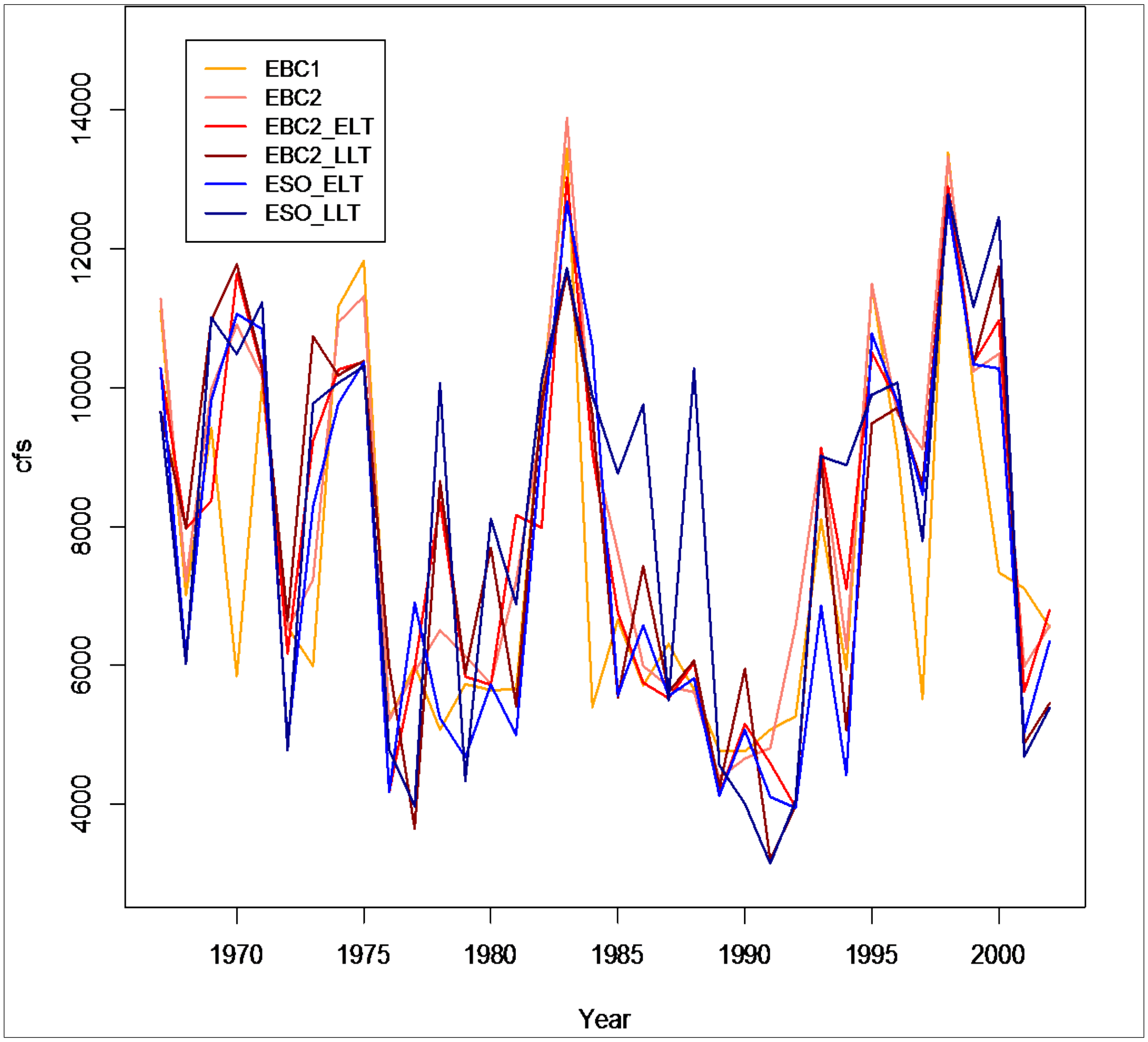


Figure 5.G-3. Annual Water Temperature Metric (STEMP) in the Sacramento River at Bend Bridge Used in the OBAN Model



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2 **Figure 5.G-4. Annual Minimum Flow Metric (FLMIN) in the Sacramento River at Bend Bridge Used in**
3 **the OBAN Model**

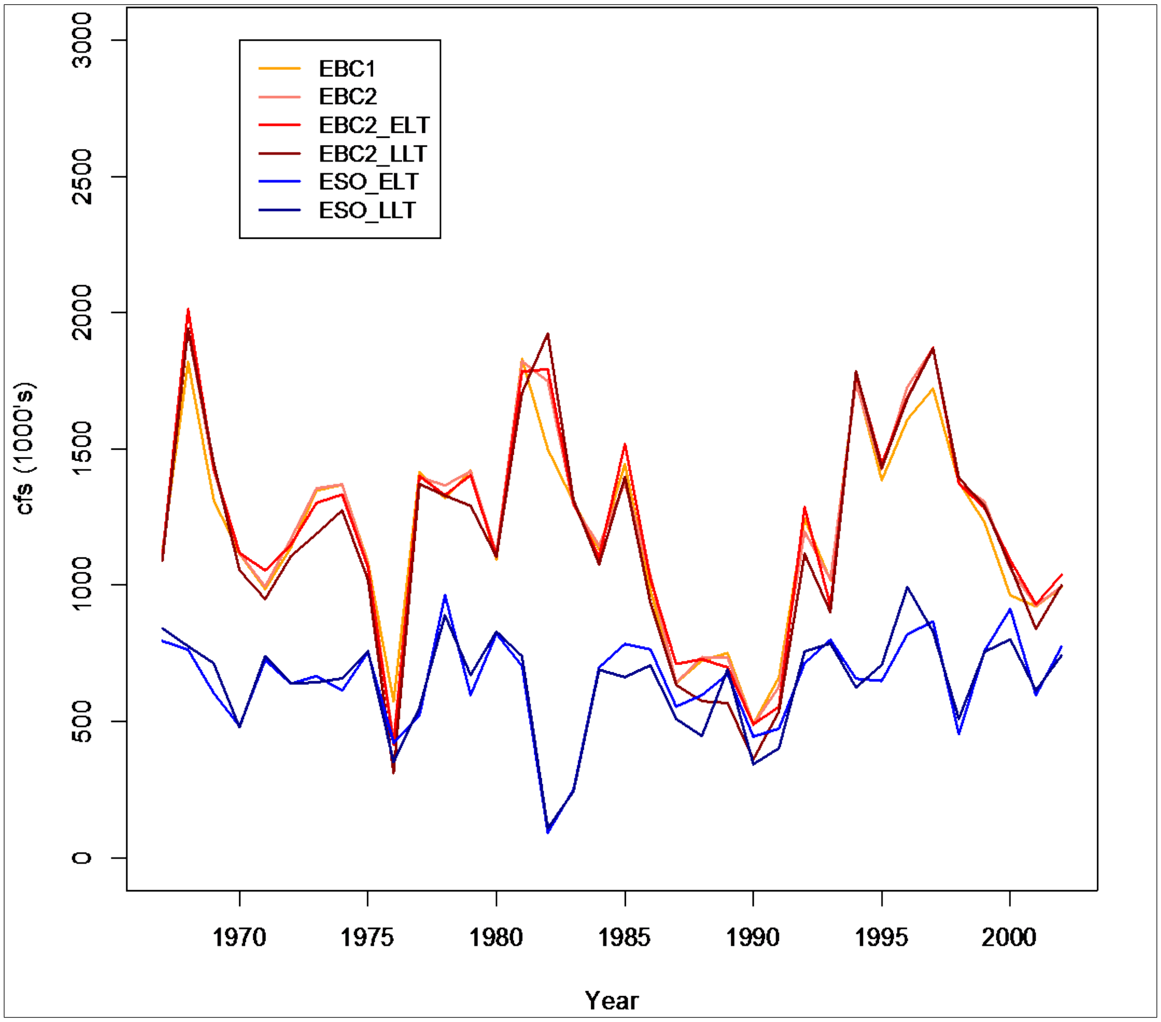


Figure 5.G-5. Annual Export Levels (EXPT) at South Delta SWP and CVP Facilities Used in the OBAN Model

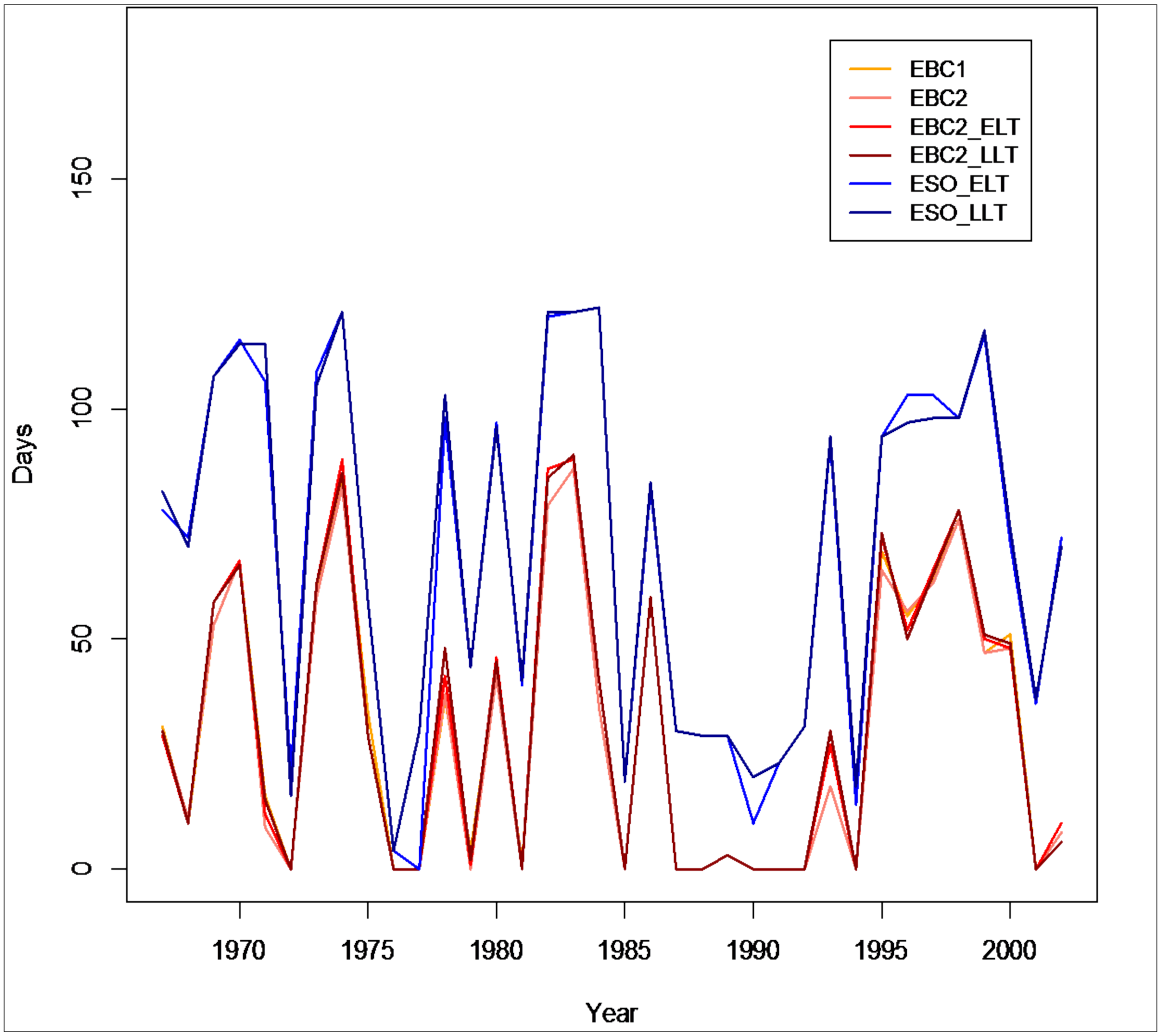
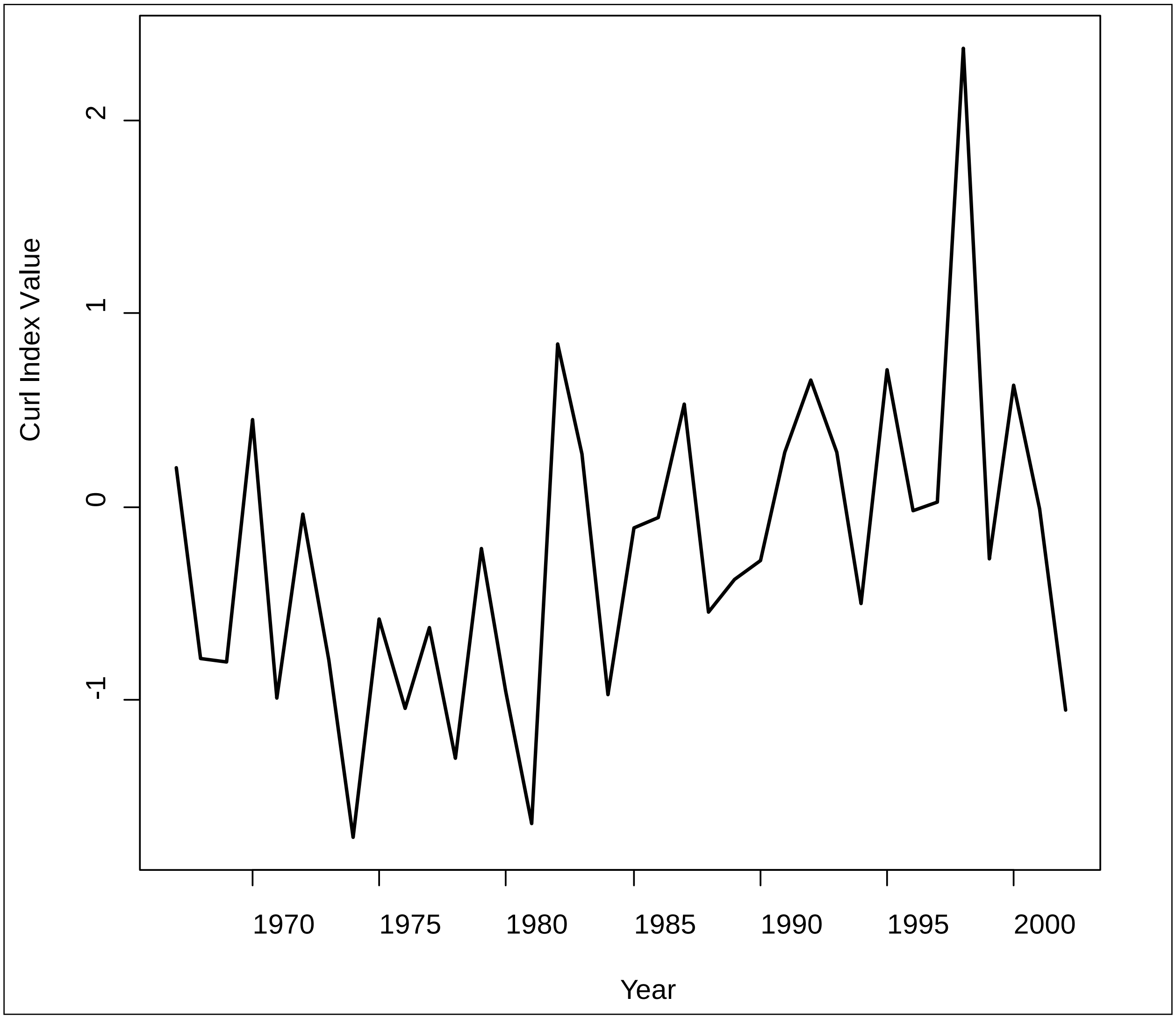


Figure 5.G-6. Annual Number of Days during Which Flows into the Yolo Bypass Were Sufficient (>100 cfs) for Salmon Entry (YOLO) Used in the OBAN Model



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2 **Figure 5.G-7. Annual Index of CURL, a Metric Related to Upwelling in the Gulf of Farallones, Used in**
3 **the OBAN Model**

Figure 5.G-8. Annual Harvest Rate Index Used in the OBAN Model

5.G.2.2.6 Model Outputs

Several outputs based on the trajectory of abundances forecasted under each model scenario were used to determine differences among model scenarios. Because of the assumptions made in the OBAN model and because these assumptions were held constant among all model scenarios, all performance metrics were compared on a relative basis rather than in an absolute sense. For example, forecasted survival rates in the Delta were not construed as the predicted absolute survival rate in the Delta, but rather as a relative measure of survival among model scenarios.

The performance metrics developed for comparing model scenarios are listed below.

- Median through-Delta survival—a measure of relative survival through the Delta under each model scenario.

- Median annual escapement—the median (50th percentile) of the distribution of annual abundance.
- Median and central 90th probability interval of escapement in 1985 (the middle year of the time series).
- Median and central 90th probability interval of escapement in 2002 (the last year of the time series).

5.G.2.2.7 Sensitivity Analyses

Sensitivity analyses were conducted in order to assess the potential effects of lower survival in the Delta reach that might be attributable to predation at the north Delta intakes or other factors. The sensitivity analyses consisted of reducing Delta survival by 0.5%, 1%, and 5% for the HOS and LOS scenarios. Note that in contrast to IOS, OBAN does not include any flow parameters that the BDCP is expected to affect, therefore it is not possible to modify flow parameters for the purpose of the sensitivity analysis. Therefore, this set of arbitrary reductions in survival is used to evaluate the cumulative sensitivity of OBAN escapement predictions to un-modeled parameters that might affect through-Delta survival.

5.G.2.2.8 Model Limitations and Assumptions

- Other than *CM1 Water Facilities and Operation* and *CM2 Yolo Bypass Fisheries Enhancement*, no conservation measures are modeled in OBAN, including predator removal, hatchery modification, and physical habitat restoration.
- The abundance indices used to formulate the model are limited to adults at spawning reaches and juveniles at RBDD. There are no abundance indices between the Delta and the ocean. Therefore, mortality in the Delta is difficult to distinguish from mortality in the bay, gulf, and ocean life stages.
- OBAN does not incorporate finer spatial structure of the Delta because of the way in which the model treats the Delta as one homogenous stage. Thus, it lacks the functionality to evaluate different routes for migration through the Delta and potential conservation measures that may alter route selection during outmigration and route-specific survival (e.g., predator removal or habitat enhancement).
- Because the relationships on which the model relies are based on historical data and conditions, the model cannot assume any changes in the physical plumbing of the Delta. Therefore, although it can account for effects of reduced exports at south Delta facilities, which were present during the historical period used, it cannot account for north Delta exports because no facilities were present during the historical period. In particular, the model does not include any Delta flow-based covariates other than exports (EXPT) and Yolo Bypass inundation (YOLO) and, therefore, cannot account for any potential changes in survival below the north Delta diversions, e.g., because of changes in water velocity.
- Because of assumptions of the model, all performance metrics should be compared on a relative basis rather than in an absolute sense.

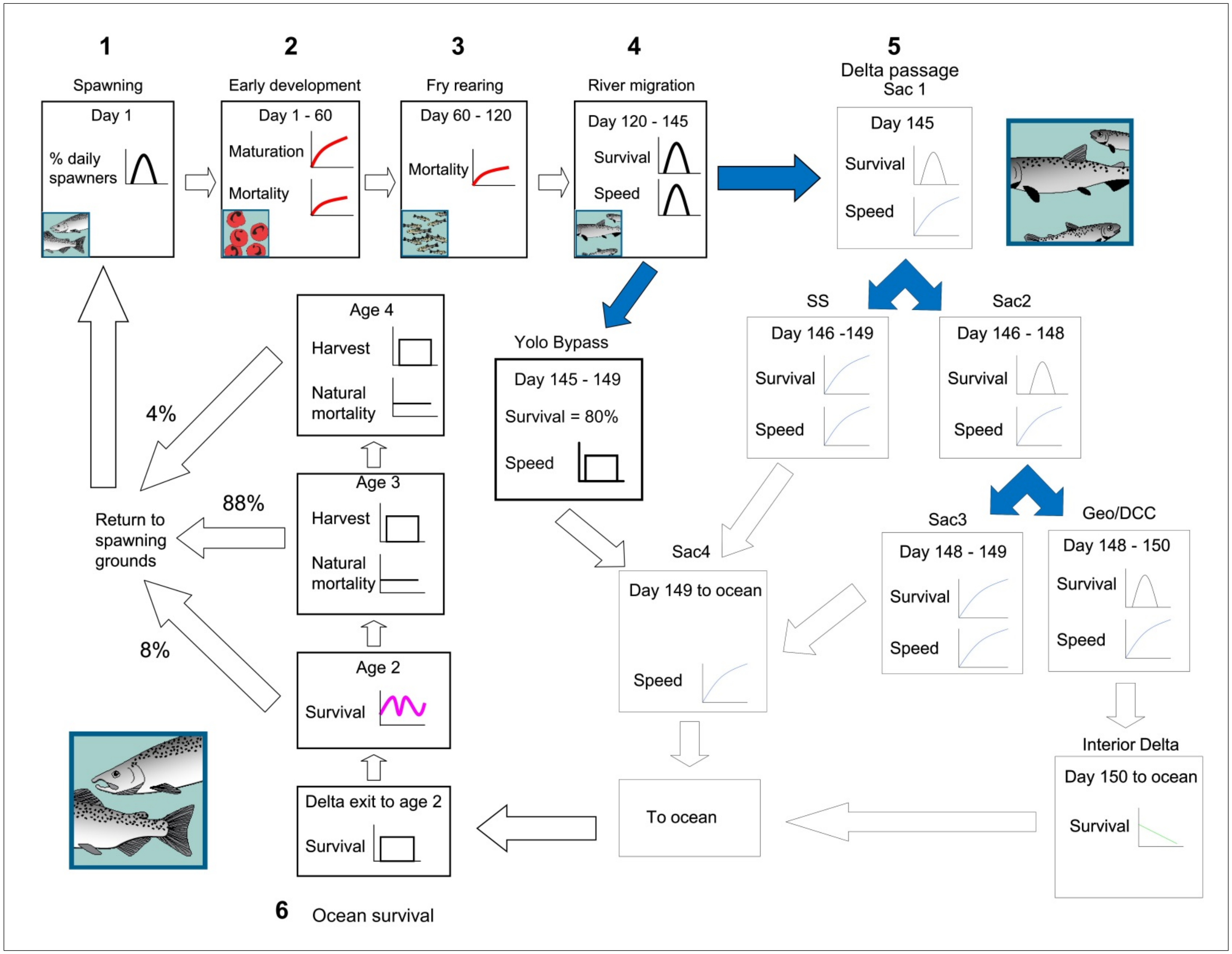
5.G.2.3 Interactive Object-Oriented Simulation (IOS) Model (Winter-Run Chinook Salmon)

5.G.2.3.1 Model Structure

The IOS Model is composed of six model stages defined by a specific spatiotemporal context and are arranged sequentially to account for the entire life cycle of winter-run Chinook salmon, from eggs to returning spawners (Figure 5.G-9). In sequential order, the IOS Model stages are listed below.

1. *Spawning*, which models the number and temporal distribution of eggs deposited in the gravel at the spawning grounds in the upper Sacramento River between Red Bluff Diversion Dam and Keswick Dam.
2. *Early Development*, which models the effect of temperature on maturation timing and mortality of eggs at the spawning grounds.
3. *Fry Rearing*, which models the relationship between temperature and mortality of fry during the river rearing period in the upper Sacramento River between Red Bluff Diversion Dam and Keswick Dam.
4. *River Migration*, which estimates mortality of migrating smolts in the Sacramento River between the spawning and rearing grounds and the Delta.
5. *Delta Passage*, which models the effect of flow, route selection, and water exports on the survival of smolts migrating through the Delta to San Francisco Bay.
6. *Ocean Survival*, which estimates the effect of natural mortality and ocean harvest to predict survival and spawning returns by age.

A detailed description of each model stage follows.



Note: Red = temperature, blue = flow, green = water exports, pink = ocean productivity.

Figure 5.G-9. Conceptual Diagram of the IOS Model Stages and Environmental Influences on Survival and Development of Winter-Run Chinook Salmon at Each Stage

5.G.2.3.1.1 Spawning

For the first four simulation years of the 82-year CALSIM simulation period, the model is seeded with 5,000 spawners, of which 3,087.5 are female based on the wild male to female ratio of spawners. In each subsequent simulation year, the number of female spawners is determined by the model's probabilistic simulation of survival to this life stage. To ensure that developing fish experience the correct environmental conditions during each year, spawn timing mimics the observed arrival of salmon on the spawning grounds as determined by 8 years of carcass surveys (2002–2009) conducted by the U.S. Fish and Wildlife Service (USFWS). Eggs deposited on a particular date are treated as cohorts that experience temperature and flow on a daily time step during the early development stage. The daily number of female spawners is calculated by multiplying the daily proportion of the total carcasses observed during the USFWS surveys by the total Jolly-Seber estimate of female spawners (Poytress and Carillo 2010).

