Appendix 9H

IOS Model Documentation

Information about the methods and assumptions used for the Coordinated Long-Term Operation of the Central Valley Project (CVP) and State Water Project (SWP) Environmental Impact Statement (EIS) analysis using the IOS model is provided in this appendix. The appendix comprises two main sections as follows:

- Section 9H.1: IOS Methodology and Assumptions
  - The IOS model analysis is used to quantify winter-run Chinook Salmon escapement and egg survival. The approach and assumptions for the IOS analysis are described in this section.
- Section 9H.2: IOS Model Analysis Results
  - The results of the IOS analysis are presented in this section in a series of figures for each alternative comparison.

9H.1 IOS Model Methodology and Assumptions

9H.1.1 IOS Model Methodology

The IOS model simulates the entire life cycle of winter-run Chinook Salmon through successive generations. This approach allows for the evaluation of individual life-stage effects on the long-term trajectory of the population. A detailed description of the model and sensitivity analysis can be found in Zeug et al. (2012).

The IOS model is composed of six model stages that are arranged sequentially to account for the entire life cycle of the winter run, from eggs to returning spawners. In sequential order, the IOS model stages are: (1) spawning, which models the number and temporal distribution of eggs deposited in the gravel at the spawning grounds; (2) early development, which models the impact 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 salmon fry during the river-rearing period; (4) river migration, which estimates the mortality of migrating salmon smolts in the Sacramento River between the spawning and rearing grounds and the Delta; (5) Delta passage, which models the impact of flow, route selection, and water exports on the survival of salmon smolts migrating through the Delta to San Francisco Bay; and (6) ocean survival, which estimates the impact of natural mortality and ocean harvest to predict survival and spawning returns (escapement) by age. Below is a detailed description of each model stage.

The IOS model uses a system dynamics modeling framework, a technique that is used for framing and understanding the behavior of complex systems over time. System dynamics models are made up of stocks (e.g., number of fish) and flows (e.g., sources of mortality) that are informed by mathematical equations. IOS was implemented in the software GoldSim, which enables the simulation of complex processes through creation of simple object relationships, while incorporating Monte Carlo stochastic methods.

The Delta portion of the model is composed of eight reaches and four junctions (see Figure 9H.1 and Table 9H.1) selected to represent primary salmonid migration corridors where high quality fish and hydrodynamic data were available. For simplification, Sutter Slough and Steamboat Slough are combined as the reach "SS," and the forks of the Mokelumne River and Georgiana Slough are combined as "Geo/DCC." The Geo/DCC reach can be entered by the Mokelumne River fall-run at the head of the South and North forks of the Mokelumne River or by Sacramento runs through the combined junction of Georgiana Slough and Delta Cross Channel (Junction C). The Interior Delta reach can be entered from three different pathways: (1) Geo/DCC, (2) San Joaquin River via Old River Junction (Junction D), or (3) Old River via Junction D. Due to lack of data informing specific routes through the Interior Delta, or tributary-specific survival, the entire Interior Delta region is treated as a single model reach. The four distributary junctions depicted in the Delta portion of the model are: (1) Sacramento River at Freemont Weir (head of Yolo Bypass), (2) Sacramento River at head of Sutter and Steamboat Sloughs, (3) Sacramento River at the combined junction with Georgiana Slough and Delta Cross Channel, and (4) San Joaquin River at the head of Old River (see Figure 9H.1 at the end of this appendix and Table 9H.1). Due to lack of data informing specific routes through the Interior Delta, or tributary-specific survival, the entire Interior Delta region is treated as a single model reach.

The IOS model uses scenario-specific daily DSM2, CalSim II, and Sacramento River Basin Water Temperature Model (HEC-5Q) data as model input. Daily DSM2 data inform fish migration speed, reach-specific survival, and routing at Delta junctions. Daily export data from CalSim II are used to inform export-dependent survival of salmon smolts that enter the Interior Delta from the Geo/DCC reach. Sacramento River Basin Water Temperature Model data at Bend Bridge, California are used to inform temperature-dependent egg and fry survival in the egg development and fry rearing stages of the model.

For Delta reaches where acoustic tagging data supported migration speed responses to flow (Sac1, Sac2, Geo/DCC), daily migration speed is influenced by mean daily flow. Migration speed is modeled as a logarithmic function of reach-specific flow occurring on the first day smolts entered a particular reach.