(Equation 1) $$S_d = C_d S_{JS}$$

where, S_d is the daily number of female spawners, C_d is the daily proportion of total carcasses and S_{JS} is the total Jolly-Seber estimate of female spawners.

To account for the time difference between egg deposition and carcass observations, the date of egg deposition is assumed to be 14 days prior to carcass observations (Niemela pers. comm.).

To obtain estimates of juvenile production, a Ricker stock-recruitment curve (Ricker 1975) was fit between the number of emergent fry produced each year (estimated by rotary screw–trap sampling at Red Bluff Diversion Dam) and the number of female spawners (from USFWS carcass surveys) for years 1996–1999 and 2002–2007:

(Equation 2) $$R = \alpha S e^{-\beta S} + \varepsilon$$

where α is a parameter that describes recruitment rate, and β is a parameter that measures the level of density dependence.

The density-dependent parameter (β) did not differ significantly from 0 (95% CI = $-6.3\text{x}10^{-6}$ – $5.5\text{x}10^{-6}$), indicating that the relationships between emergent fry and female spawners was linear (density-independent). Therefore, β was removed from the equation and a linear version of the stock-recruitment relationship was estimated. The number of female spawners explained 86% of the variation in fry production ($F_{1,9} = 268$, $p<0.001$) in the data, so the value of α was taken from the regression:

(Equation 3) $$R = 1043*S$$

In the IOS Model, this linear relationship is used to predict values for mean fry production along with the confidence intervals for the predicted values. These values are then used to define a normal probability distribution, which is randomly sampled to determine the annual fry production. Although the Ricker model accounts for mortality during egg incubation, the data used to fit the Ricker model were from a limited time period (1996–1999, 2002–2007) when water temperatures during egg incubation were too cool (<14°C) to cause temperature-related egg mortality (U.S. Fish and Wildlife Service 1999). Thus, additional mortality was imposed at higher temperatures not experienced during the years used to construct the Ricker model.

5.G.2.3.1.2 Early Development

Data from three laboratory studies were used to estimate the relationship between temperature, egg mortality, and development time (Murray and McPhail 1988; Beacham and Murray 1989; U.S. Fish and Wildlife Service 1999). Using data from these experiments, a relationship was constructed between maturation time and water temperature. First *maturation time* (days) was converted to a *daily maturation rate* (1/day):

(Equation 4) $\textit{daily maturation rate} = \textit{maturation time}^{-1}$

A significant linear relationship between maturation rate and water temperature was detected using linear regression. Daily water temperature explained 99% of the variation in *daily maturation rate* (F =2188; df =1,15; p<0.001):

(Equation 5) $\textit{daily maturation rate} = 0.00058*\textit{Temp}-0.018$

In the IOS Model, the daily mean maturation rate of the incubating eggs is predicted from daily water temperatures using a linear function; the predicted mean maturation rate, along with the confidence intervals of the predicted values, is used to define a normal probability distribution, which then is randomly sampled to determine the daily maturation rate. A cohort of eggs accumulates a percentage of total maturation each day from the above equation until 100% maturation is reached.

Data from experimental work (U.S. Fish and Wildlife Service 1999) was used to parameterize the relationship between temperature and mortality of developing winter-run Chinook salmon eggs. Predicted proportional mortality over the entire incubation period was converted to a daily mortality rate to apply these temperature effects in the IOS Model. This conversion was used to calculate daily mortality using the methods described by Bartholow and Heasley (2006):

(Equation 6) $\textit{mortality} = 1-(1-\textit{total mortality})^{(1/\textit{development time})}$

where *total mortality* is the predicted mortality over the entire incubation period observed for a particular water temperature and *development time* was the time to develop from fertilization to emergence.

Limited sample size (n = 3) in the USFWS study (1999) did not allow a statistically valid test for effects of temperature on mortality (e.g., a general additive model) to be performed. However, the following exponential relationship was fitted between observed *daily mortality* and observed water temperatures (U.S. Fish and Wildlife Service 1999) to provide the required values for the IOS Model:

(Equation 7) $\textit{daily mortality} = 1.38*10^{-15}e^{(0.503*\textit{Temp})}$

Equation 7 yields the following graphic (Figure 5.G-10), which indicates that proportional daily egg mortality increases rapidly with only small changes in water temperature. For example, within the predominant water temperature range found in model scenarios (55°F to 60°F), proportional daily mortality increases over ten-fold (~0.001 at 55°F to ~0.018 at 60°F).

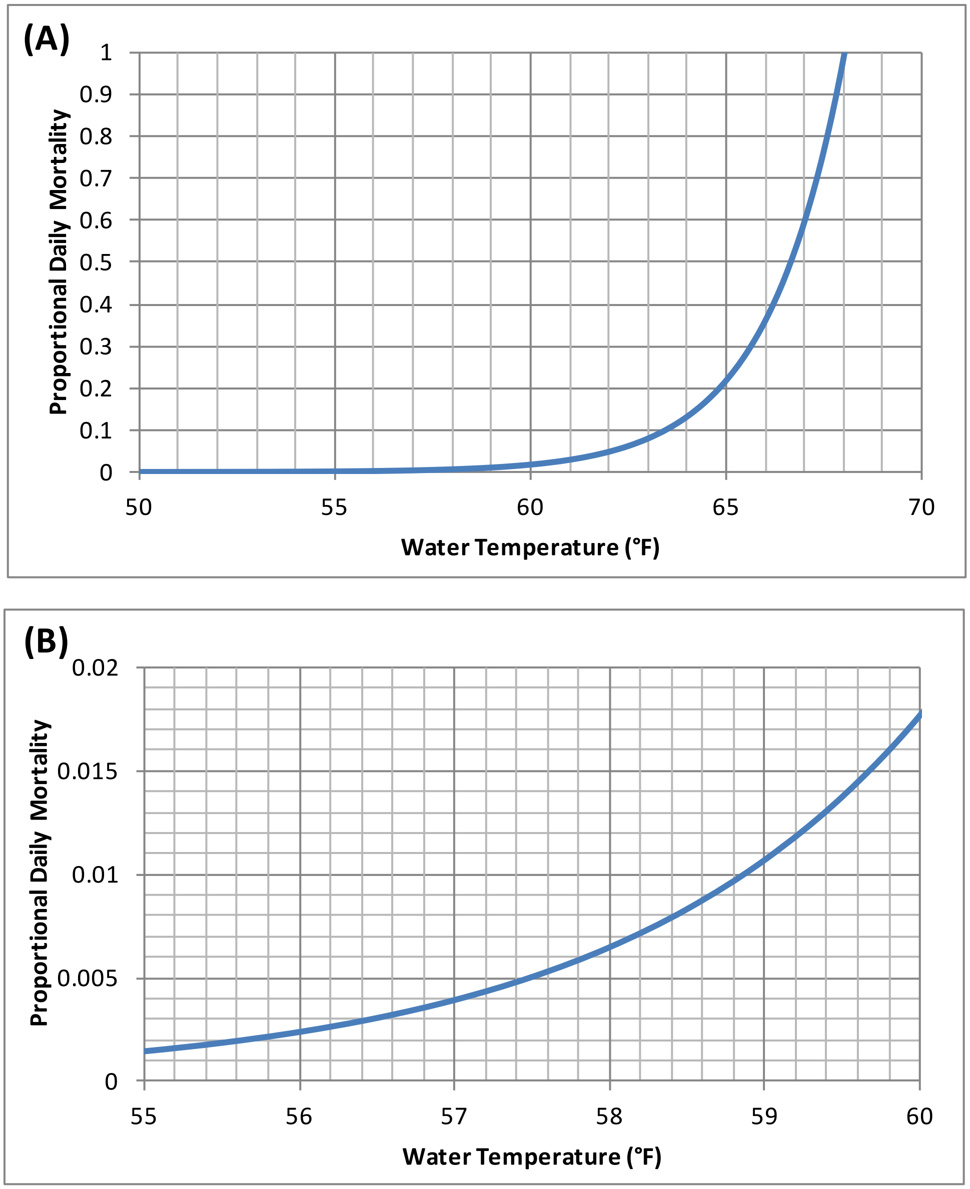


Figure 5.G-10. Relationship between Proportional Daily Mortality of Winter-Run Chinook Salmon Eggs and Water Temperature (Equation 7) for (A) the Entire Temperature Range, and (B) the Predominant Range Found in Model Scenarios

In the IOS Model, mean daily mortality rates of the incubating eggs are predicted from daily water temperatures measured at Bend Bridge on the Sacramento River using the exponential function above. The predicted mean mortality rate, along with the confidence intervals of the predicted values, is used to define a normal probability distribution, which then is randomly sampled to determine the daily egg mortality rate.

5.G.2.3.1.3 Fry Rearing

Data from USFWS (1999) was used to model fry mortality during rearing as a function of water temperature. Again, because of a limited sample size from the study by USFWS, statistical analyses to test for the effects of water temperature on rearing mortality could not be run. However, to acquire predicted values for the model, the following exponential relationship was fitted between observed daily mortality and observed water temperatures (U.S. Fish and Wildlife Service 1999):

(Equation 8) $daily\ mortality = 3.92*10-12e\ (0.349*Temp)$

Equation 8 yields the following graphic (Figure 5.G-11), which indicates that proportional daily fry mortality increases rapidly with only small changes in water temperature. For example, within the predominant water temperature range found in model scenarios (55°F to 60°F), proportional daily mortality increases over five-fold (~0.001 at 55°F to ~0.005 at 60°F). This indicates that, although fry mortality is highly sensitive to changes in water temperature, this sensitivity is not as great as that of egg mortality within the predominant range observed in the model scenarios in focus.

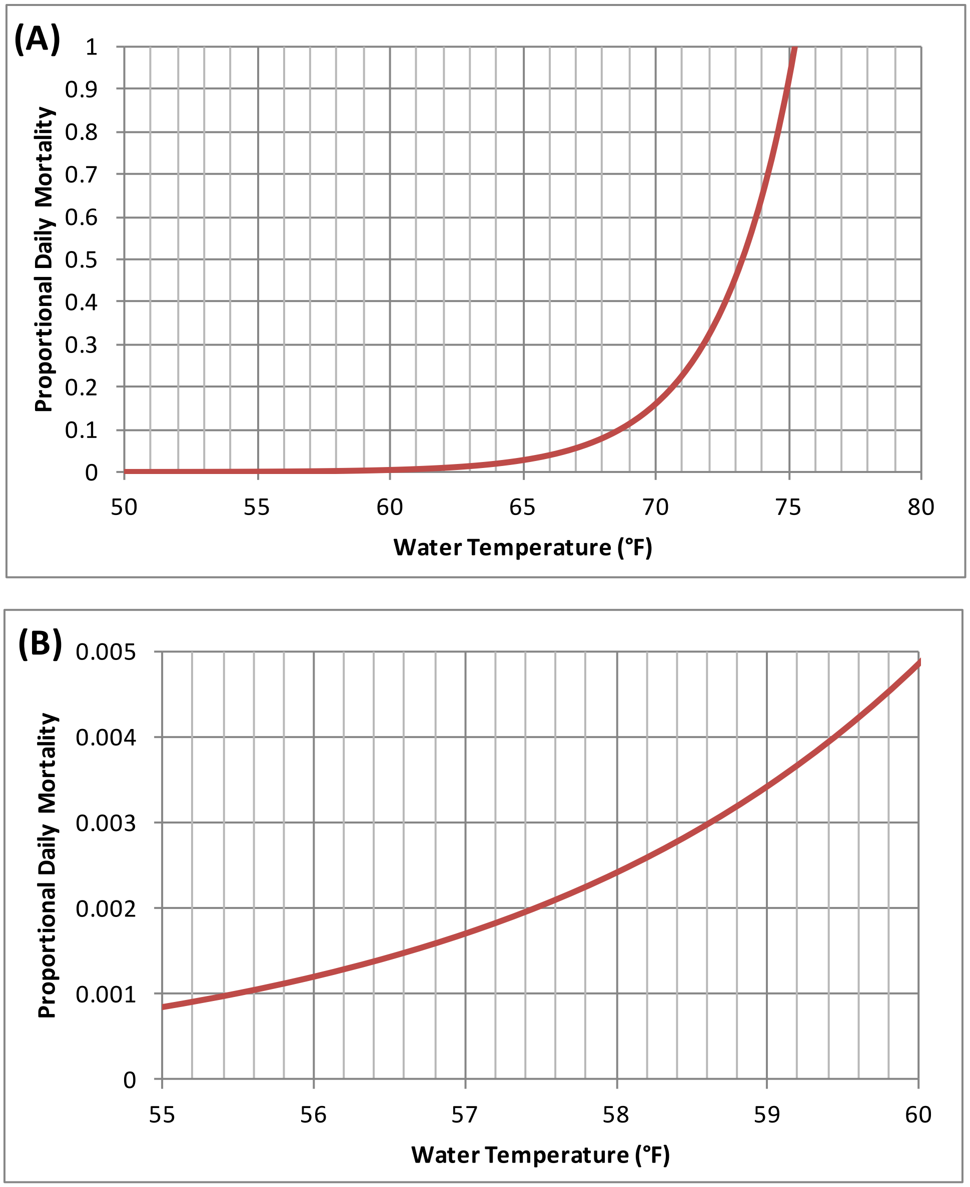


Figure 5.G-11. Relationship between Proportional Daily Mortality of Winter-Run Chinook Salmon Fry and Water Temperature (Equation 8) for (A) the Entire Temperature Range, and (B) the Predominant Range Found in Model Scenarios

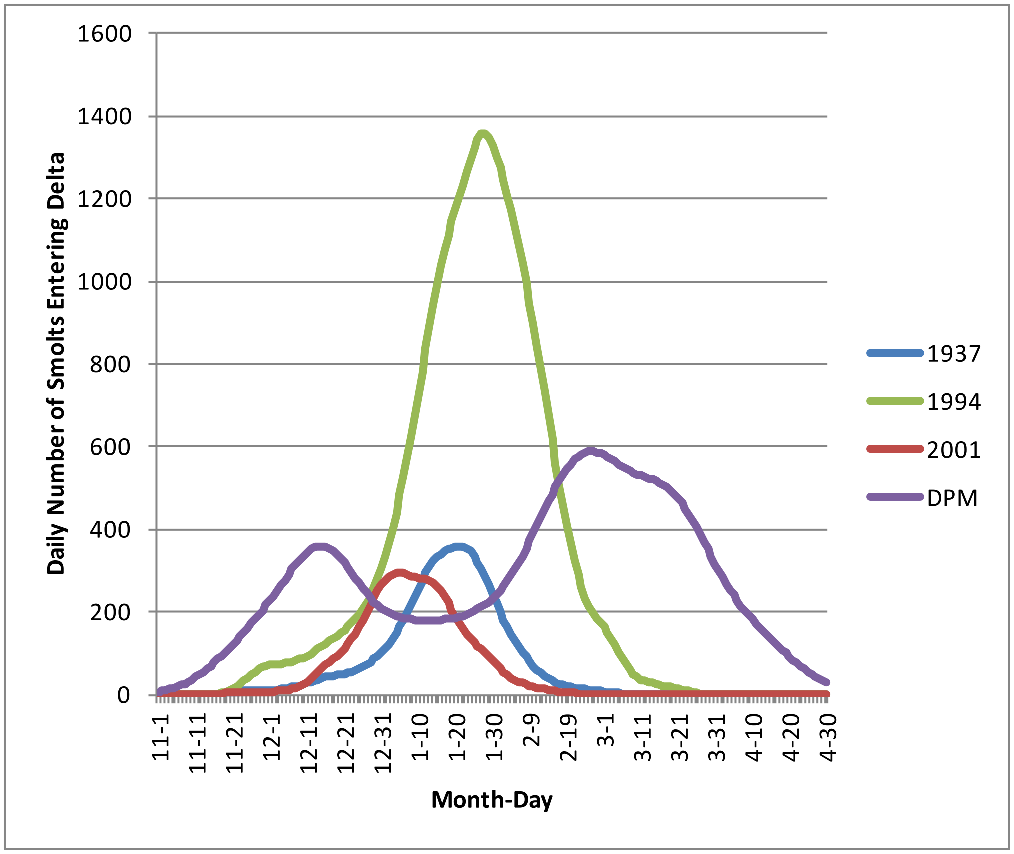
Each day the mean proportional mortality of the rearing fish is predicted from the daily water temperature using the above exponential relationship; the predicted mean mortality, along with the confidence intervals of the predicted values, is used to define a normal probability distribution, which then is randomly sampled to determine the daily mortality of the rearing fish. Temperature mortality is applied to rearing fry for 60 days, which is the approximate time required for fry to transition into smolts (U.S. Fish and Wildlife Service 1999) and enter the *River Migration* stage. All fish migrating through the Delta are assumed to be smolts.

5.G.2.3.1.4 River Migration

Survival of smolts from the spawning and rearing grounds to the Delta (city of Freeport on the Sacramento River) is a normally distributed random variable with a mean of 23.5% and a standard error of 1.7%. Mortality in this stage is applied only once in the model and occurs on the same day that a cohort of smolts enters the model stage because there were no data to support a relationship with flow or water temperature. Smolts are delayed from entering the next model stage to account for travel time. Mean travel time (20 days) is used along with the standard error (3.6 days) to define a normal probability distribution, which is randomly sampled to provide estimates of the total travel time of migrating smolts. Survival and travel time means and standard deviations were acquired from a study of late-fall run Chinook salmon smolt migration in the Sacramento River that employed acoustic tags and several monitoring stations (including Freeport) between Coleman National Fish Hatchery (Battle Creek) and the Golden Gate Bridge (Michel 2010).

5.G.2.3.1.5 Delta Passage

Winter-run Chinook salmon passage through the Delta within IOS is modeled with the DPM, which is described fully in Appendix 5.C, *Flow, Passage, Salinity, and Turbidity*. Note that there are two main differences between the implementation of the DPM in IOS and the standalone DPM as presented in Appendix 5.C. First, in contrast to the 1976–1991 DSM simulation period for the standalone DPM, IOS uses the 1922–2003 CALSIM simulation period based on monthly average data for all flow and export variables—all days within a given month for each scenario are assumed to have the same flow or export value as the other days in the month. The only exceptions to this are the flow terms determining proportional Yolo Bypass entry (i.e., at Wilkins Slough, Verona, Fremont Weir, and the Sacramento Weir), which were disaggregated to give daily flows for the standalone DPM analysis. The second main difference is that the timing of winter-run entry into the Delta is a function of upstream fry/egg rearing and so timing changes annually, in contrast to the fixed nature of Delta entry for the standalone DPM. Also, the IOS entry distribution is a unimodal term that tends to peak between the bimodal peaks of the standalone DPM entry distribution (Figure 5.G-12). As each cohort of smolts exits the final reaches of the Delta (Sac4 and the interior Delta), the cohorts accumulate until all cohorts from that year have exited the Delta. After all cohorts have arrived, they all enter the *Ocean Survival* model as a single cohort and the model begins applying mortality on an annual time step.



DPM: purple line, fixed bimodal distribution.
IOS in 1937: blue line, an average peak of January 21.
IOS in 1994: green line, a late peak of January 28.
IOS in 2001: red line, an early peak of January 4.
IOS data are from scenario ALT9_LLT of the BDCP EIR/EIS.

Figure 5.G-12. Winter-Run Chinook Salmon Smolt Delta Entry Distributions Assumed under the Delta Passage Model Compared with Entry Distributions for IOS in 1937, 1994, and 2001

5.G.2.3.1.6 Ocean Survival

As described by Zeug et al. (2012), this model stage uses a set of equations for smolt-to-age-2 mortality, winter mortality, ocean harvest, and spawning returns to predict yearly survival and escapement numbers (i.e., individuals exiting the ocean to spawn). Certain values during the ocean survival life stage were fixed constant among model scenarios. Ocean survival model-stage elements are listed in Table 5.G-3 and discussed below.

Table 5.G-3. Functions and Environmental Variables Used in the Ocean Survival Stage of the IOS Model

Model Element	Environmental Variable	Value
Smolt-age 2 survival	None	Uniform random variable between 94% and 98%
Age 2 ocean survival	Wells' Index of Ocean productivity	Equation 13
Age 3 ocean survival	None	Equation 14
Age 4 ocean survival	None	Equation 15
Age 3 harvest	None	Fixed at 17.5%
Age 4 harvest	None	Fixed at 45%

Relying on ocean harvest, mortality, and returning spawner data from Grover et al. (2004), a uniformly distributed random variable between 96% and 98% mortality was applied for winter-run Chinook salmon from ocean entry to age 2 and functional relationships were developed to predict ocean survival and returning spawners for age 2 (8%), age 3 (88%), and age 4 (4%), assuming that 100% of individuals that survive to age 4 return for spawning. In the IOS Model, ocean survival to age 2 is given by:

(Equation 13) $A_2 = A_i(1\text{-}M_2)(1\text{-}M_w)(1\text{-}H_2)(1\text{-}S_{r2})*W$

Survival to age 3 is given by:

(Equation 14) $A_3 = A_2(1\text{-}M_w)(1\text{-}H3)(1\text{-}S_{r3})$

And survival to age 4 is given by:

(Equation 15) $A_4 = A_3(1\text{-}M_w)(1\text{-}H_4)$

where A_i is initial abundance at ocean entry (from the DPM stage), $A_{2,3,4}$ are abundances at ages 2–4, $H_{2,3,4}$ are harvest percentages at ages 3–4 represented by uniform distributions bounded by historical harvest levels, M_2 is smolt-to-age-2 mortality, M_w is winter mortality for ages 2–4, and $S_{r2,r3}$ are returning spawner percentages at age 2 and age 3.

Harvest mortality is represented by a uniform distribution that is bounded by historical levels of harvest. Age 2 survival is multiplied by a scalar W that corresponds to the value of Wells Index of ocean productivity. This metric was shown to significantly influence over-winter survival of age 2 fish (Wells et al. 2007). The value of Wells Index is a normally distributed random variable that is resampled each year of the simulation. In the analysis, the following values from Grover et al. (2004) were used: $H_2 = 0\%$, $H_3 = 0\text{-}39\%$, $H_4 = 0\text{-}74\%$, $M_2 = 94\text{-}98\%$, $M_w = 20\%$, $S_{r2} = 8\%$, and $S_{r3} = 96\%$.

Adult fish designated for return to the spawning grounds are assumed to be 65% female and are assigned a pre-spawn mortality of 5% to determine the final number of female returning spawners (Snider et al. 2001).

5.G.2.3.2 Time Step

The IOS Model operates on a daily time step, advancing the age of each cohort/life stage and thus tracking their numerical fate throughout the different stages of the life cycle. Some variables (e.g., annual mortality estimates) are randomly sampled from a distribution of values and are applied once per year. Although a daily time step is implemented for the Delta Passage component of IOS, flow inputs that rely on CALSIM outputs (i.e., all flows except flows at Fremont Weir) are based on monthly modeling and are assumed to be constant within a particular month. In addition, for the ocean phase of the life cycle, the model operates on an annual time step by applying annual survival estimates to each ocean cohort.

5.G.2.3.3 Model Inputs

Delta flows and export flow into SWP and CVP pumping plants were modeled using monthly flow output from CALSIM II, with the monthly average flow in a particular month being applied to all days within that month, as described above. A separate set of flow inputs was developed for each of the BDCP scenarios, based on the CALSIM II flow predictions for each scenario across the entire 1922 to 2002 prediction record. Flows into the Yolo Bypass over Fremont Weir were based on disaggregated monthly CALSIM II data based on historical patterns of variability[1]. Temperature data for the Sacramento River was obtained from the SRWQM developed by the Bureau of Reclamation (Reclamation). The nodes in the CALSIM II and SRWQM models that were used to provide flow and temperature data for specific reaches in the Sacramento River and Delta are shown in Table 5.G-4.

Table 5.G-4. IOS Reaches and Associated Channels from CALSIM II and SRWQM Models

IOS Reach	CALSIM Channel	SRWQM
Spawning-Rearing Reach	–	Weighted average of Keswick and Balls Ferry temperatures based on spawning distribution
Sac1	Rsac155	–
Sac2	Sac_ds_stmbsl	–
Sac3	Rsac123	–
Sac4	Rsac101	–
SS	Sutr_sl+stmbt_sl	–
Geo/DCC	Dcc+georg_sl	–
Interior Delta	Total_exports	–

5.G.2.3.4 Model Outputs

Four model outputs are used to determine differences among model scenarios.

1. Egg survival: The Sacramento River between Keswick Dam and the Red Bluff Diversion Dam provides egg incubation habitat for winter-run Chinook salmon. Water temperature has a large effect on the survival of Chinook salmon during the egg incubation period by controlling mortality as well as development rate. Temperatures in this reach are partially controlled by releases of cold water from Shasta Reservoir and ambient weather conditions.
2. Fry survival: The Sacramento River between Keswick Dam and Red Bluff Diversion Dam provides rearing habitat for juvenile winter-run Chinook salmon. Water temperature can have a large effect on the survival of Chinook salmon during the fry rearing stage by controlling mortality and development rate. Temperatures in this reach are partially controlled by releases of cold water from Shasta Reservoir and ambient weather conditions.

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[1] Note that the "stand-alone" DPM presented in Appendix 5.C uses daily DSM2 data for 1976–1991 for the Delta and disaggregated daily CALSIM data for 1976–1991 for Fremont Weir flows.

3. Through-Delta survival: The Delta between the Fremont Weir on the Sacramento River and Chipps Island is a migration route for juvenile winter-run Chinook salmon. Flow magnitude in different reaches of the Delta influences survival and travel time through the Delta and entrainment into alternative migration routes. Fish entering the interior Delta via the Geo/DCC reach are potentially exposed to mortality from water exports in the interior Delta.

4. Escapement: Each year of the IOS Model simulation, escapement is calculated as the combined number of 2-, 3-, and 4-year-old fish that leave the ocean and migrate back into the Sacramento River to spawn between Keswick Dam and the Red Bluff Diversion Dam. These numbers are influenced by the combination of all previous life stages and the functional relationships between environmental variables and survival rates. Only the 1926–2002 water years were considered because the first four years of the CALSIM modeling (1922–1925) were used to seed the model and had fixed numbers of spawners assumed, as described above.

5.G.2.3.5 Model Limitations and Assumptions

The following model limitations and assumptions should be recognized when interpreting results.

1. Other than *CM1 Water Facilities and Operation* and *CM2 Yolo Bypass Fisheries Enhancement*, no other BDCP conservation measures are modeled in the current analysis, although IOS is capable of doing so. There is potential for other conservation measures to affect winter-run Chinook salmon, but this potential is not modeled in IOS with the exception of the potential effects of *CM16 Nonphysical Fish Barriers* on through-Delta smolt survival. For this conservation measure, a prior sensitivity analysis is described under Section 5.G.5.2.7, *Sensitivity Analyses*, below.

2. Other important ecological relationships likely exist but quantitative relationships are not available for integration into IOS (e.g., the interaction among flow, turbidity, and predation). To the extent that these unrepresented relationships are important and alter IOS outcomes, each alternative considered is assumed to be affected in the same way.

3. For relationships that are represented in IOS, the operational alternatives considered are not assumed to alter those underlying functional relationships.

4. There is a specific range of environmental conditions (temperature, flow, exports, and ocean productivity) under which functional relationships were derived. These functional relationships are assumed to hold true for the environmental conditions in the scenarios considered.

5. Differential growth because of different environmental conditions (e.g., river temperature) and subsequent potential differences in survival and other factors are not directly included in the model. Differences in survival related to growth are indirectly included to an unknown extent in flow-survival, temperature-survival, and ocean productivity-survival relationships.

6. Survival and travel time during Stages 4 (River Migration) and 5 (Delta Passage) are based on studies of yearling late fall–run Chinook salmon (c. 150–170-mm fork length) (Stage 4: Michel 2010; Stage 5: Perry et al. 2010), which are appreciably larger than downstream-migrating winter-run Chinook salmon (c. 70–100-mm fork length during the peak downstream migration) (Williams 2006:101); however, differences between model scenarios do not occur during stage 4 because survival and travel time during River Migration are independent of flow.

7. Juvenile winter-run Chinook salmon migrating through the Delta all are assumed to be smolts that are not rearing in the Delta.

8. Between Stage 5 (Delta Passage) and Stage 1 (Spawning), the only differences in survival between model scenarios comes from random differences based on probability distributions, although some functions have been fixed at constant values to minimize these random differences. There are no modeled flow effects on adult upstream migration (e.g., attraction flows) because there are no data available for such effects to be modeled.

5.G.2.3.6 Model Sensitivity and Influence of Environmental Variables

Zeug et al. (2012) examined the sensitivity of the IOS model estimates of escapement to its input parameter values, input parameters being the functional relationships between environmental inputs and biological outputs. Although revisions have been undertaken to IOS since that time, the main points from their analysis are still likely to be valid.

Zeug et al. (2012) found that escapement of different age classes was sensitive to different input parameters (Table 5.G-5). Escapement of age-2 fish (which compose 8% of the total returning fish in a given cohort) was most sensitive to smolt-to-age-2-survival and water year when considering either independent or interactive effects of these parameters, and there was also sensitivity to river migration survival when considering interactive effects of this parameter with other parameters. Escapement of age-3 fish (which compose 88% of the total returning fish in a given cohort) was sensitive to several input parameters when considering the independent effects of these parameters but was sensitive to through-Delta survival alone when considering first-order interactions between parameters. Escapement of age-4 fish (which compose 4% of the total returning fish in a given cohort) was sensitive to nearly all input parameters when considering the independent effects of these parameters, but was not sensitive to any of the parameters when considering first-order interactions between parameters (Zeug et al. 2012).

Zeug et al. (2012) also explored how uncertainty in model parameter estimates influences model output by increasing by 10–50% the variation around the mean of selected parameters that could be addressed by management actions (egg survival, fry-to-smolt survival, river migration survival, Delta survival, age-3 harvest, and age-4 harvest). They found that model output was robust to parameter uncertainty and that age-3 and age-4 harvest had the greatest coefficients of variation as a result of the uniform distribution of these parameters. Zeug et al. (2012) noted that there are limitations in the data used to inform certain parameters in the model that may be ecologically relevant but that are not sensitive in the current IOS configuration: river survival is a good example because it is based on a three-year field study of relatively low-flow conditions that does not cover the range of potential conditions that may be experienced by downstream-migrating juvenile Chinook salmon.

To understand the influence of environmental parameter inputs on escapement estimates from IOS, Zeug et al. (2012) performed three sets of simulations of a baseline condition and either a 10% increase or a 10% decrease in river flow, exports, water temperature (on the Sacramento River at Bend Bridge; see above), and ocean productivity (i.e., Wells Index; see above). They found that only 10% changes in temperature produced a statistically significant change in escapement; a 10% increase in temperature produced a far greater reduction in escapement (>95%) than a 10% decrease in temperature gave an increase in escapement (>10%). Zeug et al. (2012) suggested that the lack of significant changes in escapement with 10% changes of flow, exports, and ocean productivity may reflect the fact that these variables' relationships within the model were based on observational studies with large error estimates associated with the responses. In contrast, temperature functions were parameterized with data from controlled experiments with small error estimates. Also, Zeug et al. (2012) noted that water temperatures within the winter-run Chinook salmon spawning and rearing area are close to the upper tolerance limit for the species; therefore, even small changes have the potential to significantly affect the population.

5.G.2.3.7 Sensitivity Analyses

The ability of the IOS model to characterize the effects of the BDCP is limited in certain respects because it does not directly consider several ecological parameters in the Delta that would change over time with implementation of the BDCP. For example, it does not consider the likely beneficial effects of actions that are expected to increase the quality and quantity of critical habitats used by juvenile winter-run Chinook in the Delta (e.g., *CM 4 Tidal Natural Communities Restoration*, *CM 5 Seasonally inundated floodplain restoration, CM 6 Channel Margin Enhancement,* and *CM 7 Riparian Natural Community Restoration*), or others that will address other sources of direct mortality (e.g. *CM 15 Localized Predatory Fish Reduction, CM 17 Illegal Harvest Reduction, CM 21 Non-project Diversions*).

A sensitivity analysis was conducted to address this shortcoming by evaluating two additional elements of the BDCP in the IOS model: the implementation of the Georgiana Slough nonphysical barrier system (NPB) under *CM16 Nonphysical Fish Barriers*; and increased predation on juvenile Chinook in and around new structures associated with the north Delta Intakes. These elements were selected because they could be readily incorporated into the IOS model infrastructure and they are expected to have beneficial and negative effects on through-Delta survival, respectively.

An ELT and LLT scenario was created for each of the sensitivity analysis components. The NPB scenarios, abbreviated as ESO_33_ELT and ESO_33_LLT, assumed that that 67% of winter-run smolts that would have entered Georgiana Slough are diverted by the barrier back into the more favorable Sacramento River migration corridor. The deterrence estimate is based on a 2011 field study of migration conditions at Georgiana Slough (California Department of Water Resources 2012). The north Delta intake predation scenarios, abbreviated as ESO_95_ELT and ESO_95_LLT, assumed a 5% reduction in survival through the reach containing the north Delta intakes (Sac1), after the effects of flow conditions were calculated. The 95% survival figure is consistent with the biological goals and objectives for salmon migration survival through this reach. Model runs for each set of scenarios were conducted independently.

Table 5.G-5. Sobol' Sensitivity Indices (Standard Deviation in Parentheses) for Each Age Class of Returning Spawners Based on 1,000 Monte Carlo Iterations, Conducted to Test Sensitivity of IOS Input Parameters by Zeug et al. (2012)

	Age 2		Age 3		Age 4	
Input Parameter	**Main Index (Effect Independent of Other Input Parameters)**	**Total Index (Effect Accounting for First-Order Interactions with Other Input Parameters)**	**Main Index (Effect Independent of Other Input Parameters)**	**Total Index (Effect Accounting for First-Order Interactions with Other Input Parameters)**	**Main Index (Effect Independent of Other Input Parameters)**	**Total Index (Effect Accounting for First-Order Interactions with Other Input Parameters)**
Water year	0.300[a] (0.083)	0.306[a] (0.079)	0.181[a] (0.091)	0.150 (0.091)	0.073 (0.067)	0.012 (0.065)
Egg survival	0.030 (0.016)	-0.006 (0.016)	0.222[a] (0.081)	-0.021 (0.081)	0.102[a] (0.044)	-0.072 (0.044)
Fry-to-smolt survival	0.039 (0.020)	-0.009 (0.020)	0.166 (0.090)	0.091 (0.092)	0.079a (0.017)	-0.071 (0.017)
River migration survival	0.007 (0.034)	0.135a (0.034)	0.164 (0.084)	0.062 (0.085)	0.079 (0.018)	-0.07 (0.018)
Delta survival	0.010[a] (0.002)	-0.009 (0.002)	0.404[a] (0.180)	0.643[a] (0.177)	0.313[a] (0.134)	-0.009 (0.132)
Smolt to age 2 survival	0.734[a] (0.118)	0.454[a] (0.113)	0.015 (0.016)	-0.006 (0.016)	0.057a (0.017)	-0.052 (0.017)
Ocean productivity	0.003 (0.009)	0.009 (0.009)	0.034[a] (0.015)	-0.034 (0.015)	0.061[a] (0.030)	-0.048 (0.029)
Age 3 harvest	N/A	N/A	0.029[a] (0.001)	-0.028 (0.001)	1.48[a] (0.306)	0.188 (0.293)
Age 4 harvest	N/A	N/A	N/A	N/A	0.055a (0.003)	-0.054 (0.003)

Source: Zeug et al. 2012.

[a] Index value was statistically significant at $\alpha=0.05$.

5.G.3 Results

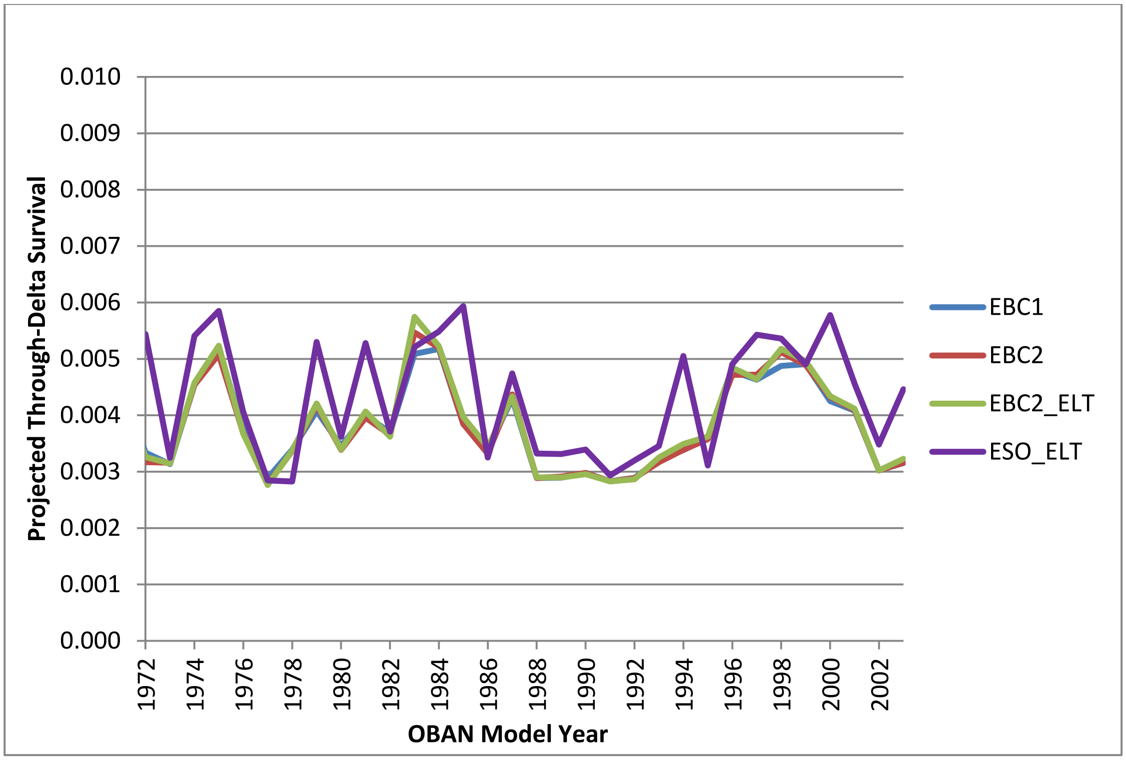
The following sections describe the results of the winter-run Chinook salmon OBAN and IOS life cycle models. These models generate results that are used as a foundation for determining the overall species effects of the ESO, which are included in the roll-up of Chapter 5, *Effects Analysis.*

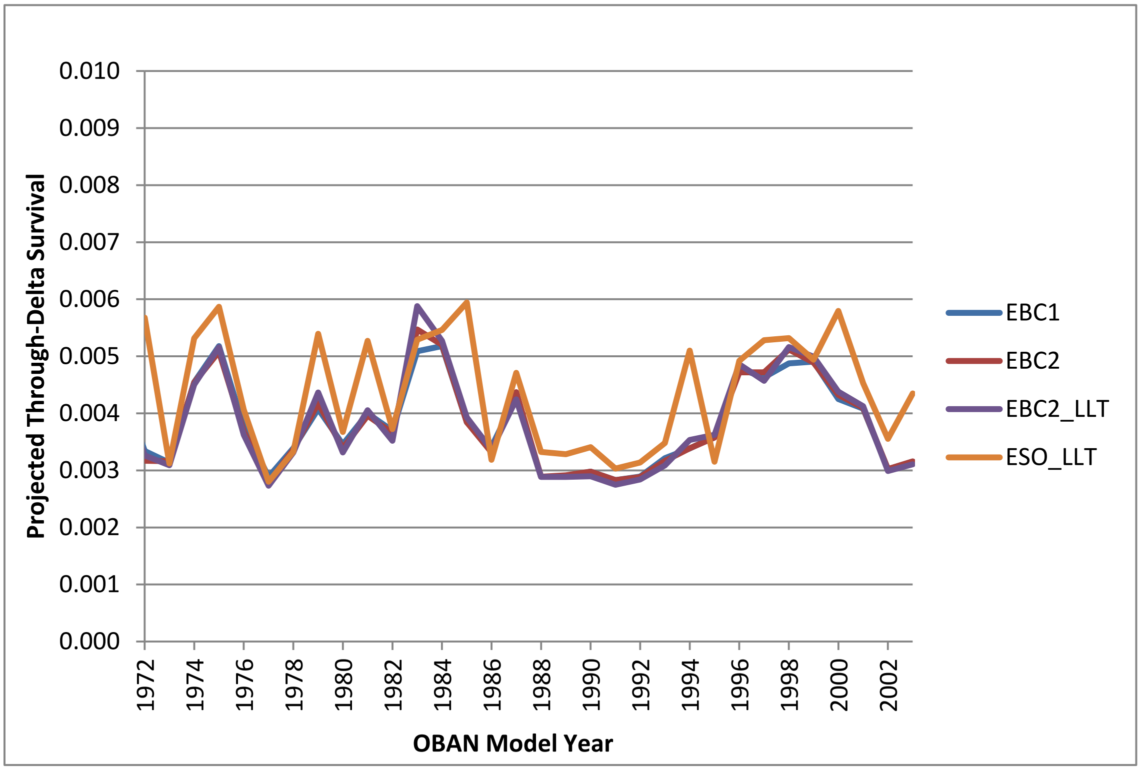
5.G.3.1 Oncorhynchus Bayesian Analysis (OBAN)

The OBAN analysis produced model predictions for winter-run Chinook salmon through-Delta survival and adult escapement under the EBC1 and EBC2 current conditions scenarios, and projected future conditions under the EBC2 and ESO scenarios under the ELT and LLT time frames. The OBAN sensitivity analysis was conducted to evaluate the sensitivity of model results to BDCP-related effects on through-Delta mortality under the HOS and LOS scenarios over the ELT and LLT time frames. The purpose of this analysis is to characterize the sensitivity of model results to potential through-Delta mortality effects that cannot be characterized empirically in the model. OBAN does not directly consider north Delta export effects because the model relies on a statistical relationship to historical flow conditions in the absence of the intakes. These results are intended to provide insight into how sensitive winter-run Chinook escapement might be to changes in Plan Area flows under BDCP.

5.G.3.1.1 Through-Delta Survival

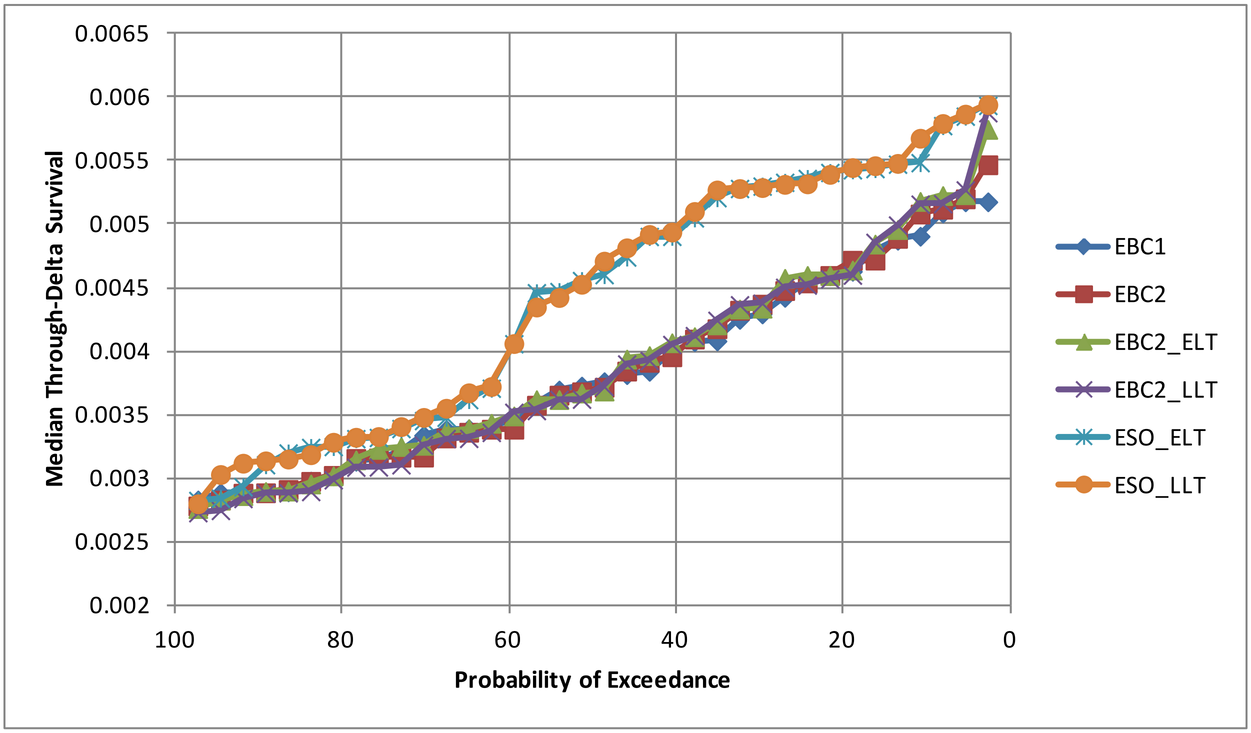
Median survival of juvenile winter-run Chinook salmon through the Delta for each model scenario examined with OBAN is presented in Figure 5.G-13, and an exceedance plot of the results is presented in Figure 5.G-14. Median through-Delta survival was variable among years, reflecting annual variability in levels of south Delta exports (Figure 5.G-5) and Yolo Bypass inundation flows (Figure 5.G-6). Because of the manner in which the OBAN model calculates through-Delta survival rates, these results are meaningful only on a relative basis. Median and mean median survival rates through the Delta were higher under ESO model scenarios than under all EBC1 and EBC2 scenarios (Table 5.G-6 and Table 5.G-7). Median and mean median survival rates under ESO_ELT and ESO_LLT were 13–20% greater than survival rates under EBC2_ELT and EBC2_LLT, respectively. This increase in predicted survival results from differences in Plan Area water operations between EBC and ESO scenarios, particularly a decrease south Delta exports (Figure 5.G-17), greater frequency of flows into the Yolo Bypass (Figure 5.G-18) under the ESO scenarios, and the absence of the NDD effects in any of the scenarios. Survival estimates through the Plan Area were relatively insensitive to future climate change, as reflected in the similarities among EBC2, EBC2_ELT, and EBC2_LLT results.





[1] Because of assumptions made in the OBAN model, only relative comparisons of survival among scenarios should be used.

Figure 5.G-13. Median Annual through-Delta Survival of Winter-Run Chinook Predicted by OBAN for Each Model Scenario[1]



[1] Because of assumptions made in the OBAN model, only relative comparisons of survival among scenarios should be used.

Figure 5.G-14. Probability of Exceedance Plot for Median Annual through-Delta Survival (Proportion of Fish) of Winter-Run Chinook Predicted under the OBAN Model Scenarios[1]

Table 5.G-6. Mean and Median of Median Annual through-Delta Survival (Proportion of Fish) for Existing Biological Conditions (EBC1, EBC2, EBC2_ELT, and EBC2_LLT) and Evaluated Starting Operations (ESO_ELT and ESO_LLT) Scenarios[1], as Evaluated for Winter-Run Chinook Salmon with OBAN

	EBC1	EBC2	EBC2_ELT	EBC2_LLT	ESO_ELT	ESO_LLT
Mean	0.0038	0.0038	0.0039	0.0039	0.0044	0.0044
Median	0.0037	0.0037	0.0037	0.0037	0.0046	0.0046

[1] Because of assumptions made in the OBAN model, only relative comparisons of survival among scenarios should be used.