Table 9H.1 Descriptions of Modeled Delta Reaches and Junctions in the IOS Model

Reach/Junction	Description	Reach Length (kilometers)
Sac1	Sacramento River from Freeport to junction with Sutter Slough	41.04
Sac2	Sacramento River from Sutter Slough junction to junction with DCC	10.78
Sac3	Sacramento River from DCC to Rio Vista	22.37
Sac4	Sacramento River from Rio Vista to Chipps Island	23.98
Yolo	Yolo Bypass from entrance at Fremont Weir to Rio Vista	- [a]
SS	Combined reach of Sutter Slough and Steamboat Slough ending at Rio Vista	26.72
Geo/DCC	Combined reach of Georgiana Slough, DCC, and Sough and North forks of the Mokelumne River ending at confluence with San Joaquin River	25.59
Interior Delta	Begins at end of reach Geo/DCC, San Joaquin River via Junction D, or Old River via Junction D, and ends at Chipps Island	- [b]
A	Junction of Yolo Bypass and Sacramento River	Not applicable
B	Combined junction of Sutter Slough and Steamboat Slough with Sacramento River	Not applicable
C	Combined junction of DCC and Georgiana Slough with Sacramento River	Not applicable
D	Junction of Old River with San Joaquin River	Not applicable

Notes:

a. Reach length for Yolo Bypass is currently undefined because reach length is not currently used to calculate Yolo Bypass speed and ultimate travel time.

b. Reach length for the Interior Delta is undefined due to multiple pathways salmon can take. Timing through the Interior Delta does not affect Delta survival because there are no Delta reaches located downstream of the Interior Delta.

DCC = Delta Cross Channel

Reach-specific survival through a given Delta reach is calculated and applied the first day smolts enter the reach. For reaches where literature or available tagging data showed support for reach-level responses to environmental variables, survival is influenced by flow (Sac1, Sac2, Sac3, Sac4, SS, Interior Delta via San Joaquin River, and Interior Delta via Old River) or water exports (Interior Delta via Geo/DCC). For these reaches, daily flow (DSM2 data) or exports (CalSim II data) occurring the day of reach-entry is used to predict reach survival through the entire reach. For all other reaches (Geo/DCC and Yolo), reach survival is uninfluenced by Delta conditions and is informed by means and standard deviations of survival from acoustic tagging studies.

At each Delta junction in the model, smolts move in relation to the proportional movement of flow entering each route. Daily DSM2 flow data entering each route are used to inform the proportion of smolts entering each route at a junction. Smolts move in direct proportion to flow at all junctions except Junction C, where a non-proportional relationship is applied as defined by acoustic tagging study data.

Daily simulated water temperature data at Bend Bridge from the Sacramento River Basin Water Temperature Model were applied to inform temperature-dependent egg and fry survival. Daily mortality of eggs and fry is exponentially related to daily water temperature at Bend Bridge

9H.1.2 Model Analysis Scenario Assumptions

A major assumption of the IOS model is that surrogate fish data can be used to inform many model relationships. When local data are limited, model relationships can often be informed by field data from outside the study region, laboratory studies in controlled experimental settings, or artificially raised (hatchery) surrogates. For example, many model relationships rely on data from tagged hatchery surrogates because experimental studies often rely on easily accessible hatchery-origin fish and assume that fish responses are at least similar among individuals of different natal origins. In addition to limited data on wild fish, many of the model relationships are informed by data from a single Chinook Salmon race, thereby making the assumption that all races move, grow, and survive according to the same rules.

9H.2 Model Analysis Results

IOS model results are displayed as comparisons between scenarios. Differences in escapement and egg survival are displayed as time histories across all 81 water years (1922-2002) and box plots of median survival across all years. The following scenario comparisons are presented in Figures 9H.2 through 9H.21 at the end of this appendix.

- No Action Alternative compared to the Second Basis of Comparison
- Alternative 3 compared to the No Action Alternative
- Alternative 3 compared to the Second Basis of Comparison
- Alternative 5 compared to the No Action Alternative
- Alternative 5 compared to the Second Basis of Comparison

9H.3 Reference

Zeug, S.C., P.S. Bergman, B.J. Cavallo and K.S. Jones. 2012. "Application of a life cycle simulation model to evaluate impacts of water management and conservation actions on an endangered population of Chinook Salmon." *Environmental Modeling and Assessment* 17:455-467.