Table 5.G-7. Differences (Percent Differences) in Mean and Median of Median Annual through-Delta Survival (Proportion of Fish) between Pairs of Model Scenarios[1,2], as Evaluated for Winter-Run Chinook Salmon with OBAN

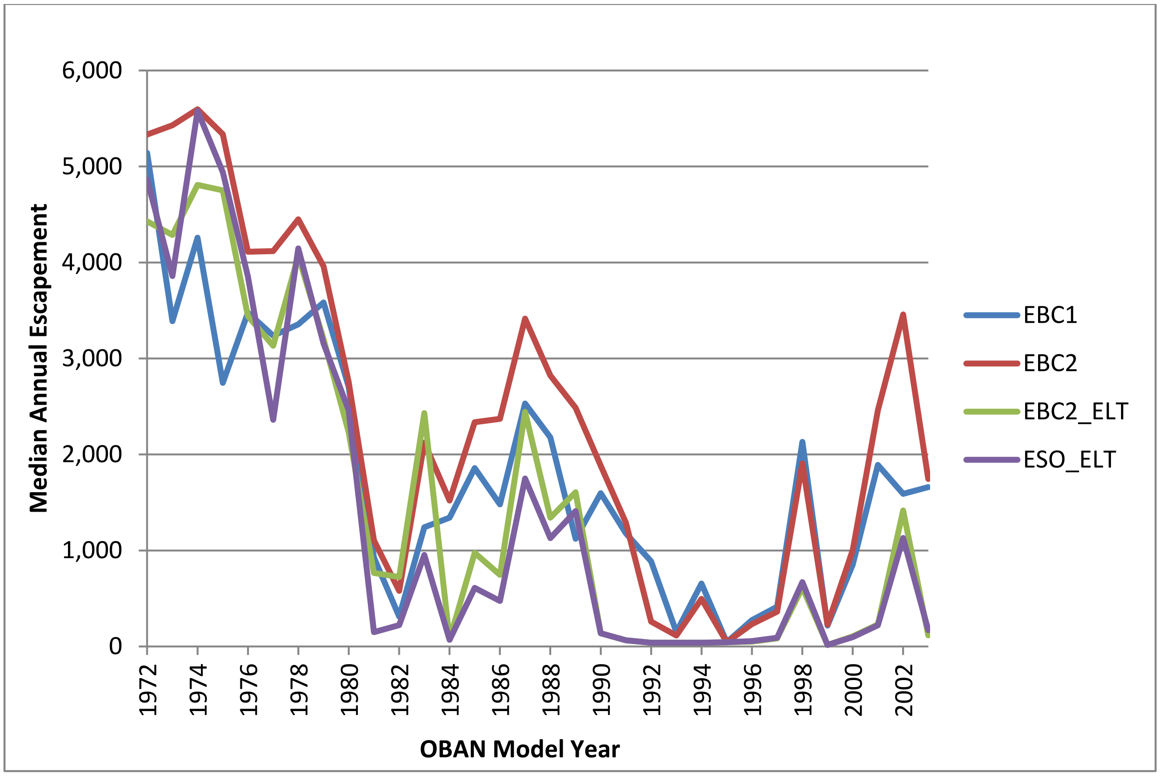
	EBC1 vs. ESO_ELT	EBC1 vs. ESO_LLT	EBC2 vs. ESO_ELT	EBC2 vs. ESO_LLT	EBC2_ELT vs. ESO_ELT	EBC2_LLT vs. ESO_LLT
Mean	0.0006 (15%)	0.0006 (15%)	0.0006 (14%)	0.0006 (15%)	0.0005 (12%)	0.0006 (13%)
Median	0.0008 (22%)	0.0009 (23%)	0.0009 (24%)	0.0009 (25%)	0.0009 (20%)	0.0009 (20%)

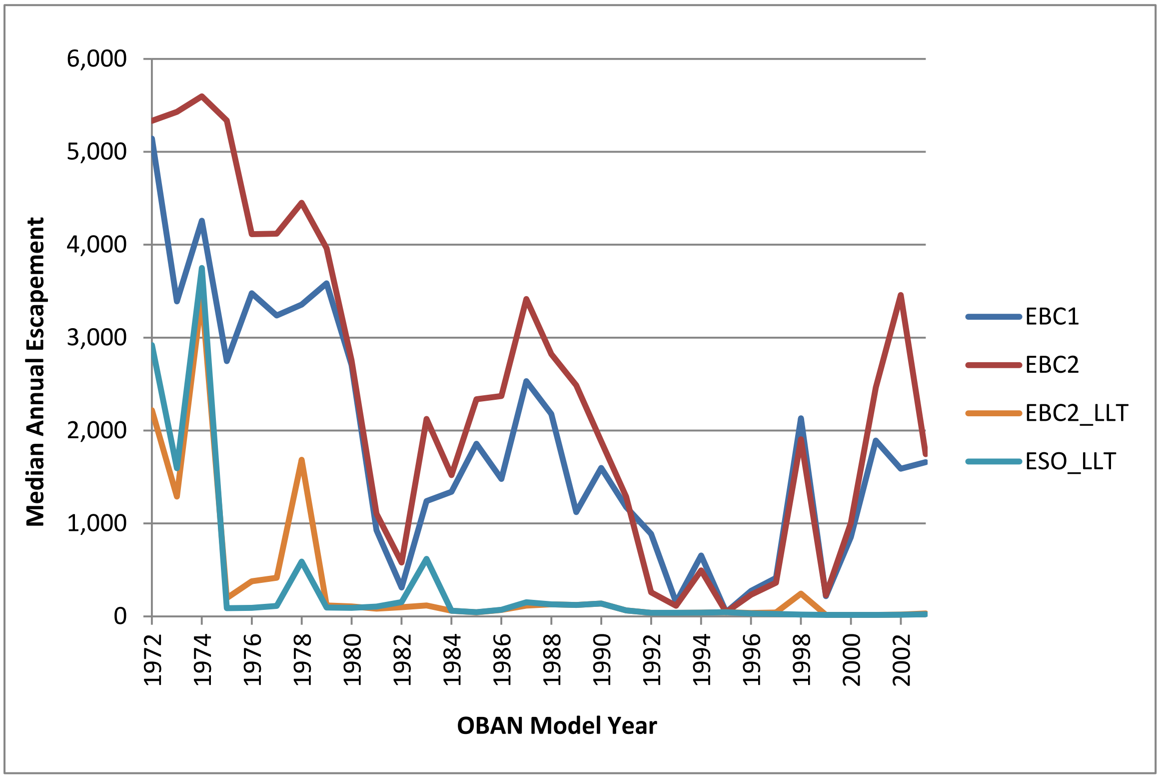
[1] A positive value indicates higher survival under the ESO.

[2] Because of assumptions made in the OBAN model, only relative comparisons of survival among scenarios should be used.

5.G.3.1.1.1 Adult Escapement

Median annual escapement (adults surviving to spawn) of winter-run Chinook varied among model scenarios and among years within each model scenario (Figure 5.G-15 and Figure 5.G-16). Escapement under all scenarios was low during the drought in the early 1990s. Median escapement generally was lower under EBC2_ELT than under EBC2 and generally lower under EBC2_LLT than under EBC2_ELT, indicating that climate change had an adverse effect on winter-run escapement. Median escapement under EBC2_ELT was generally higher than under ESO_ELT during the early portion of the time series, but escapement was similar after the late 1980s. Median escapement was similar under EBC2_LLT and ESO_LLT throughout much of the time series, with some exceptions in the 1970s (when EBC2_LLT was higher) and the early 1980s (when ESO_LLT was higher) (Figure 5.G-15). Median escapement under ESO_ELT and ESO_LLT was lower than EBC1 and EBC2 scenarios. Mean median escapement under ESO_ELT was 8% lower than that under EBC2_ELT, but mean median escapement under ESO_LLT was similar to that under EBC2_LLT (Table 5.G-8 and Table 5.G-9). Differences between the medians of median annual escapement were greater than the differences between means. The median of median escapement for ESO_ELT was 28% lower than the median for EBC2_ELT, and the median of median escapement for ESO_LLT was 13% lower than the median for EBC2_LLT (Table 5.G-9).





Note: Identical model input values not shown for years 1968-1971

Figure 5.G-15. Median Annual Adult Escapement (Thousands of Fish) of Winter-Run Chinook Predicted by OBAN for Each Model Scenario

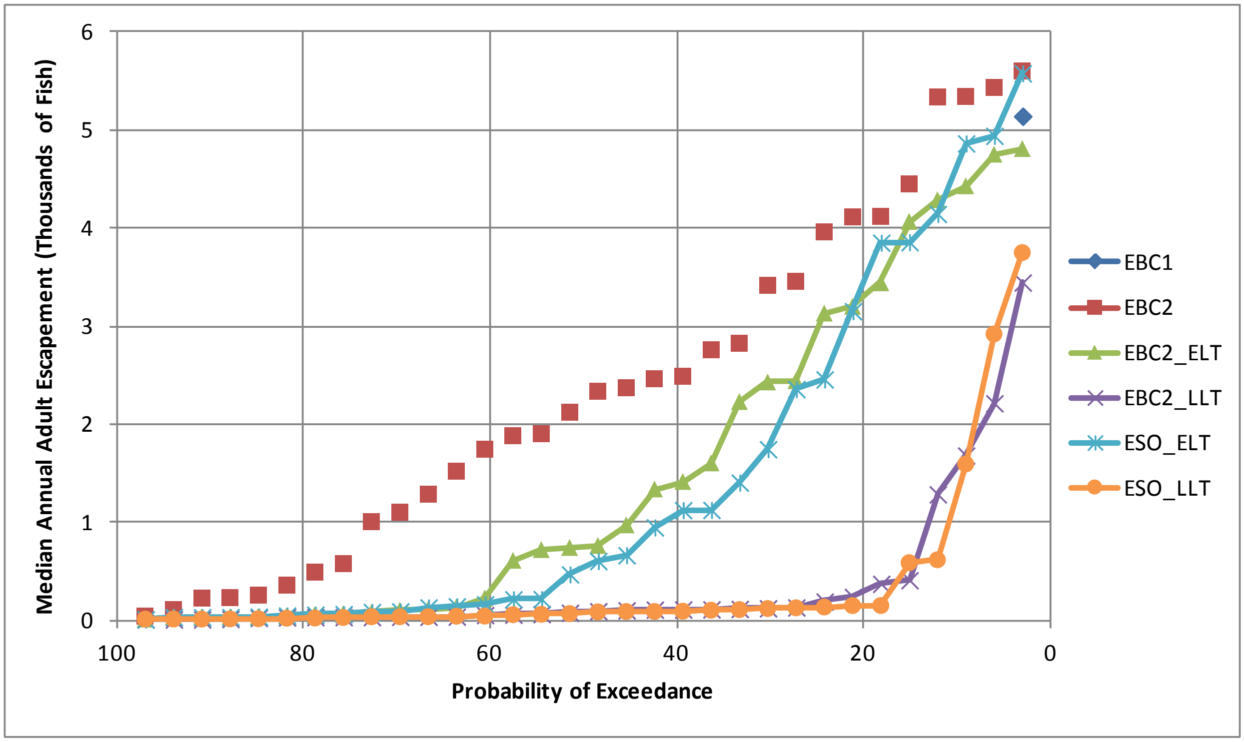


Figure 5.G-16. Probability of Exceedance Plot of Median Annual Adult Escapement (Thousands of Fish) Predicted Under the OBAN Model Scenarios

Table 5.G-8. Mean and Median of Median Annual Adult Escapement (Proportion of Fish) for Existing Biological Conditions (EBC1, EBC2, EBC2_ELT, and EBC2_LLT) and Evaluated Starting Operations (ESO_ELT and ESO_LLT) Scenarios[1], as Evaluated for Winter-Run Chinook Salmon with OBAN

	EBC1	EBC2	EBC2_ELT	EBC2_LLT	ESO_ELT	ESO_LLT
Mean	1,826	2,354	1,514	358	1,400	353
Median	1,593	2,231	755	91	542	80

[1] Because of assumptions made in the OBAN model, only relative comparisons of survival among scenarios should be used.

Table 5.G-9. Differences (Percent Differences) in Mean and Median of Median Annual Adult Escapement between Pairs of Model Scenarios[1]

	EBC1 vs. ESO_ELT	EBC1 vs. ESO_LLT	EBC2 vs. ESO_ELT	EBC2 vs. ESO_LLT	EBC2_ELT vs. ESO_ELT	EBC2_LLT vs. ESO_LLT
Mean	-426 (-23%)	-1,472 (-81%)	-954 (-41%)	-2,001 (-85%)	-114 (-8%)	-5 (-1%)
Median	-1,051 (-66%)	-1,513 (-95%)	-1,689 (-76%)	-2,151 (-96%)	-213 (-28%)	-12 (-13%)

[1] A negative value indicates lower escapement under the ESO.

[2] Because of assumptions made in the OBAN model, only relative comparisons of survival among scenarios should be used.

The lower escapement of winter-run Chinook under ESO compared with EBC2, even though through-Delta survival was higher under ESO, is the result of differences in modeled conditions in the Sacramento River above the Delta. In the Sacramento River spawning reaches, modeled water temperatures at Bend Bridge were higher (Figure 5.G-3) and minimum flow rate were lower (Figure 5.G-4) under the ESO compared to EBC2 scenarios, particularly during the ELT. These differences in Sacramento River conditions cause lower survival in ESO scenarios relative to EBC2 scenarios in the alevin and fry stages and are ultimately reflected in lower escapement under ESO. In the south Delta, December to June south Delta exports were lower under the ESO than under EBC2 scenarios (Figure 5.G-5), and winter-run access to Yolo bypass was greater under ESO than EBC2 scenarios (Figure 5.G-6).

The uncertainty in the escapement estimates was summarized by plotting the central 0.90 probability interval in two years, 1985 and 2002. In 1985 (the middle year of the time series), median escapement declined as climate change increases water temperature by the LLT in both the EBC and ESO scenarios (Figure 5.G-17). Median escapement under ESO_ELT (~610 fish) was lower than that under EBC2_ELT (~975 fish). Median escapement under ESO_LLT (~43 fish) was similar to that under EBC2_LLT (45 fish). However, there is a large 0.90 probability interval around each median value, reducing the confidence that there are true differences in predicted median escapement among model scenarios.

Patterns in estimated median escapement in 2002 (Figure 5.G-18), close to the end of the time series, have similarities and differences to those in 1985. Median escapement declines as climate change increases from EBC2 to EBC2_ELT to EBC_LLT and from ESO_ELT to ESO_LLT. Median escapement is around 20% lower under ESO_ELT (~1130 fish) than EBC2_ELT (~1420 fish) and 13% lower under ESO_LLT (~17 fish) than EBC2_ELT (~19 fish). The patterns in uncertainty in escapement indicate that the ESO_ELT and ESO_LLT could have occasionally higher escapement, despite median levels being slightly less than EBC2_ELT and EBC2_LLT, respectively.

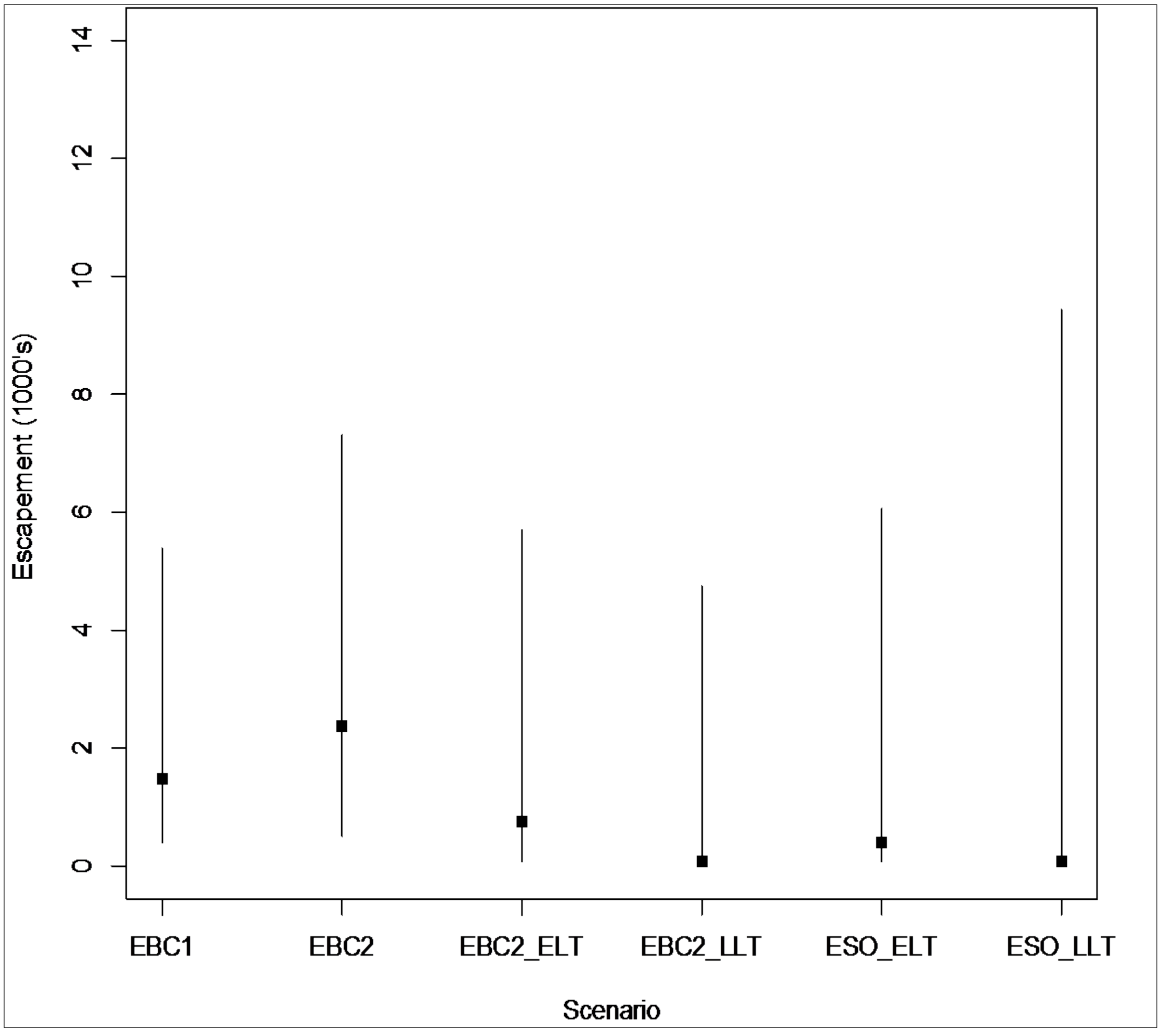


Figure 5.G-17. Median and Central 0.90 Probability Interval (5% to 95% Range) of Annual Adult Winter-Run Escapement (Thousands of Fish) in 1985 Predicted by OBAN for Each Model Scenario

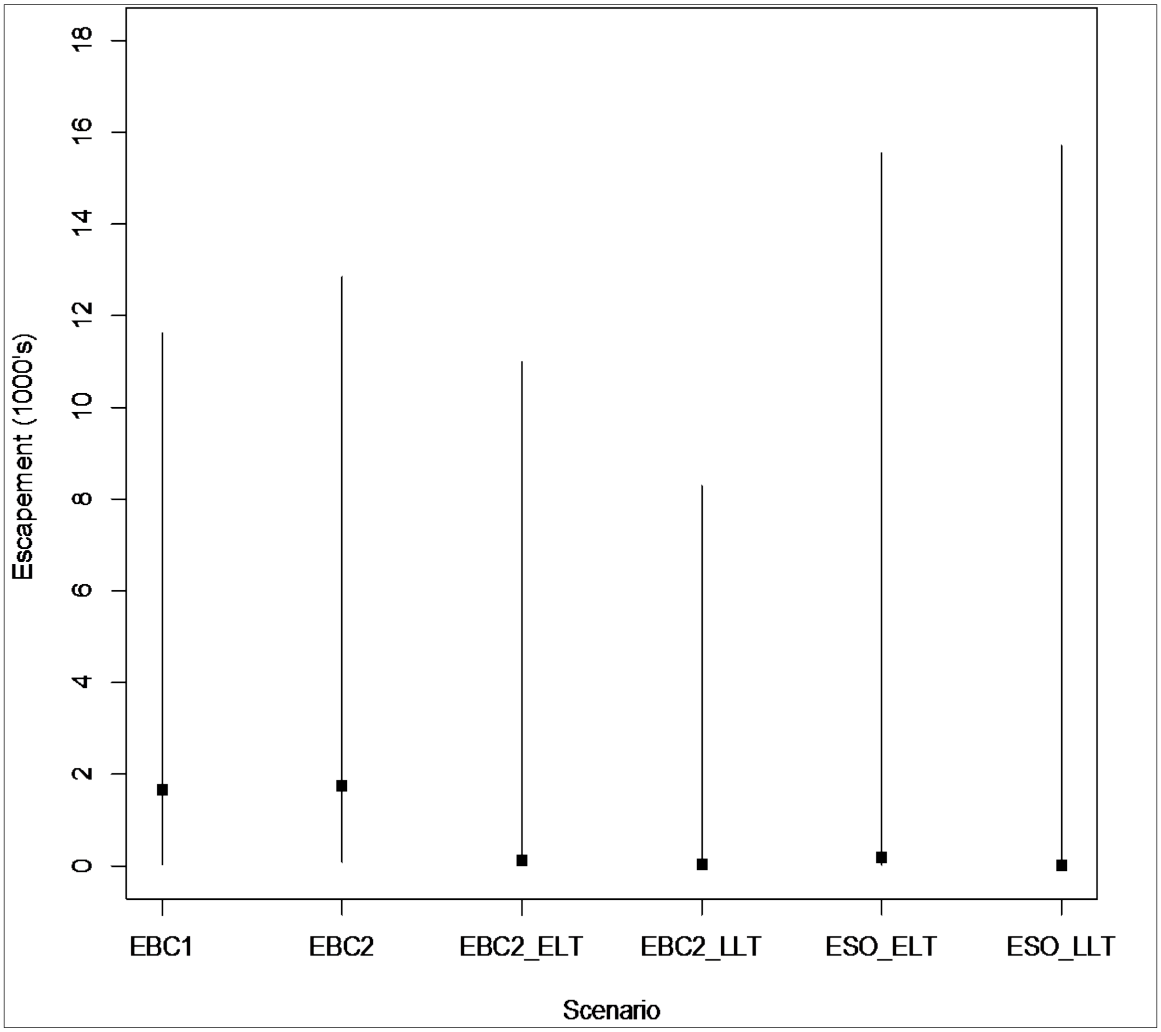


Figure 5.G-18. Median and Central 0.90 Probability Interval (5% To 95% Range) of Annual Adult Winter-Run Escapement (Thousands of Fish) in 2002 Predicted by OBAN for Each Model Scenario

5.G.3.1.1.2 HOS-LOS Scenarios

Mean and median of median through-Delta survival for HOS-LOS scenarios was similar to ESO scenarios at around 0.0044–0.0046 (Table 5.G-10). The HOS-LOS scenarios in the ELT and LLT were around 11–21% greater than EBC2 scenarios, depending on whether the mean or median of median through-Delta survival was compared (Table 5.G-11).

Table 5.G-10. Mean and Median of Median Annual through-Delta Survival (Proportion of Fish) for Existing Biological Conditions (EBC2_ELT and EBC2_LLT) and High-Outflow/Low-Outflow (HOS_ELT, HOS_LLT, LOS_ELT, and LOS_LLT) Scenarios[1], as Evaluated for Winter-Run Chinook Salmon with OBAN

	EBC2_ELT	EBC2_LLT	HOS_ELT	HOS_LLT	LOS_ELT	LOS_LLT
Mean	0.0039	0.0039	0.0044	0.0043	0.0044	0.0045
Median	0.0037	0.0037	0.0045	0.0045	0.0046	0.0046

[1] Because of assumptions made in the OBAN model, only relative comparisons of survival among scenarios should be used.

Table 5.G-11. Differences (Percent Differences) in Mean and Median of Median Annual through-Delta Survival (Proportion of Fish) between Pairs of Model Scenarios[1,2], as Evaluated for Winter-Run Chinook Salmon with OBAN

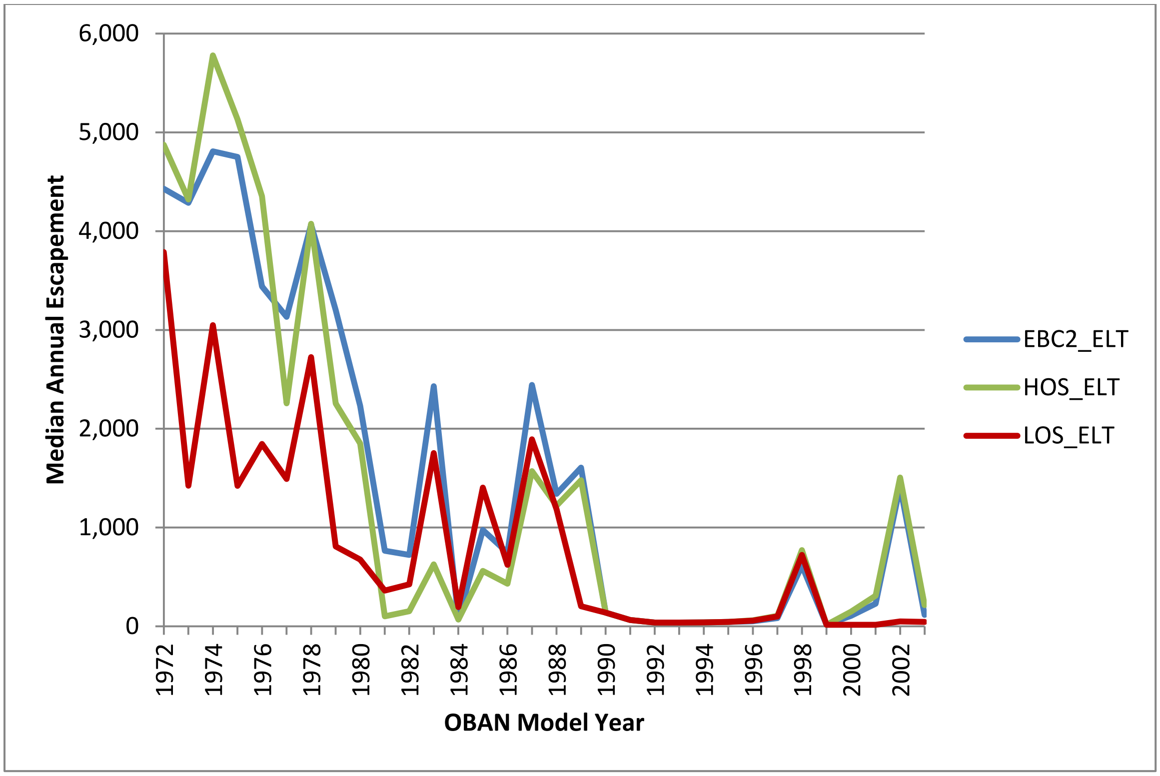
	EBC2_ELT vs. HOS_ELT	EBC2_LLT vs. HOS_LLT	EBC2_ELT vs. LOS_ELT	EBC2_LLT vs. LOS_LLT
Mean	0.0005 (11%)	0.0005 (11%)	0.0005 (12%)	0.0006 (14%)
Median	0.0008 (18%)	0.0008 (18%)	0.0009 (19%)	0.0010 (21%)

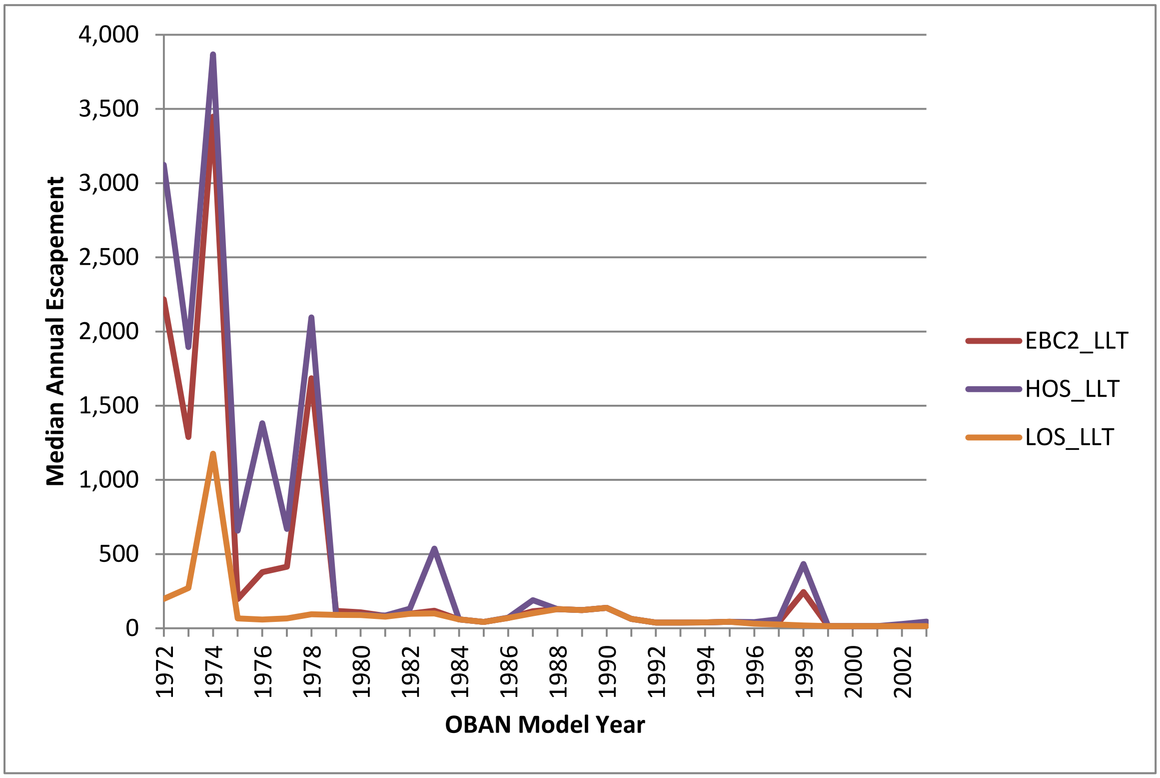
[1] A positive value indicates higher survival under the ESO.

[2] Because of assumptions made in the OBAN model, only relative comparisons of survival among scenarios should be used.

As noted for ESO scenarios, median annual escapement was appreciably lower for HOS_LLT and LOS_LLT scenarios than for HOS_ELT and LOS_ELT scenarios (Figure 5.G-19; Table 5.G-12). This resulted from the assumed upstream effects of climate change on the alevin life stage during the July–September period, which resulted in lower survival in upstream areas in the LLT than in the ELT. Mean HOS_ELT median escapement was slightly lower (8%) than mean EBC2_ELT median escapement, whereas the median of HOS_ELT median escapement was more than 30% lower than mean EBC2_ELT median escapement (Table 5.G-13). In contrast, the median of HOS_ELT median escapement was similar to the median of EBC2_ELT median escapement and the mean HOS_LLT median escapement was more than 40% greater than the mean EBC2_LLT median escapement. The LOS scenarios had escapement estimates that were ~30–70% less than the corresponding EBC2 scenarios (Table 5.G-13).

Synthesizing the differences between the EBC2 scenarios and the ESO/HOS/LOS scenarios showed that there was a similar relative difference between the ESO_ELT/HOS_ELT scenarios and the EBC2_ELT scenario, at 8–34% less than under the ESO/HOS scenarios depending if the mean or median statistic was used. This was not the case for the LLT scenarios, which showed differences between HOS and ESO compared with EBC2. The HOS_LLT scenario had similar or greater escapement than the EBC2_LLT scenario, whereas the ESO_LLT scenario had similar or slightly lower escapement than the EBC2_LLT scenario. The LOS scenarios had mean/median annual median escapement that was appreciably less than the EBC2 scenarios. Because the through-Delta survival estimates were very similar among the ESO/HOS/LOS scenarios, the results reflect upstream differences in survival caused by flow or temperature differences between scenarios. The OBAN model includes Bend Bridge inputs for July–September average temperature and August–November minimum flow rate, which affect alevin and fry survival. The HOS, ESO, and EBC2 scenarios are differentiated from the LOS scenario by the exclusion of the Fall X2 action, which would require reservoir releases and, therefore, give lower flows and higher water temperatures under the LOS scenario. ESO, LOS, and HOS scenarios were modeled to avoid changes in Shasta Reservoir criteria, and thus avoid BDCP-related changes in upstream water temperatures. However, some small summertime flow changes in the model likely drive the differences in ESO, HOS, and LOS escapement, which are amplified over the 50-year modeling horizon.





Note: Identical model input values not shown for years 1968-1971

Figure 5.G-19. Median Annual Escapement of Winter-Run Chinook Salmon from OBAN for EBC2 and HOS/LOS Scenarios

Table 5.G-12. Mean and Median of Median Annual Adult Escapement for Existing Biological Conditions (EBC2_ELT and EBC2_LLT) and High-Outflow/Low-Outflow (HOS_ELT, HOS_LLT, LOS_ELT, and LOS_LLT) Scenarios[1], as Evaluated for Winter-Run Chinook Salmon with OBAN

	EBC2_ELT	EBC2_LLT	HOS_ELT	HOS_LLT	LOS_ELT	LOS_LLT
Mean	1,514	358	1,394	508	833	107
Median	755	91	496	88	393	65

[1] Because of assumptions made in the OBAN model, only relative comparisons of escapement among scenarios should be used.

Table 5.G-13. Differences (Percent Differences) in Mean and Median of Median Annual Adult Escapement between Pairs of Model Scenarios[1,2], as Evaluated for Winter-Run Chinook Salmon with OBAN

	EBC2_ELT vs. HOS_ELT	EBC2_LLT vs. HOS_LLT	EBC2_ELT vs. LOS_ELT	EBC2_LLT vs. LOS_LLT
Mean	-120 (-8%)	150 (42%)	-681 (-45%)	-252 (-70%)
Median	-259 (-34%)	-3 (-3%)	-362 (-48%)	-26 (-29%)

[1] A positive value indicates higher survival under the HOS or LOS.

[2] Because of assumptions made in the OBAN model, only relative comparisons of survival among scenarios should be used.

The results of the sensitivity analysis showed that, in comparison with the 0% mortality scenarios, increasing through-Delta mortality under the HOS and LOS scenarios resulted in slightly lower overall escapement. The mean of median escapement was 0.3% lower under the 0.5% mortality assumption, 0.6% lower with 1% mortality, and ~3% lower with 5% mortality, for the HOS_ELT, HOS_LLT, and LOS_ELT scenarios (Table 5.G-14). For the HOS_ELT and LOS_ELT scenarios, the median of median escapement was 0.4–0.5% lower with 0.5% mortality, 0.8–0.9% lower with 1% mortality, and 4.4–4.6% lower with 5% mortality. Increasing through-Delta mortality by up to 5% had little effect on the mean or median of the median escapement for the LOS_LLT scenario. Increasing through-Delta mortality had little effect on the median of the median escapement for HOS_LLT until 5% mortality was assumed, resulting in a 1% reduction in escapement (Table 5.G-14).

On this basis, the results of the preliminary sensitivity analyses indicate that increases of through-Delta mortality of up to 5% would not have a large effect on overall adult escapement. Therefore, the OBAN model analysis suggests that the results are driven by modeled flow modifications in the upper Sacramento River and associated effects on water temperature conditions experienced by aelvins on and near the spawning grounds. However, as noted above, the BDCP does not include Shasta Reservoir operational criteria changes, and therefore does not affect how cold water pool and flows in the upper Sacramento River are managed. The reduced escapement under ESO, and improved escapement under LOS and HOS, demonstrates the variable nature of flows in the Sacramento River and that the range of BDCP scenarios are able to ensure that there is no change from BDCP in the upper Sacramento River compared to conditions without BDCP.

Table 5.G-14. Mean and Median of Median Annual Escapement of Winter-Run Chinook Salmon from OBAN for HOS/LOS Scenarios, Applying Delta Mortality Rates of 0%, 0.5%, 1%, and 5%

	Escapement		Difference from 0%	
Scenario	**Mean**	**Median**	**Mean**	**Median**
HOS_ELT 0.0%	1,394	496		
HOS_ELT 0.5%	1,390	494	-0.3%	-0.4%
HOS_ELT 1.0%	1,385	492	-0.6%	-0.8%
HOS_ELT 5.0%	1,350	474	-3.1%	-4.4%
HOS_LLT 0.0%	508	88		
HOS_LLT 0.5%	507	88	-0.3%	0.0%
HOS_LLT 1.0%	505	88	-0.6%	-0.1%
HOS_LLT 5.0%	494	87	-2.8%	-1.0%
LOS_ELT 0.0%	833	393		
LOS_ELT 0.5%	830	391	-0.3%	-0.5%
LOS_ELT 1.0%	828	389	-0.6%	-0.9%
LOS_ELT 5.0%	810	375	-2.8%	-4.6%
LOS_LLT 0.0%	107	65		
LOS_LLT 0.5%	107	65	0.0%	0.0%
LOS_LLT 1.0%	107	65	0.0%	0.0%
LOS_LLT 5.0%	106	65	-0.1%	0.0%
Percentages are Differences from 0% Mortality for 0.5-5% Mortality Scenarios for HOS_ELT, HOS_LLT, LOS_ELT, and LOS_LLT				

5.G.3.2 Interactive Object-Oriented Simulation (IOS) Model

5.G.3.2.1 Winter-Run Chinook Salmon

5.G.3.2.1.1 Egg Survival

IOS model results for egg survival are calculated as a proportion of eggs projected to survive incubation each year, or the annual egg survival rate. As discussed in Section 5.G.5 *Methods*, the egg survival rate reflects the projected effects of water temperature conditions on incubation success. The model water temperature inputs are a weighted average of representative water temperatures for spawning habitat, calculated for each model year. The yearly water temperature inputs are derived from an average of SRWQM-modeled temperatures for the Balls Ferry and Keswick model nodes, weighted by the observed spawning distribution of winter-run Chinook between these two locations.

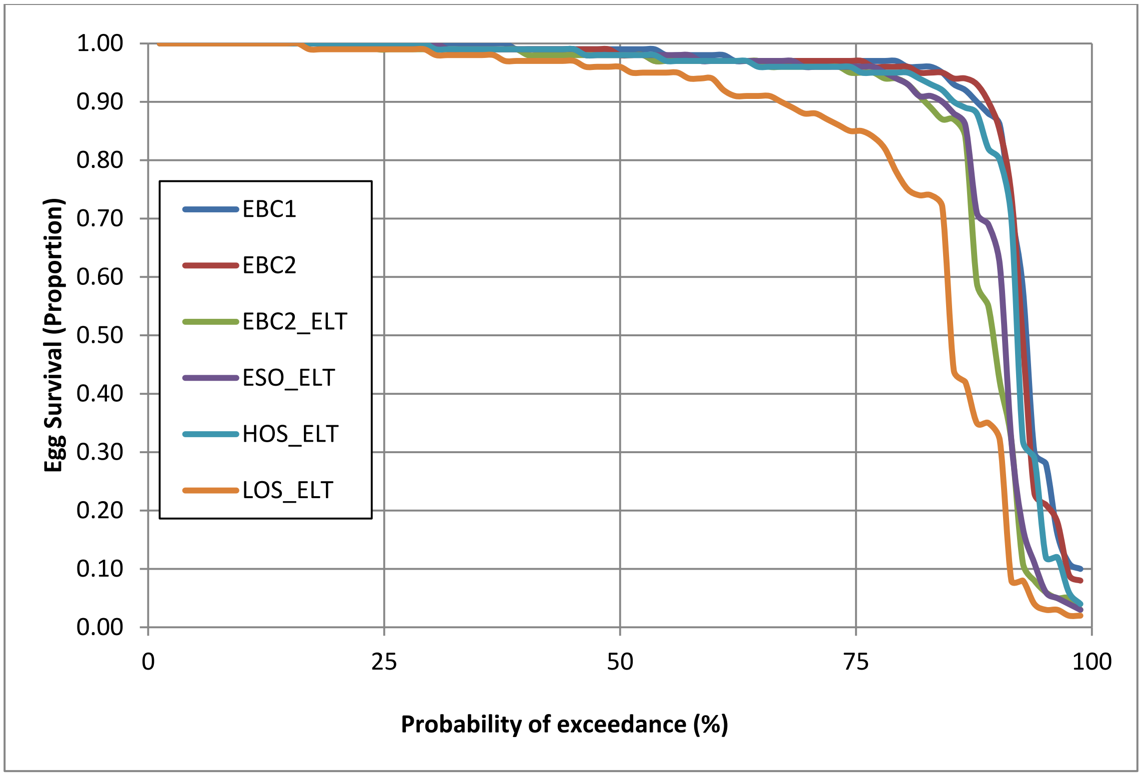
IOS egg survival results are summarized in Table 5.G-15, and illustrated graphically in Figure 5.G-20, and Figure 5.G-21. The proportion of eggs surviving was highly variable among years and model scenarios and ranged from 0.10 to 1.00 (Table 5.G-15, Figure 5.G-20). Mean proportion of eggs surviving ranged from 0.81 (EBC2_LLT, LOS_LLT) to 0.92 (EBC1 and EBC2); median proportion of eggs surviving ranged from 0.94 (ESO_LLT) to 0.99 (EBC1) (Table 5.G-15, Figure 5.G-21). There are distinct differences in estimated egg survival rates between existing conditions (EBC1 and EBC2), the ELT period (EBC2_ELT and ESO_ELT), and the LLT period (EBC2_LLT and ESO_LLT). In general, IOS predicted decreasing egg survival rates as water temperatures in the Sacramento River warm under projected climate change conditions.

Differences in mean and median proportion of egg survival between pairs of ELT and LLT scenarios are presented in Table 5.G-16 and Table 5.G-17, respectively. In the ELT, mean egg survival rates were similar to or better than EBC2 under the ESO (0.01, 1%) and HOS (0.03, 3%) scenarios, and lower under the LOS scenario (-0.05, -6%). Median ESO_ELT and HOS_ELT survival rates were identical to EBC2_ELT, while the LOS_ELT survival rate was slightly lower at -0.02 (-2%). Over the LLT, the ESO scenario had slightly lower mean (-0.01, -1%) and median (-0.02, -2%) than EBC2. The LOS scenario had an identical mean and slightly lower median (-0.01, -1%) survival rate. In contrast, the HOS scenario had a substantially higher mean (0.07, 9%) and higher median survival rates (0.02, 2%) than EBC2_LLT.

As described in Section 5.G.5, *Methods*, the IOS model assumes a high sensitivity of winter-run Chinook salmon eggs to elevated water temperature. Weighted mean daily water temperatures between Keswick and Balls Ferry during the predominant egg deposition period (roughly estimated as the May through August spawning window) was 0.0.8°F higher under ESO_ELT compared to EBC2_ELT and 0.15°F higher under ESO_LLT compared to EBC2_LLT. These small temperature differences are potentially significant, however they occur below the inflection point on the egg survival curve calculated by Equation 7 (Section 5.G.5, *Methods*). Climate change had a much larger effect on projected temperatures, with temperature increases under all scenarios ranging from 0.76°F to 1.6°F higher than EBC2 under both the ELT and LLT time frames. Overall, the BDCP scenarios are projected to maintain, if not improve egg survival over time. The modeled results for the LOS scenario show a decrease in egg survival rates over the ELT, and survival rates similar to EBC2 over the LLT. However, as noted above, the BDCP does not include Shasta Reservoir operational criteria changes, and therefore does not affect how cold water pool and flows in the upper Sacramento River are managed. The modeled slight changes in egg survival from BDCP scenarios demonstrates the variable nature of flows in the Sacramento River and that the range of BDCP scenarios are able to ensure that there is no change from BDCP in the upper Sacramento River compared to conditions without BDCP.

Table 5.G-15. Winter-Run Chinook Salmon Egg Survival (Proportion) for Each Model Scenario

Statistic	EBC1	EBC2	EBC2_ELT	EBC2_LLT	ESO_ELT	ESO_LLT	HOS_ELT	HOS_LLT	LOS_ELT	LOS_LLT
Mean	0.92	0.92	0.88	0.81	0.89	0.80	0.91	0.89	0.83	0.81
Minimum	0.10	0.08	0.03	0.02	0.03	0.02	0.04	0.03	0.02	0.02
25th Percentile	0.97	0.97	0.95	0.82	0.96	0.77	0.96	0.96	0.85	0.80
Median	0.99	0.98	0.98	0.96	0.98	0.94	0.98	0.98	0.96	0.95
75th Percentile	1.00	1.00	0.99	0.99	1.00	0.98	1.00	0.99	0.99	0.99
Maximum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00



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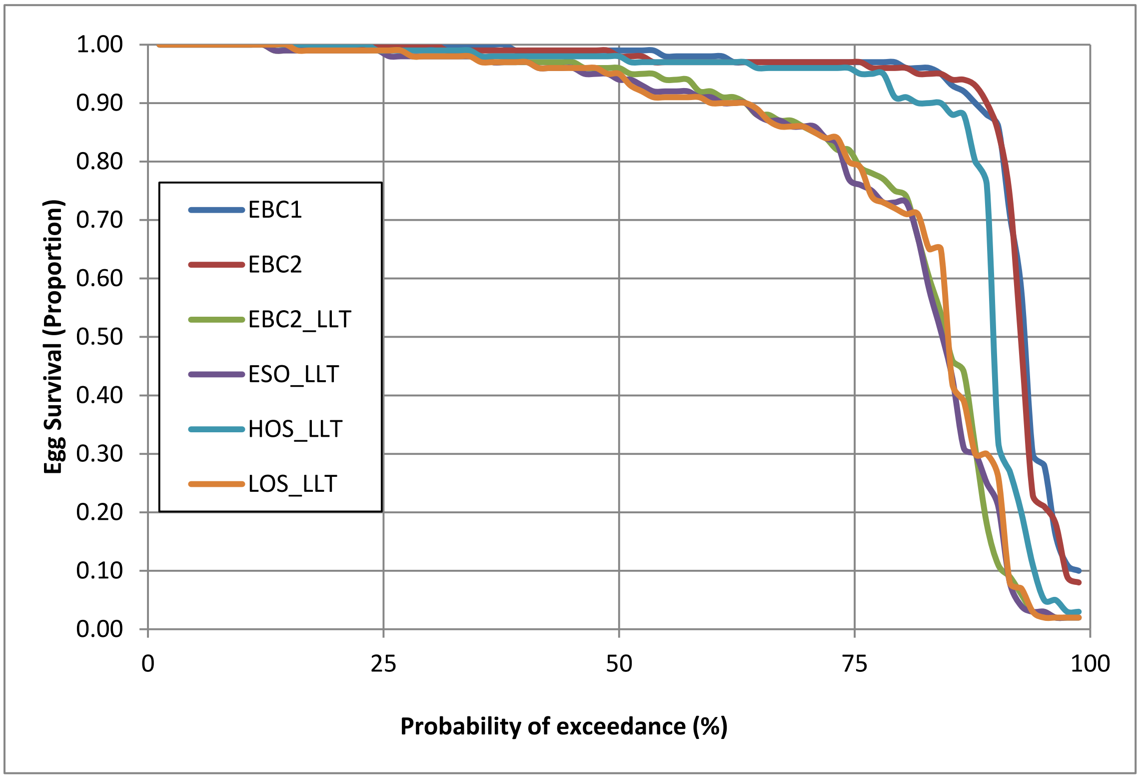

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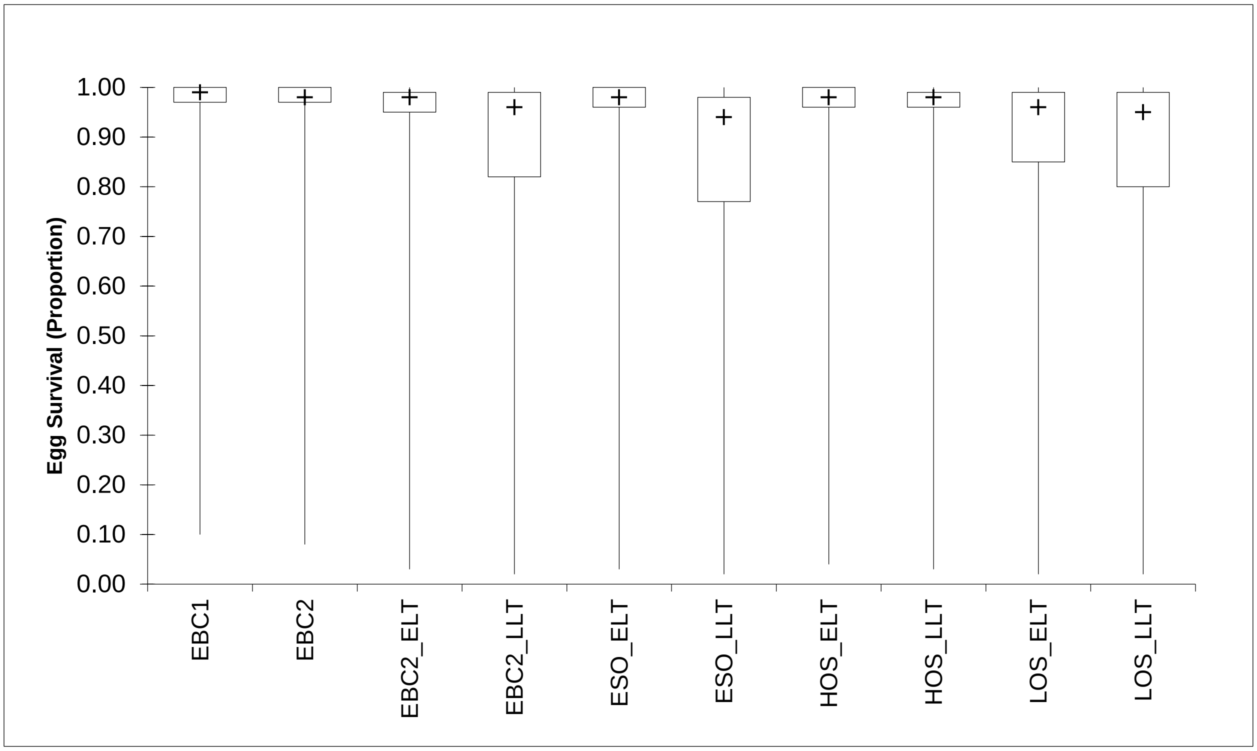
3 **Figure 5.G-20. Probability of Exceedance Plots for Sacramento Winter-Run Chinook Salmon Egg**
4 **Survival Under Each Model Scenario in the Early-Long Term and Late-Long Term**



Median is marked with "+," the boundaries of the box indicate 75th and 25th percentiles, upper and lower whiskers indicate maximum and minimum proportional survival.

Figure 5.G-21. Box Plots of Sacramento Winter-Run Chinook Salmon Egg Survival (Proportion) for Each Model Scenario

Table 5.G-16. Differences (Percent Differences) in Mean and Median Proportion of Egg Survival between Pairs of Early-Long Term Model Scenarios[1]

Statistic	EBC1 vs. ESO_ELT	EBC2 vs. ESO_ELT	EBC2_ELT vs. ESO_ELT	EBC2_ELT vs. HOS_ELT	EBC2_ELT vs. LOS_ELT
Mean	-0.03 (-4%)	-0.03 (-3%)	0.01 (1%)	0.03 (3%)	-0.05 (-6%)
Median	-0.01 (-1%)	0.0 (0%)	0.0 (0%)	0.0 (0%)	-0.02 (-2%)
[1] A positive value indicates higher egg survival under the BDCP.					

Table 5.G-17. Differences (Percent Differences) in Mean and Median Proportion of Egg Survival between Pairs of Late-Long Term Model Scenarios[1]

Statistic	EBC1 vs. ESO_LLT	EBC2 vs. ESO_LLT	EBC2_LLT vs. ESO_LLT	EBC2_LLT vs. HOS_LLT	EBC2_LLT vs. LOS_LLT
Mean	-0.12 (-13%)	-0.12 (-13%)	-0.01 (-1%)	0.07 (9%)	0 (0%)
Median	-0.05 (-5%)	-0.04 (-4%)	-0.02 (-2%)	0.02 (2%)	-0.01 (-1%)
[1] A positive value indicates higher egg survival under the BDCP.					

5.G.3.2.1.2 Fry Rearing

IOS model results for winter-run Chinook fry survival are calculated as the proportion of fry that survive fry dispersal and migration through the Sacramento River corridor each year, or the annual fry survival rate. As discussed in Section 5.G.5 *Methods*, the fry survival rate reflects the projected effects of water temperature conditions on fry survival. Similar to the methods used in IOS to calculate the egg survival rate, weighted average of representative water temperatures for spawning habitat are used to calculate fry survival on the basis that fry dispersal and early rearing occurs in the same general area as spawning.

IOS estimates of fry survival are summarized in Table 5.G-18, and illustrated graphically in Figure 5.G-22, and Figure 5.G-23. As shown, the range of projected fry survival rates varies widely in every scenario, driven by a small number of low outliers, but the central tendency is restricted to a relatively narrow rage that is generally consistent between scenarios across the ELT and LLT timeframes. Mean proportion of fry surviving ranged from 0.75 (ESO_LLT) to 0.90 (EBC1); median proportion of eggs surviving ranged from 0.88 (ESO_LLT) to 0.95 (EBC1, EBC2) (Table 5.G-18, Figure 5.G-23).

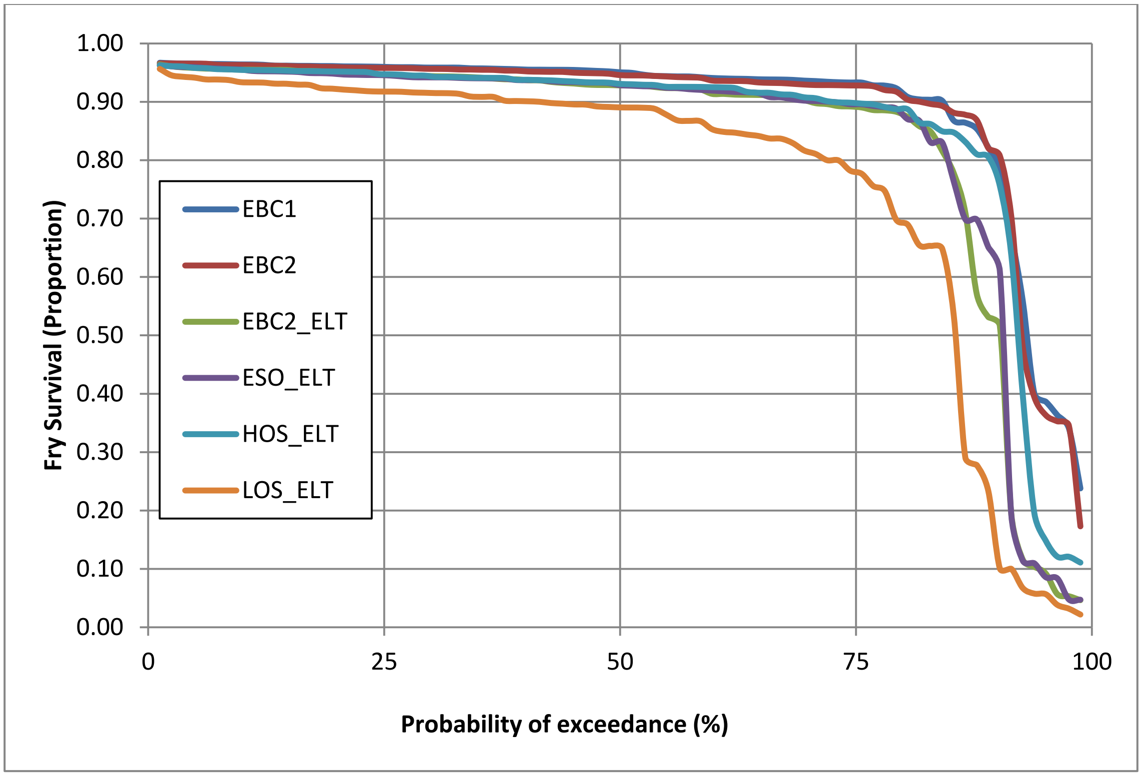
Table 5.G-19 summarizes the differences in mean and median fry survival between pairs of model scenarios over the ELT and LLT, respectively. Table 5.G-20 summarizes differences in mean and median fry survival between pairs of model scenarios over the LLT.

As described in Section 5.G.5, *Methods*, the IOS model assumes a high sensitivity of winter-run Chinook salmon fry survival to elevated water temperature, slightly lower than for egg survival as fry have the ability to adapt to temperature conditions behaviorally. Therefore, the future climate change scenarios would be expected to have a negative effect on fry survival over time. The IOS model results reflect this temperature sensitivity. Mean and median fry survival rates under future conditions without BDCP (EBC2_ELT) are -0.05 (-6%) and -0.02 (-2%) lower than EBC1 and EBC2. Over the LLT, mean and median fry survival rates without the BDCP decline by -0.15 (16%) and -0.07 (-7%), respectively, reflecting a clear climate change-related temperature effect.

With the exception of the LOS scenarios, the BDCP produces fry survival rates that are generally comparable to EBC2 over the same periods. The ESO_ELT generally maintains comparable mean (0.005, 1%) and median (0, 0%) survival rates to EBC2_ELT, but mean and median ESO_LLT survival rates both decline slightly (-0.01, -1%) compared with EBC2_LLT. In contrast, the HOS scenario is projected to slightly increase the mean survival rate by 0.03 (3%) relative to EBC2 over the ELT. The HOS_LLT scenario maintains the same survival rates as the EBC2_ELT scenario. Relative to EBC2_LLT, the HOS_LLT scenario increases mean and median fry survival rates by 0.09 (11%) and 0.04 (4%), respectively. The LOS scenario results in a -0.07 (-9%) reduction in mean and -0.04 (-4%) reduction in median survival rate relative to EBC2 over the ELT. In contrast, over the LLT the LOS scenario maintains median survival and slightly increases (0.01, 1%) mean survival relative to EBC2.

Table 5.G-18. Winter-Run Chinook Salmon Fry Survival (Proportion) for Each Model Scenario

Statistic	EBC1	EBC2	EBC2_ELT	EBC2_LLT	ESO_ELT	ESO_LLT	HOS_ELT	HOS_LLT	LOS_ELT	LOS_LLT
Mean	0.90	0.89	0.84	0.76	0.84	0.75	0.86	0.84	0.77	0.77
Minimum	0.24	0.17	0.05	0.02	0.05	0.03	0.11	0.06	0.02	0.03
25th Percentile	0.93	0.93	0.89	0.79	0.90	0.79	0.90	0.90	0.78	0.80
Median	0.95	0.95	0.93	0.89	0.93	0.88	0.93	0.93	0.89	0.89
75th Percentile	0.96	0.96	0.95	0.92	0.95	0.91	0.95	0.95	0.92	0.92
Maximum	0.97	0.97	0.96	0.96	0.96	0.95	0.96	0.96	0.96	0.96



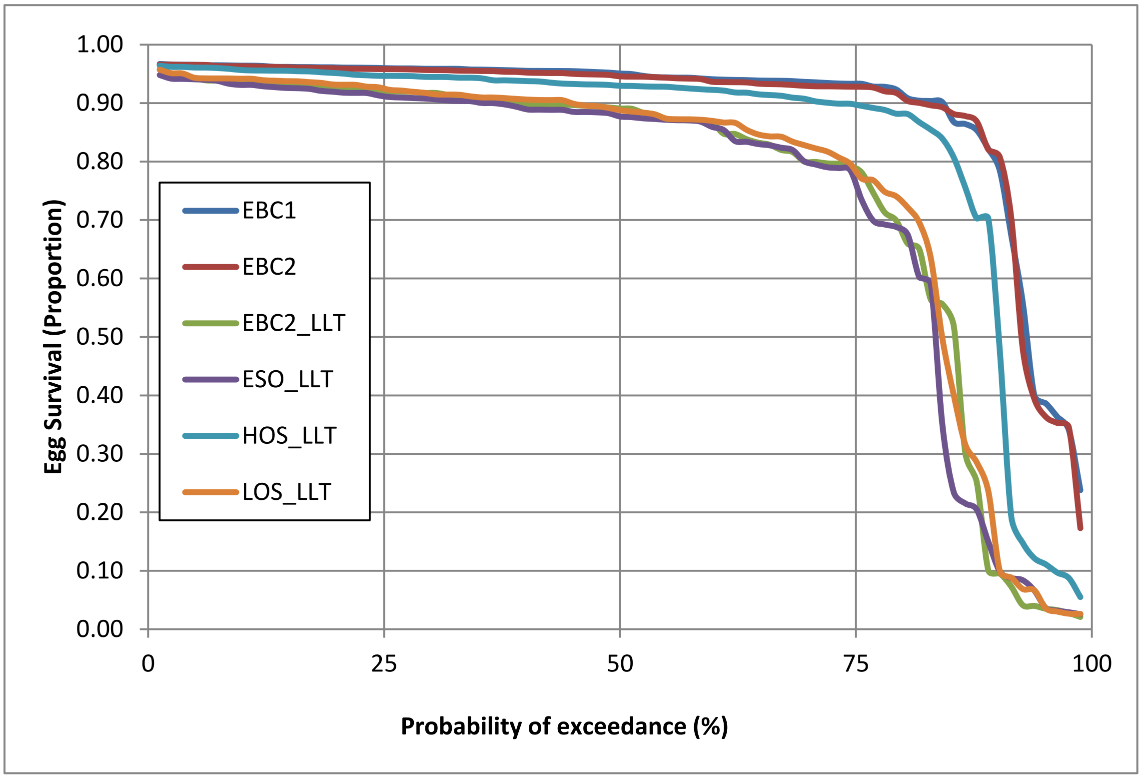
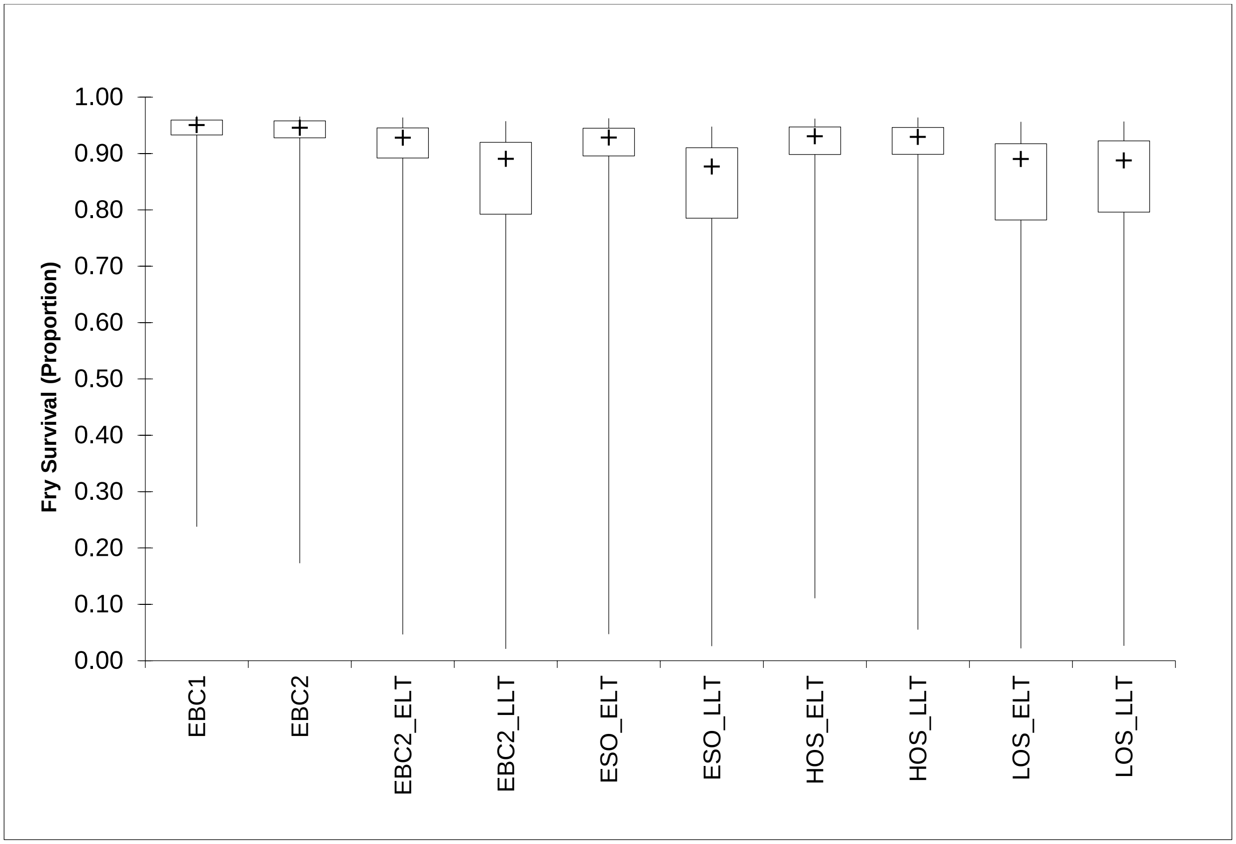


Figure 5.G-22. Exceedance Plots for Sacramento Winter-Run Chinook Salmon Fry Survival (Proportion) for Each Model Scenario



Median is marked with "+," the boundaries of the box indicate 75th and 25th percentiles, upper and lower whiskers indicate maximum and minimum proportional survival.

Figure 5.G-23. Box Plots of Sacramento Winter-Run Chinook Salmon Fry Survival (Proportion) for Each Model Scenario

Table 5.G-19. Differences (Percent Differences) in Mean and Median Proportion of Fry Survival between Pairs of Early-Long Term Model Scenarios[1]

Statistic	EBC1 vs. ESO_ELT	EBC2 vs. ESO_ELT	EBC2_ELT vs. ESO_ELT	EBC2_ELT vs. HOS_ELT	EBC2_ELT vs. LOS_ELT
Mean	-0.06 (-6%)	-0.05 (-6%)	0.005 (1%)	0.03 (3%)	-0.07 (-9%)
Median	-0.02 (-2%)	-0.02 (-2%)	0.0 (0%)	0.0 (0%)	-0.04 (-4%)
[1] A positive value indicates higher egg survival under the BDCP.					

Table 5.G-20. Differences (Percent Differences) in Mean and Median Proportion of Fry Survival between Pairs of Late-Long Term Model Scenarios[1]

Statistic	EBC1 vs. ESO_LLT	EBC2 vs. ESO_LLT	EBC2_LLT vs. ESO_LLT	EBC2_LLT vs. HOS_LLT	EBC2_LLT vs. LOS_LLT
Mean	-0.15 (-17%)	-0.15 (-16%)	-0.01 (-2%)	0.09 (11%)	0.01 (1%)
Median	-0.07 (-8%)	-0.07 (-7%)	-0.01 (-2%)	0.04 (4%)	0.0 (0%)

[1] A positive value indicates higher egg survival under the BDCP.

5.G.3.2.1.3 Through-Delta Survival

IOS model results for through-Delta survival of juvenile winter-run Chinook salmon are presented as a proportion of migrant smolts that survive passage through the Delta and reach the San Francisco Bay estuary each year. As discussed in Section 5.G.5, *Methods*, the through-Delta survival rate is evaluated in IOS using four primary functional relationships: 1) route selection by migrating juveniles at river junctions; 2) reach-specific flow to survival rate relationships for each potential migratory pathway; 3) migration speed, which is a function of reach-specific flow rate; and 4) export mortality resulting from entrainment at the existing State and Federal water pumping facilities in the South Delta.

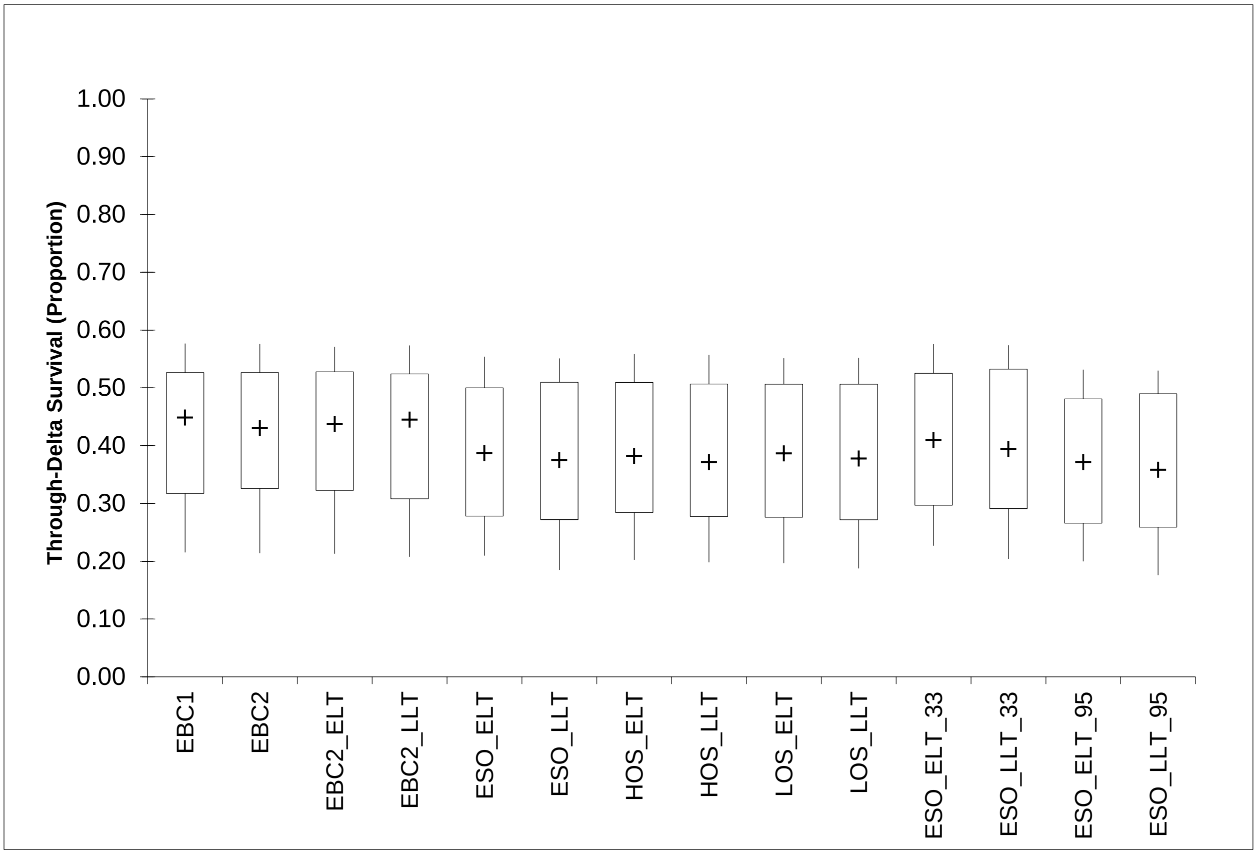
IOS estimates of winter-run Chinook salmon smolt survival through the Delta are summarized in Table 5.G-21, and illustrated graphically in Figure 5.G-24, and Figure 5.G-25. Minimum survival rates ranged from 0.18 (ESO_LLT) to 0.22 (EBC1) and maximum survival rates ranged from 0.55 (ESO_ELT, LOS_ELT, LOS_LLT) to 0.58 (EBC1, EBC2) (Table 5.G-21, Figure 5.G-25). Mean and median survival rates ranged from a high of 0.42 and 0.45, respectively, under the EBC1 scenario to a low of 0.38 and 0.37, respectively, under the ESO_LLT scenario. The EBC2_ELT and EBC2_LLT scenarios are projected to maintain a similar range of through-Delta rates to the current EBC2 scenario.

In general, the BDCP scenarios resulted in slightly lower through-Delta survival rates overall, with the survival rates for each scenario varying over a similar range. Table 5.G-25 and Table 5.G-26 illustrate the comparative range and extent of survival rates between scenarios.

Table 5.G-22 and Table 5.G-23 summarize the differences in mean and median through-Delta smolt survival between pairs of model scenarios. Projected mean and median through-Delta survival were lower under ESO than EBC2, with the differences of -0.03 (-7%) in mean and -0.05 to -0.07 (-12% to -16%) median rates over the ELT, and -0.03 (-8%) and -0.05 to -0.07 (-12% to -17%) over the LLT, respectively. The differences were similar when compared to the current EBC1 and EBC2 scenarios. The differences are largest between scenarios in the central tendency of survival rates (Figure 5.G-23). The lower BDCP scenario survival rates were the result of increased flow-related mortality in specific model reaches in the Delta.

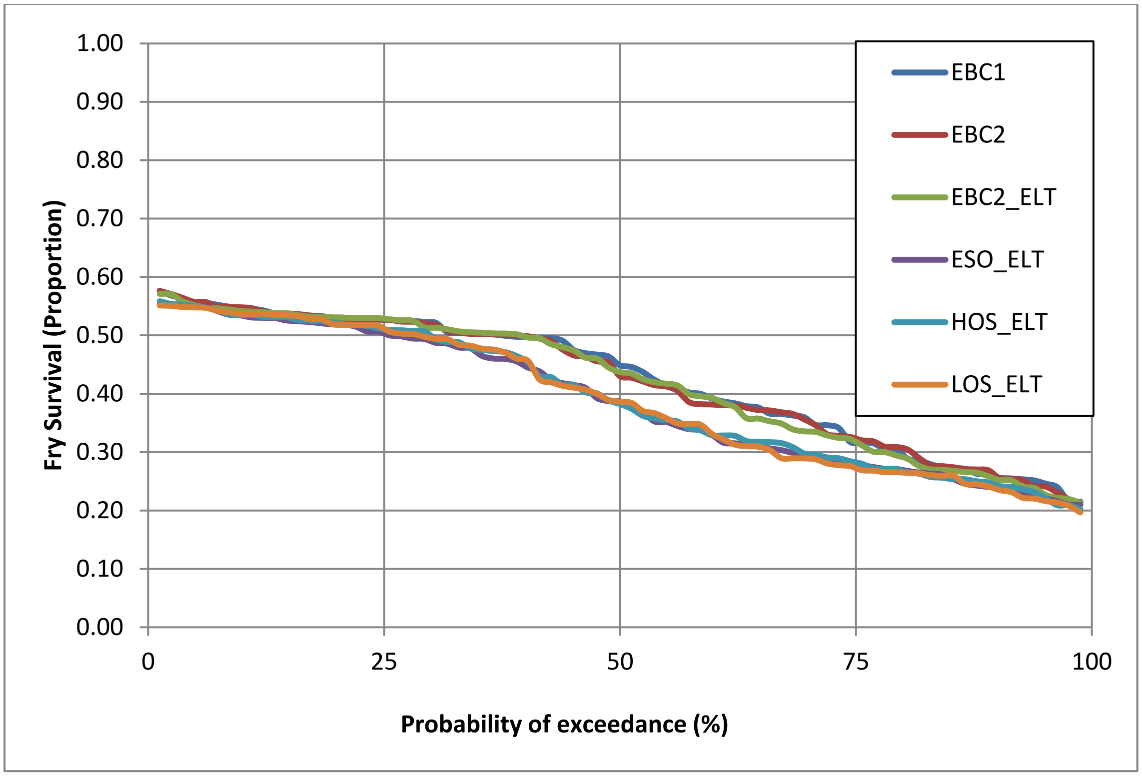
Table 5.G-21. Winter-Run Chinook salmon Smolt Survival through the Delta (Proportion) for each model scenario.

Statistic	EBC1	EBC2	EBC2_ELT	EBC2_LLT	ESO_ELT	ESO_LLT	HOS_ELT	HOS_LLT	LOS_ELT	LOS_LLT
Mean	0.42	0.42	0.42	0.42	0.39	0.38	0.39	0.39	0.39	0.39
Minimum	0.22	0.21	0.21	0.21	0.21	0.18	0.20	0.20	0.20	0.19
25th Percentile	0.32	0.33	0.32	0.31	0.28	0.27	0.28	0.28	0.28	0.27
Median	0.45	0.43	0.44	0.44	0.39	0.37	0.38	0.37	0.39	0.38
75th Percentile	0.53	0.53	0.53	0.52	0.50	0.51	0.51	0.51	0.51	0.51
Maximum	0.58	0.58	0.57	0.57	0.55	0.55	0.56	0.56	0.55	0.55



Median is marked with "+," the boundaries of the box indicate 75th and 25th percentiles, upper and lower whiskers indicate maximum and minimum proportional survival.

Figure 5.G-24. Box Plots of Sacramento Winter-Run Chinook Salmon Smolt Survival through the Delta for Each Model Scenario



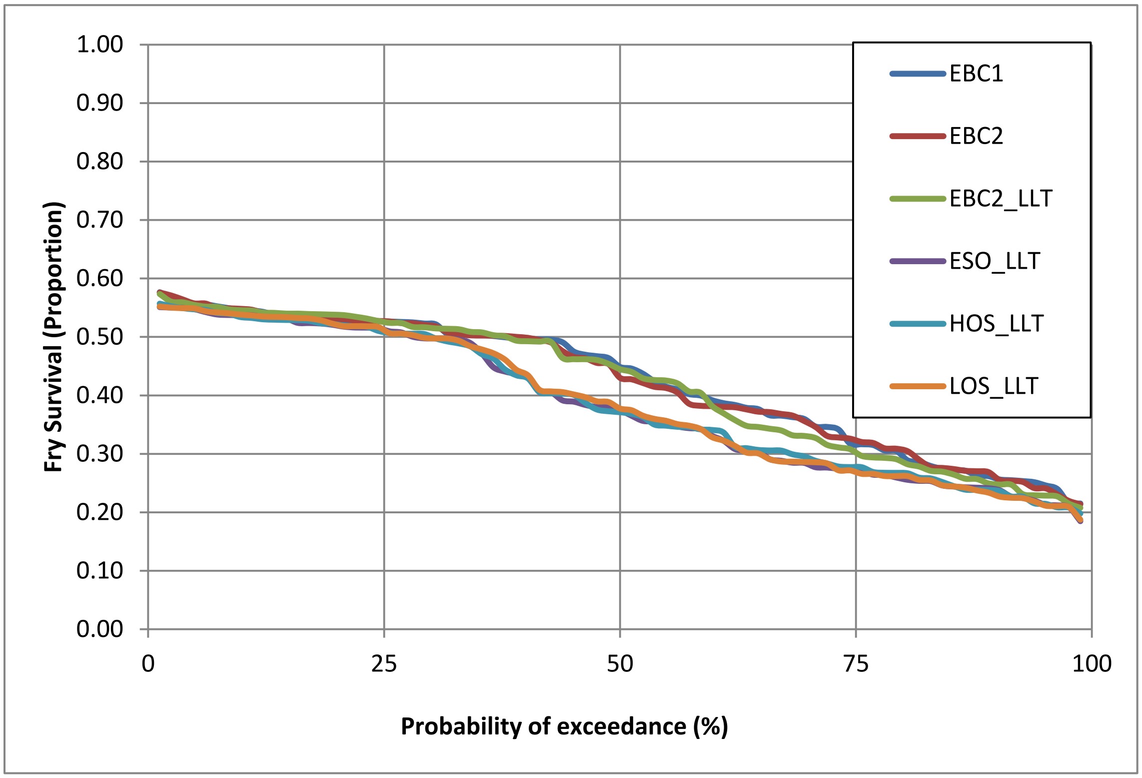


Figure 5.G-25. Exceedance Plots for Sacramento Winter-Run Chinook Salmon Smolt Survival through the Delta for Each Model Scenario

Table 5.G-22. Differences (Percent Differences) in Mean and Median Proportion of through-Delta Smolt Survival between Pairs of Early-Long Term Model Scenarios[1]

Statistic	EBC1 vs. ESO_ELT	EBC2 vs. ESO_ELT	EBC2_ELT vs. ESO_ELT	EBC2_ELT vs. HOS_ELT	EBC2_ELT vs. LOS_ELT
Mean	-0.04 (-9%)	-0.03 (-8%)	-0.03 (-7%)	-0.03 (-7%)	-0.03 (-7%)
Median	-0.06 (-14%)	-0.04 (-10%)	-0.05 (-12%)	-0.05 (-13%)	-0.05 (-12%)
[1] A positive value indicates higher through-Delta smolt survival under the ESO.					

Table 5.G-23. Differences (Percent Differences) in Mean and Median Proportion of through-Delta Smolt Survival between Pairs of Late-Long Term Model Scenarios[1]

Statistic	EBC1 vs. ESO_LLT	EBC2 vs. ESO_LLT	EBC2_LLT vs. ESO_LLT	EBC2_LLT vs. HOS_LLT	EBC2_LLT vs. LOS_LLT
Mean	-0.04 (-10%)	-0.04 (-9%)	-0.03 (-8%)	-0.03 (-8%)	-0.03 (-8%)
Median	-0.07 (-16%)	-0.06 (-13%)	-0.07 (-16%)	-0.07 (-17%)	-0.07 (-15%)
[1] A positive value indicates higher through-Delta smolt survival under the ESO.					

5.G.3.2.1.4 Escapement

IOS model results for winter-run Chinook salmon escapement are presented as the estimated number of adults returning to upper Sacramento River spawning grounds each year, or the annual escapement. Annual escapement is a function of all preceding life stages in the model. The number of returning adult spawners in any given scenario model year determines the number of eggs contributing to the following year class. The annual egg and fry survival rate determines the number of smolts reaching the Delta, and the through-Delta survival rate determines the number of smolts leaving the Delta and entering the ocean. Once in the ocean, a set of annual marine survival and harvest rate functions determine the survival rate of each year class that contributes to adult recruitment in subsequent model years. Therefore the model results for each scenario reflect the cumulative effects of contributing year escapement across the entire data record. It is important to emphasize that these escapement calculations should not be used for prediction of actual escapement rates in the future. Rather, they should be used strictly as an index for interpreting the relative difference in effects of the BDCP model scenarios, based on the BDCP components assumed in the model.

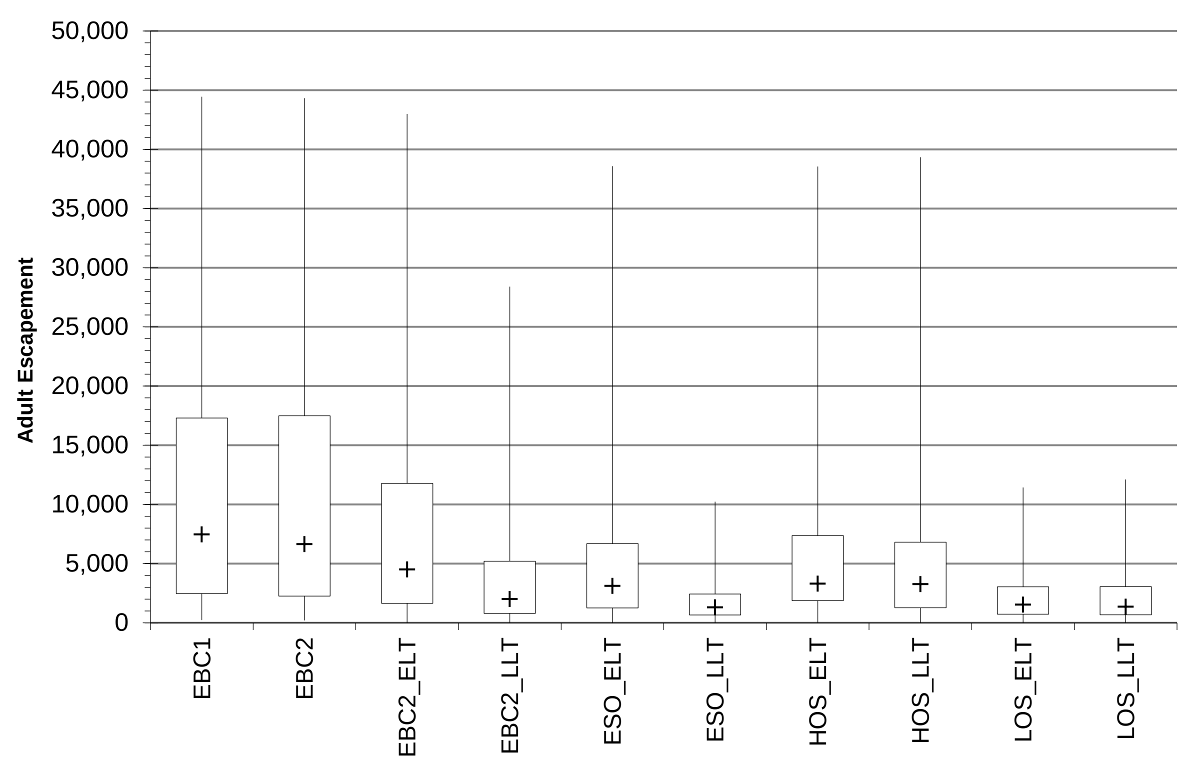
Estimated winter-run Chinook salmon escapement is summarized by model scenario in Table 5.G-24 and illustrated graphically in Figure 5.G-26 and Figure 5.G-28. Figure 5.G-28 and Figure 5.G-29 depict the 6-year geometric mean of estimated escapement for the purpose of comparison to Global Objective 1.1 of the BDCP species-specific goals and objectives (Chapter 3 *Conservation Strategy*). The 6-year geometric mean provides a useful measure of the central tendency of escapement that smooths interannual variability and integrates the contribution of multiple year classes to each generation of adult spawners. As with the annual escapement estimates, these results are only appropriate for relative comparisons of the alternatives. They should not be used to evaluate the probability of achieving BDCP global conservation objectives because they incorporate a number of existing and planned environmental actions that are not considered in the IOS model.

IOS annual escapement estimates varied widely under all scenarios, ranging from minimums of 0-1 fish (EBC2_LLT, ESO_LLT, LOS_LLT) to maximums exceeding 40,000 fish (EBC1, EBC2, EBC2_ELT) (Table 5.G-24, Figure 5.G-26). (Escapement values are rounded to the nearest 100 for discussion purposes.) Mean and median escapement ranged from 1,900 and 1,300 fish under ESO_LLT, respectively, to 11,500 and 7,500 fish under EBC1, respectively (Table 5.G-24, Figure 5.G-28).

Modeled differences in egg and through-Delta survival accounted for the largest differences in escapement between scenarios after the effects of climate change are considered. Mean and median escapement levels were -37% (-3,000 fish) and -31% (1,400 fish) lower under ESO than EBC2 over the ELT, respectively (Table 5.G-25). Differences under the HOS scenario were smaller over the ELT, with mean and median escapement levels -27% lower (2,200 and 1,200 fish, respectively). In contrast, mean and median escapement under the LOS_ELT scenario were substantially lower, by -72% (6,000 fish) and -66% (3,000 fish), respectively, reflecting large flow-related effects on through-Delta survival. The differences become less distinct over time as the climate change effects become more predominant. Mean and median survival rates under ESO_LLT are -50% (2,000 fish) and -35% (700 fish) lower than under EBC2_LLT. LOS performance improves over the LLT, with mean and median survival rates -45% (1,700 fish) and -32% (650 fish) lower, respectively, than EBC2. In contrast, the HOS scenario outperforms EBC2 over the LLT, increasing mean and median escapement by 31% (1,200 fish) and 62% (1,300 fish), respectively (Table 5.G-26). Other model components (e.g., ocean harvest) were held constant and, therefore, would not have resulted in the observed differences in survival between scenarios.

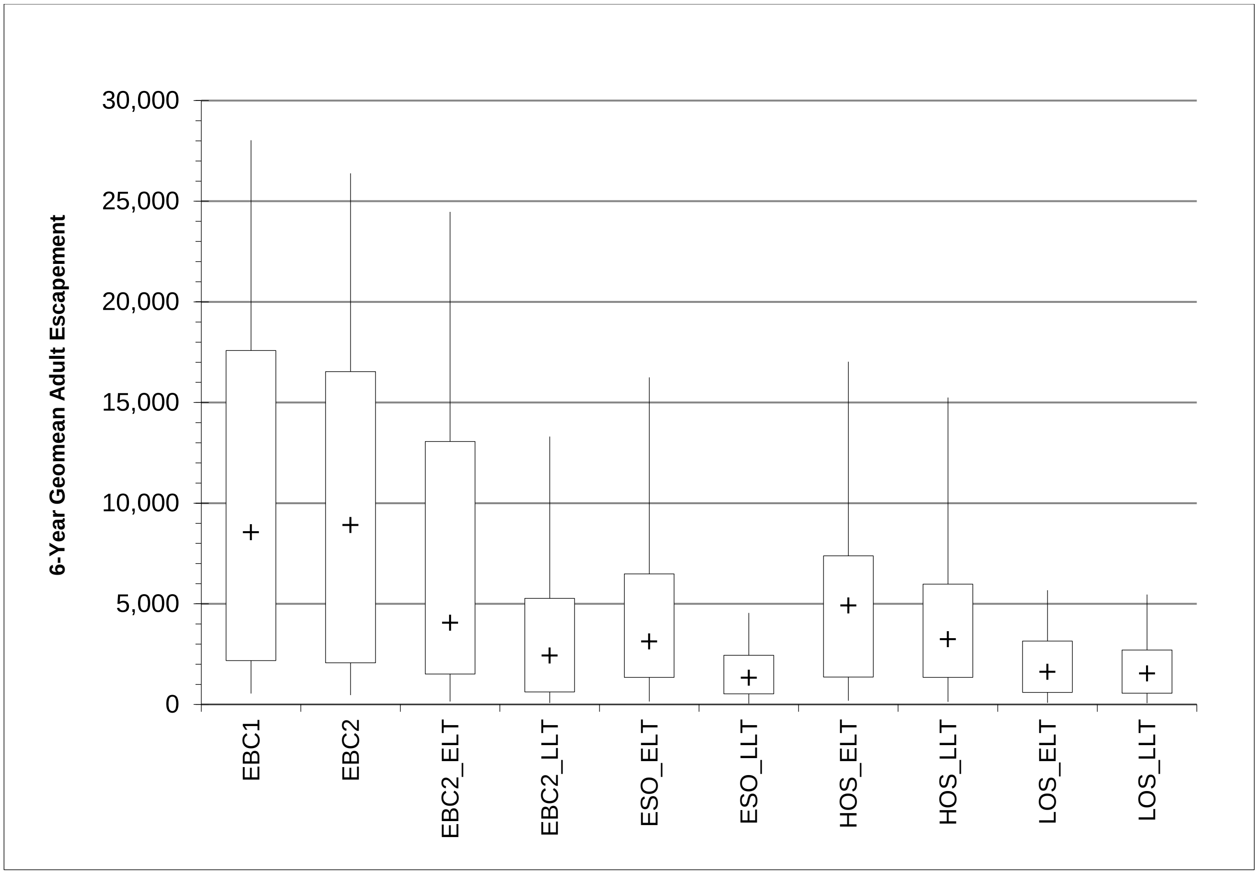
Table 5.G-24. Winter-Run Chinook Adult Escapement for Each Model Scenario

Statistic	EBC1	EBC2	EBC2_ELT	EBC2_LLT	ESO_ELT	ESO_LLT	HOS_ELT	HOS_LLT	LOS_ELT	LOS_LLT
Mean	11,491	11,017	8,284	3,867	5,260	1,916	6,064	5,081	2,323	2,118
Minimum	220	195	8	1	15	0	29	11	1	0
25th Percentile	2,632	2,608	1,674	844	1,517	676	1,891	1,326	728	700
Median	7,470	6,639	4,499	2,008	3,119	1,304	3,298	3,258	1,526	1,358
75th Percentile	17,294	17,484	11,769	5,199	6,691	2,437	7,371	6,807	3,035	3,049
Maximum	44,445	44,320	42,981	28,398	38,583	10,230	38,548	39,339	11,431	12,103



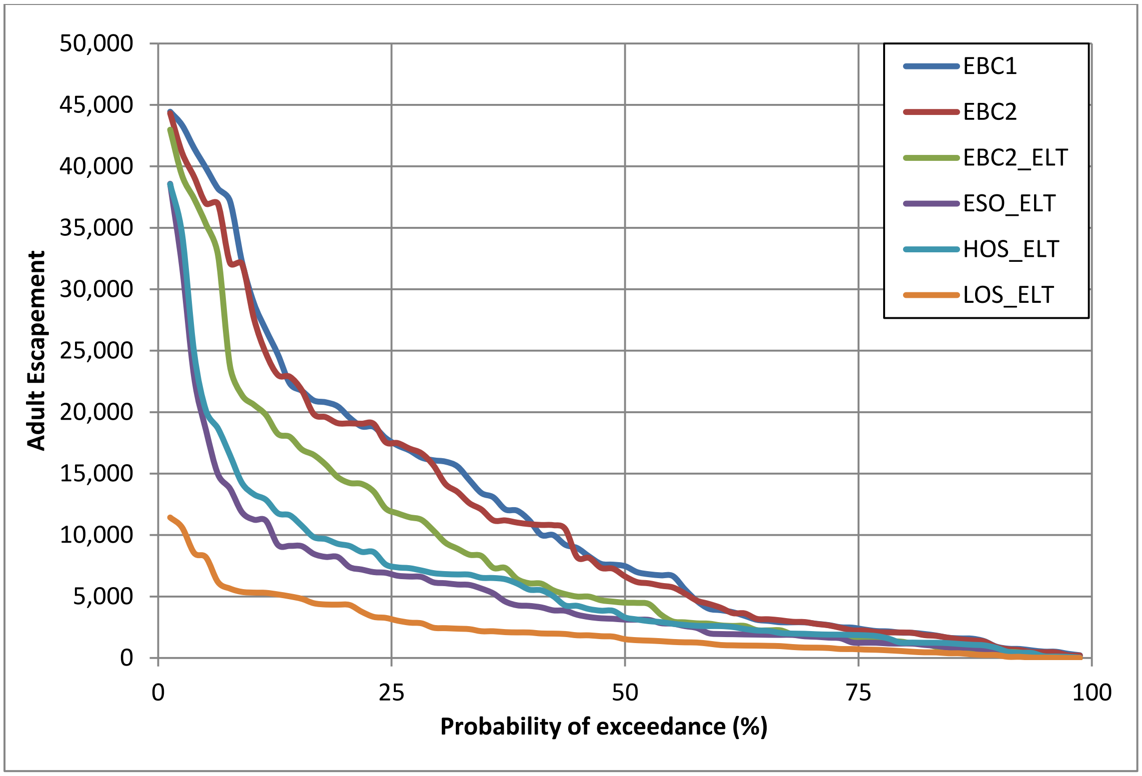
Median is marked with "+," the boundaries of the box indicate 75th and 25th percentiles, upper and lower whiskers indicate maximum and minimum escapement.

Figure 5.G-26. Box Plots of Sacramento Winter-Run Chinook Salmon Adult Escapement for Each Model Scenario



Median is marked with "+," the boundaries of the box indicate 75th and 25th percentiles, upper and lower whiskers indicate maximum and minimum escapement.

Figure 5.G-27. Box Plots of 6-Year Geometric mean Sacramento Winter-Run Chinook Salmon Adult Escapement for Each Model Scenario



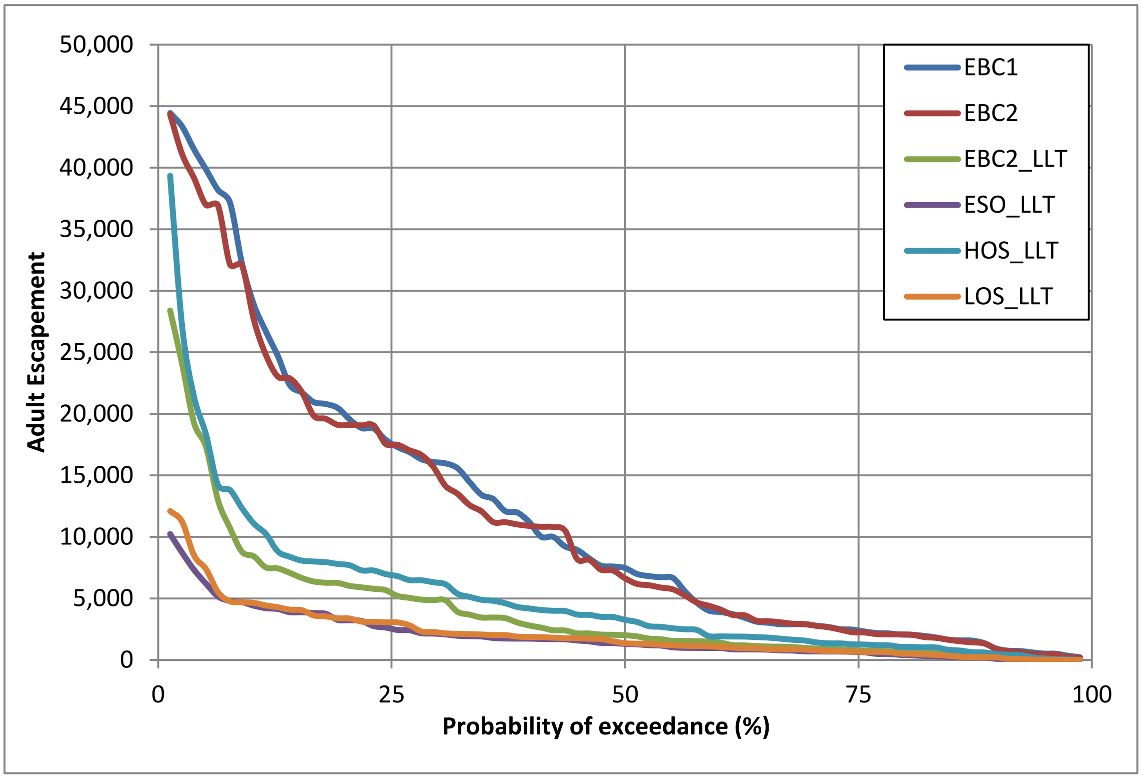
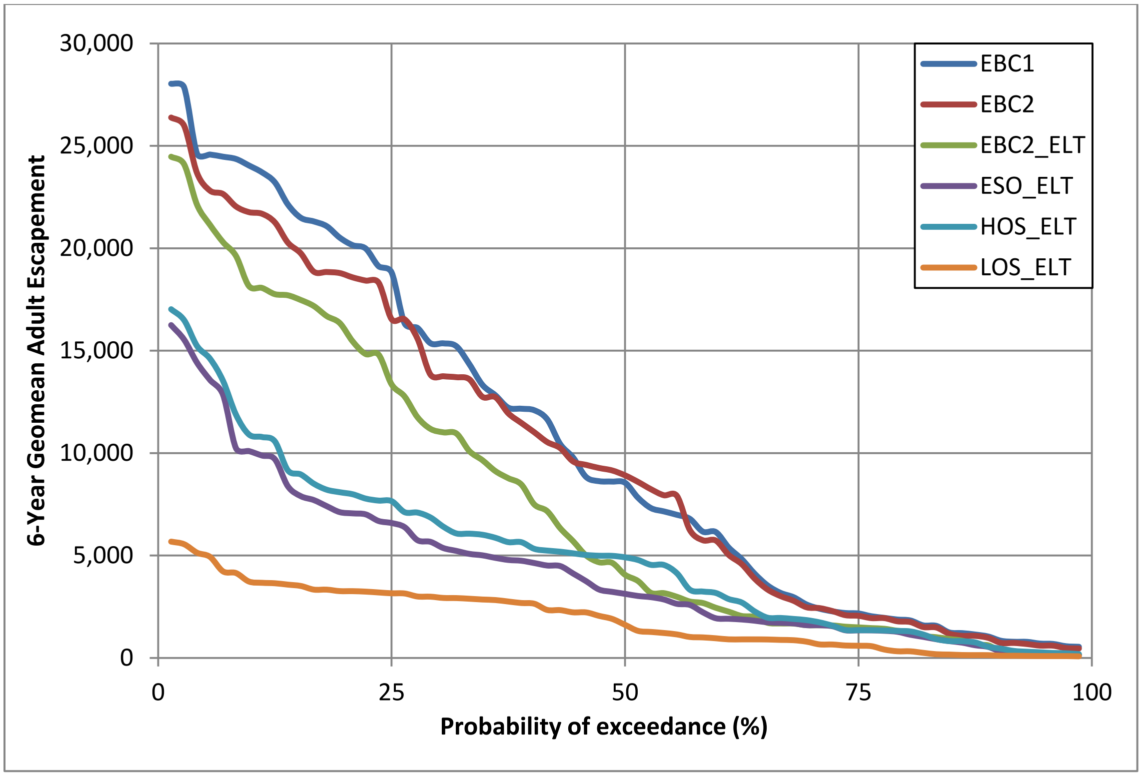


Figure 5.G-28. Exceedance Plots for Sacramento Winter-Run Chinook Salmon Adult Escapement for Each Model Scenario



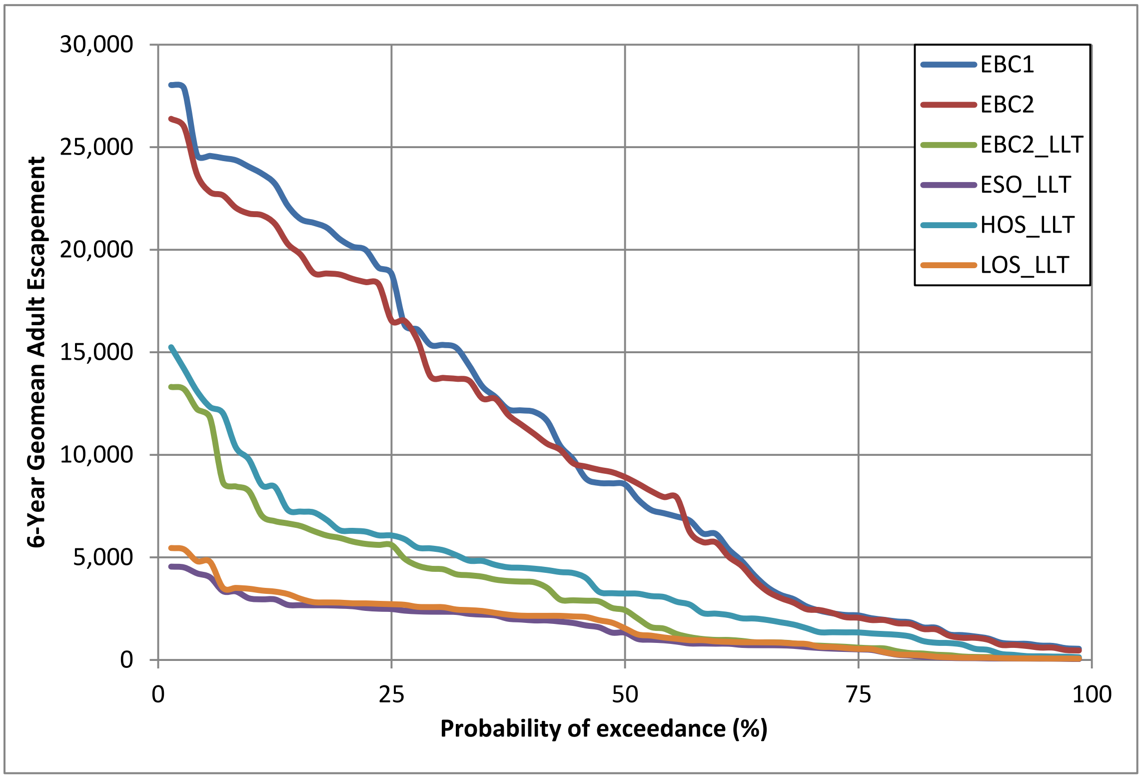


Figure 5.G-29. Exceedance Plots for 6-Year Geometric mean Sacramento Winter-Run Chinook Salmon Adult Escapement for Each Model Scenario

Table 5.G-25. Differences (Percent Differences) in Mean and Median Number of Adult Spawners between Pairs of Early-Long Term Model Scenarios[1]

Statistic	EBC1 vs. ESO_ELT	EBC2 vs. ESO_ELT	EBC2_ELT vs. ESO_ELT	EBC2_ELT vs. HOS_ELT	EBC2_ELT vs. LOS_ELT
Mean	-6,231 (-54%)	-5,757 (-52%)	-3,024 (-37%)	-2,219 (-27%)	-5,961 (-72%)
Median	-4,350 (-58%)	-3,519 (-53%)	-1,380 (-31%)	-1,202 (-27%)	-2,973 (-66%)

[1] A positive value indicates higher estimate under the ESO with the nonphysical barrier.

Table 5.G-26. Differences (Percent Differences) in Mean and Median Number of Adult Spawners between Pairs of Late-Long Term Model Scenarios[1]

Statistic	EBC1 vs. ESO_LLT	EBC2 vs. ESO_LLT	EBC2_LLT vs. ESO_LLT	EBC2_LLT vs. HOS_LLT	EBC2_LLT vs. LOS_LLT
Mean	-9,575 (-83%)	-9,101 (-83%)	-1,951 (-50%)	1,214 (31%)	-1,749 (-45%)
Median	-6,166 (-83%)	-5,335 (-80%)	-704 (-35%)	1,251 (62%)	-650 (-32%)

[1] A positive value indicates higher estimate under the ESO with the nonphysical barrier.

5.G.3.2.1.5 Sensitivity Analyses

IOS through-Delta survival and adult escapement estimates were generated separately for each sensitivity analysis scenario and compared with the corresponding EBC2 and ESO scenarios. The intent of this component of the analysis is to provide a relative measure of the sensitivity of IOS results to ecological parameters that are likely to be affected by the BDCP but could not be incorporated into the model. The effects of the Georgiana Slough NPB and increased Sac1 predation scenarios were evaluated separately and in combination to facilitate the overall interpretation of the IOS model results.

Georgiana Slough Nonphysical Barrier

As stated in Section 5.G.5 *Methods*, the Georgiana Slough NPB scenarios assumed that 67% of smolts that would have migrated into Georgiana Slough are effectively deterred by the NPB and remain in the Sacramento River migration corridor where survival rates are known to be higher (California Department of Water Resources 2012). Once diverted, the same set of reach-specific IOS flow effects applied to smolts travelling through the Sacramento River.

Table 5.G-27 presents differences in mean and median through-Delta survival and adult escapement estimates for the ESO_33_ELT and ESO_33_LLT scenarios relative to the corresponding EBC2 and ESO scenarios without the NPB. As shown, the Georgiana Slough NPB scenarios increased through-Delta survival by 0.02 (5% to 6%) relative to the ESO scenario without the NPB over both the ELT and LLT. Mean and median escapement increased by 42% (2,200 fish) and 31% (1,000 fish) over the ELT, respectively, and by 49% (900 fish) and 21% (300 fish) over the LLT, respectively. The ESO_33_ELT scenario reduces through-Delta survival by a mean and median of -3% (-0.01) and -6% (-0.03), and mean and median adult escapement by -10% (800 fish) and -9% (400 fish) relative to EBC2_ELT. This represents a reduction in adverse effect for the ESO_ELT scenario, which had a mean and median through-Delta survival -0.03 (-7%) and -0.05 (-13%) and mean and median escapement

-37% (-3,000 fish) and -31% (-1,400 fish) lower than EBC2_ELT (see Table 5.G-15 and Table 5.G-17).

Results for the ESO_33_LLT scenario were of similar magnitude (Table 5.G-27). Mean and median through-Delta survival was reduced by -0.01 (-3%) and -0.05 (-11%) compared with EBC2_LLT, versus a -0.03 (-8%) and -0.07 (-15%) reduction comparing ESO_LLT to EBC2_LLT. ESO_33_LLT increased adult escapement by a mean and median of 49% (900 fish) and 21% (300 fish) relative to ESO_LLT, respectively. Mean and median adult escapement was -26% (1,000 fish) and -22% (400 fish) lower than EBC2_LLT, compared with a -45% (1,700 fish) and -32% (650 fish) reduction in mean and median escapement under ESO_LLT.

These results indicate that IOS is sensitive to the beneficial effects of conservation measures like *CM 16*, indicating that other conservation measures could have a similarly large effect on model outcomes if they could be incorporated into IOS or another similar life cycle model. Given this limitation, IOS results alone do not provide a sufficient basis for drawing conclusions about the overall effect of the BDCP on winter-run Chinook salmon.

Note that each of the sensitivity analysis scenarios produced some small differences in egg and fry survival rates relative to the corresponding EBC2 scenarios. These differences are the result of the stochastic effects of the model on adult spawn timing and do not reflect any upstream effect of this in-Delta conservation measure. They are therefore useful as measure of the effect of model stochasticity on survival and escapement when interpreting IOS model results.

Table 5.G-27. Differences (Percent Differences) in Mean and Median Values for Each IOS Model Parameter between ESO with a Nonphysical Barrier at Georgiana Slough and Either ESO without the Barrier or EBC2

Model Parameter	Statistic	ESO_ELT vs. ESO_33_ELT	ESO_LLT vs. ESO_33_LLT	EBC2_ELT vs. ESO_33_ELT	EBC2_LLT vs. ESO_33_LLT
Egg Survival (Proportion)	Mean	0.0 (0%)	0.0 (0%)	0.01 (1%)	-0.01 (-1%)
	Median	0.0 (0%)	0.0 (0%)	0.0 (0%)	-0.02 (-2%)
Fry Survival (Proportion)	Mean	0.0 (0%)	0.0 (0%)	0.01 (1%)	-0.01 (-2%)
	Median	0.0 (0%)	0.0 (0%)	0.0 (0%)	-0.01 (-2%)
Through-Delta Survival (Proportion)	Mean	0.02 (5%)	0.02 (5%)	-0.01 (-3%)	-0.01 (-3%)
	Median	0.02 (6%)	0.02 (5%)	-0.03 (-6%)	-0.05 (-11%)
Adult Escapement (Fish)	Mean	2,209 (42%)	938 (49%)	-814 (-10%)	-1,013 (-26%)
	Median	975 (31%)	272 (21%)	-405 (-9%)	-432 (-22%)

[1] A positive value indicates higher estimate under the ESO with the nonphysical barrier.

North Delta Intake Mortality

As stated in Section 5.G.5 *Methods*, the north Delta intake mortality scenarios assume a 5% reduction in survival rates in the Sac1 model reach to represent the effects of increased predation mortality associated with the intake structures. In other words, smolt survival through the Sac1 reach was calculated as 95% of survival after all flow-related model effects are considered.

Table 5.G-28 presents differences in mean and median estimates for each IOS output parameter between the ESO_95 scenario and the corresponding ESO and EBC2 scenarios for the ELT and LLT

(which assume no predation-related mortality). As with the ESO_33 sensitivity analysis scenario, differences in egg and fry survival do not reflect any model-related effect of in-Delta predation on upstream survival. Rather, these differences result from the influence of model stochasticity related to adult abundance, spawn timing and egg and fry survival rates in subsequent generations. The only direct effect of these scenarios occurs in the through-Delta survival calculation in the Sac1 reach.

As shown, a 5% reduction in survival rate through Sac1 reduces both through-Delta survival and subsequent adult escapement. The ESO_95 scenarios reduced mean and median through-Delta survival by a uniform -0.02 (-4%) compared with the corresponding ESO_ELT and ESO_LLT scenarios. ESO_95_ELT decreased mean and median adult escapement by -30% (1,600 fish) and -20% (600 fish) relative to ESO_ELT, respectively, while ESO_95_LLT decreased mean and median escapement by -22% (400 fish) and -19% (250 fish) relative to ESO_LLT. Mean and median through-Delta survival rates were -0.05 (-9%) and -0.07 (-15%) lower under ESO_95_ELT than under EBC2_ELT, respectively, and mean and median adult escapement was -58% (6,800 fish) and -45% (2,000 fish) lower than under EBC2_ELT. The ESO_95_LLT scenario produced mean and median though-Delta survival rates -0.05 (-12%) and -0.09 (-19%) lower than EBC2_LLT, respectively, and mean and median adult escapement were reduced by -61% (2,400 fish) and -48% (1,000 fish), respectively.

Table 5.G-28. Differences (Percent Differences) in Mean and Median Values for Each IOS Model Parameter between ESO with 5% Mortality Associated with the North Delta Intakes and Either ESO with 0% Mortality or EBC2

Model Parameter	Statistic	ESO_ELT vs. ESO_95_ELT	ESO_LLT vs. ESO_95_LLT	EBC2_ELT vs. ESO_95_ELT	EBC2_LLT vs. ESO_95_LLT
Egg Survival (Proportion)	Mean	0 (0%)	0 (0%)	0.01 (1%)	-0.01 (-1%)
	Median	0 (0%)	0 (0%)	0 (0%)	-0.02 (-2%)
Fry Survival (Proportion)	Mean	0 (0%)	0 (0%)	0 (0%)	-0.01 (-2%)
	Median	0 (0%)	0 (0%)	0 (0%)	-0.01 (-2%)
Through-Delta Survival (Proportion)	Mean	-0.02 (-4%)	-0.02 (-4%)	-0.05 (-9%)	-0.05 (-12%)
	Median	-0.02 (-4%)	-0.02 (-4%)	-0.07 (-15%)	-0.09 (-19%)
Adult Escapement (Fish)	Mean	-1,577 (-30%)	-417 (-22%)	-6,784 (-58%)	-2,367 (-61%)
	Median	-630 (-20%)	-250 (-19%)	-2,010 (-45%)	-954 (-48%)

[1] A positive value indicates higher estimate under the ESO with the nonphysical barrier.

Summary of Sensitivity Analysis Findings

The results of the sensitivity analysis indicate that IOS model results are highly sensitive to changes in survival parameters at critical points in the Delta. The ESO_95_ELT and ESO_95 scenario results show that relatively small changes in model mortality at a critical point in the Delta can have a large effect on the number of smolts leaving the Delta and subsequent adult escapement. Similarly, the ESO_33_ELT and ESO_33_LLT scenarios suggest that the incorporation of beneficial conservation measures like *CM 16* would have a large effect on model outcomes if they could be incorporated into IOS or another similar life cycle model. This shortcoming is of particular concern because the IOS is not currently parameterized to consider the beneficial effects of large scale habitat restoration designed to improve habitat capacity, function and connectivity along a significant portion of the migratory corridor used by winter-run Chinook salmon. Therefore IOS is likely underestimating the performance of the BDCP scenarios. Given this limitation, IOS results alone do not provide a sufficient basis for drawing conclusions about the overall effect of the BDCP on winter-run Chinook salmon or other focus fish species.

Another interesting finding of the sensitivity analysis is that three out of four scenarios generated small differences in egg and fry survival rates when compared with the corresponding EBC2 scenarios. These differences do not reflect any upstream effect of the sensitivity analysis scenarios because their effects are restricted to the Delta component of the model. Rather they are the result of the stochastic effects of the model that result in differences in spawn timing between scenarios. They are therefore useful as measure of the effect of model stochasticity on IOS results when making comparisons between scenarios.

5.G.4 Conclusions

This section summarizes the results described above from the OBAN and IOS models. Both models rely on temperature modeling, which is based on monthly CALSIM modeling results. A portion of the results is driven by modeled changes in upstream temperatures included in the BDCP modeling scenarios. These modeled changes are generally small compared to EBC1 and EBC2 scenarios, but nonetheless are highlighted in the OBAN and IOS results. However, the BDCP does not include any Shasta Reservoir operational criteria changes and results in less than a 3% change in Shasta storage, ensuring that it can be operated with the same tools as under conditions without BDCP. No actual meaningful changes in storage or flows are anticipated to occur. Climate change was the largest driver of results and lowered adult escapement similarly under both the EBC2_ELT and ESO_ELT.

OBAN estimated slightly lower escapement of winter-run Chinook under the ESO than under future conditions without BDCP over the early- and late-long term, with the projected effects of climate change being the greatest determinant of overall escapement over time. The majority of the effects of both BDCP and climate change were driven by increases in upstream temperatures affecting egg survival, which may not be an accurate determinant of future effects because the Bend Bridge temperature node is not representative of temperature conditions experienced during incubation and early rearing.

The OBAN model estimated that through-Delta survival of winter-run Chinook salmon would be higher with implementation of the BDCP than under baseline conditions. This finding is driven primarily by lower exports in the south Delta and greater duration of Yolo Bypass flooding, and the lack of a direct mechanism for modeling the effects of the BDCP in OBAN, including the NDD effects.

The OBAN results suggest a tradeoff between the modeled negative effects of the BDCP on flow and temperature conditions in the upper Sacramento River and the beneficial effects of increased Yolo Bypass inundation and reduced south Delta entrainment (OBAN assumes that any increase in Yolo Bypass inundation will increase through-Delta survival). Independent of climate change, upstream negative effects on escapement appeared to outweigh downstream positive effects in the ELT. In the LLT, the negative effects of climate change on adult escapement increased substantially under both EBC2_LLT and ESO_LLT.

It is critical to note when interpreting OBAN model results that this model does not consider the likely beneficial effects of in-Delta habitat restoration and other Plan Area conservation measures on through-Delta survival rates, nor do they consider are the potential negative effects of the north

Delta diversions (e.g., reduced downstream flows and increased predation). The OBAN sensitivity analysis was used to characterize model sensitivity to the latter negative effects. That analysis indicated that increasing through-Delta mortality up to 5% gave changes in escapement between 0 and 4.6%. These results indicate that OBAN is sensitive to in-Delta survival assumptions, and suggest that an expanded sensitivity analysis that evaluated the beneficial effects of Delta habitat restoration would produce similarly proportional increases in overall escapement.

IOS estimated lower escapement of winter-run Chinook under the ESO, HOS and LOS scenarios over the ELT, with the modeled decreased through-Delta survival being the primary driver of these effects, although only flow-related effects were included in the model. Estimated escapement under the EBC2, ESO, HOS, LOS decreased substantially over the LLT relative to EBC2 under current conditions, reflecting the modeled climate change effects on water temperature conditions in the upper Sacramento River and the resulting effects on egg and fry survival. The HOS_LLT scenario resulted in higher estimated escapement levels than the EBC2_LLT scenario, while both the ESO_ELT and LOS_ELT produced lower overall escapement than EBC2_LLT. The IOS sensitivity analysis evaluated the effects of two offsetting in-Delta parameters on through-Delta survival and escapement; increased predation mortality at the north Delta intakes, and implementation of the Georgiana Slough NPB system. The results of the sensitivity analysis demonstrate that IOS escapement estimates are highly sensitive to through-Delta survival assumptions. Therefore IOS results must be interpreted with caution when evaluating the potential effects of the BDCP because this analysis did not consider the beneficial effects of Delta habitat restoration or several other potentially beneficial conservation measures.

IOS escapement estimates in any given year integrate escapement levels from all preceding years as well as in-river and Delta flow conditions during that year. Additionally, the performance of the BDCP scenarios varied considerably over time relative to EBC2, with the BDCP producing similar or superior egg, fry and through-Delta survival rates for extended periods relative to corresponding EBC2. IOS results indicate that mean/median adult winter-run Chinook salmon escapement was 52-53% lower under ESO_ELT than under EBC2 and 80-83% lower under ESO_LLT, compared with EBC2 (i.e., existing conditions). However, mean and median escapement under ESO_ELT and ESO_LLT were 31-37% and 35-50% lower, respectively, than the corresponding EBC2 scenarios over the same timeframes, indicating that climate change is a dominant driver of model results. In contrast, mean and median escapement under the HOS_ELT scenario were only 27% lower than EBC2_ELT, while the HOS_LLT scenario resulted in a 31-62% increase in mean and median escapement relative to EBC2_LLT. The LOS scenario resulted in 66-72% and 32-45% reductions in mean and median escapement over the ELT and LLT, respectively, relative to the corresponding EBC2 scenarios.

Modeled reductions in through-Delta survival were the primary cause of reduced escapement under the BDCP scenarios. However, the BDCP scenarios performed poorly during the initial IOS model years (1922 to 1932), resulting in reduced levels of escapement that propagated comparatively lower levels of escapement through several following decades even though the BDCP produced higher egg, fry, and through-Delta survival rates during many years. The IOS model predicted 7-17% lower mean and median through-Delta survival rates under all BDCP scenarios relative to the corresponding EBC2 scenario time frames. If the model record had started during a period with relatively high through-Delta survival under the BDCP, the IOS analysis would have predicted better overall performance for the BDCP relative to EBC2. The decrease in through-Delta survival is offset under the HOS scenario by a 0-3% increases in mean and median egg and fry survival rates over the

ELT, and 2-11% increases over the LLT. Increased egg and fry survival accounts for the overall increase in escapement under HOS_LLT relative to EBC2_LLT.

The findings of the life cycle model analyses indicate that both the OBAN and IOS model results must be interpreted with caution. While both models predict lower overall performance for most BDCP scenarios relative to EBC2, these results must be viewed as incomplete. Neither model is fully representative of the conditions experienced by winter-run Chinook across their entire life history. Importantly, neither model considers the entire range of beneficial effects likely to occur under the BDCP. Specifically, both models estimate through-Delta survival rates by evaluating the effects of changes in migration speed against a constant set of habitat conditions so the beneficial effects of Delta habitat restoration and other potential effects of the BDCP are not captured. These effects have a high degree of uncertainty so they cannot be parameterized with confidence. However, the results of sensitivity analyses for both models indicate that small changes in through-Delta survival rates can have a large effect on escapement estimates.

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5.G.5.1 Literature Cited

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5.G.5.2 Personal Communications

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Miller, B. J. Consulting Engineer, Port Richmond, CA. Excel spreadsheets containing processed California Department of Fish and Game zooplankton data for Miller et al. (2012) delta smelt survival regression EPAJ and EPSD covariates provided by email to Marin Greenwood, Aquatic Ecologist, ICF International, Sacramento, CA.

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Sommer, Ted. Program Manager. Department of Water Resources, Sacramento, CA. June 23, 2011—Discussion about benefits to juvenile salmonids in the Yolo Bypass during Delta Passage Model Workshop, State Water Contractors Office, Sacramento, CA.