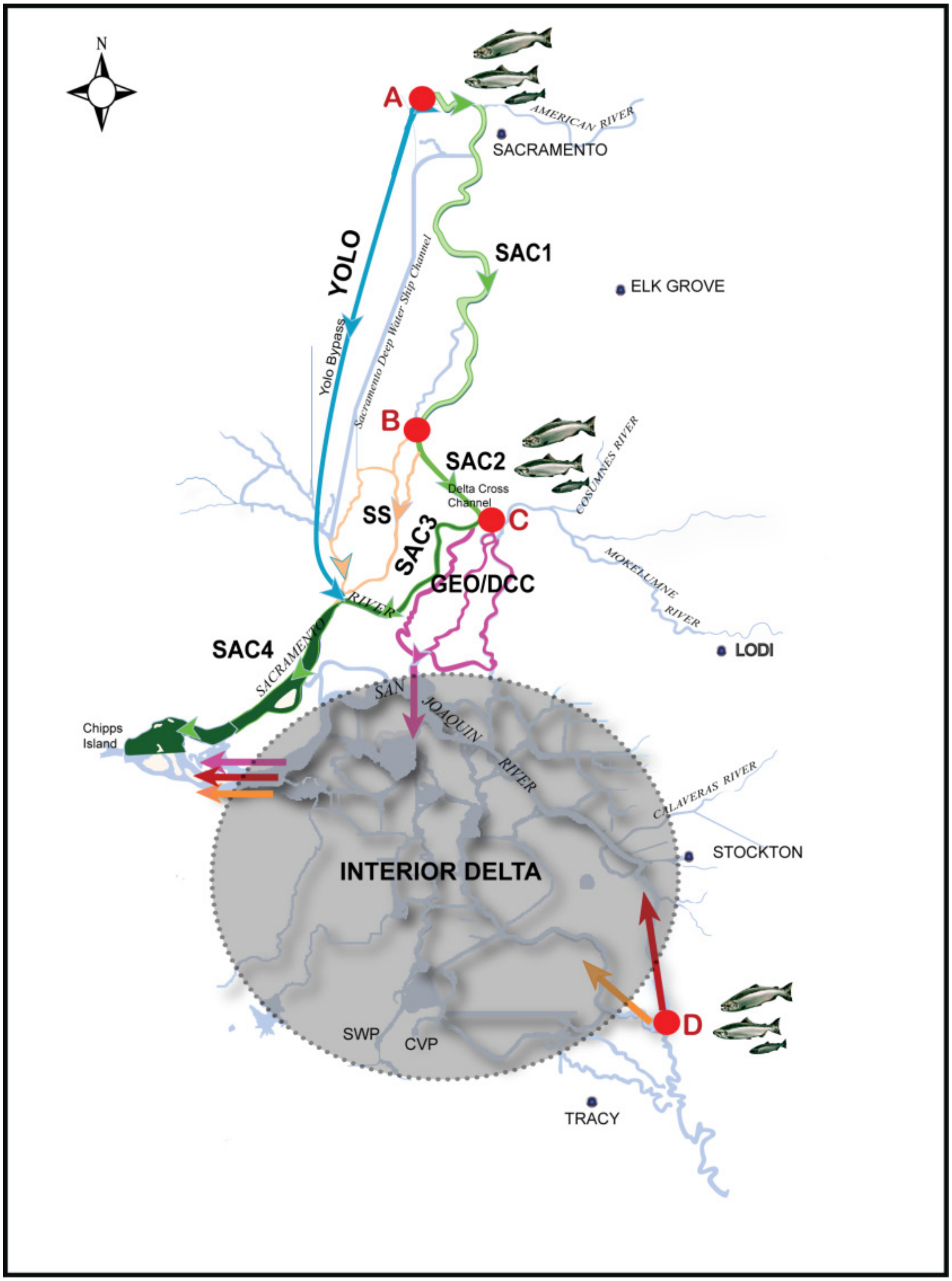

Figure 9H.1 IOS Model Reaches and Junctions in the Delta

Notes: Bold headings label modeled reaches and red circles indicate model junctions. Salmonid icons indicate locations where smolts enter the Delta in the IOS model.

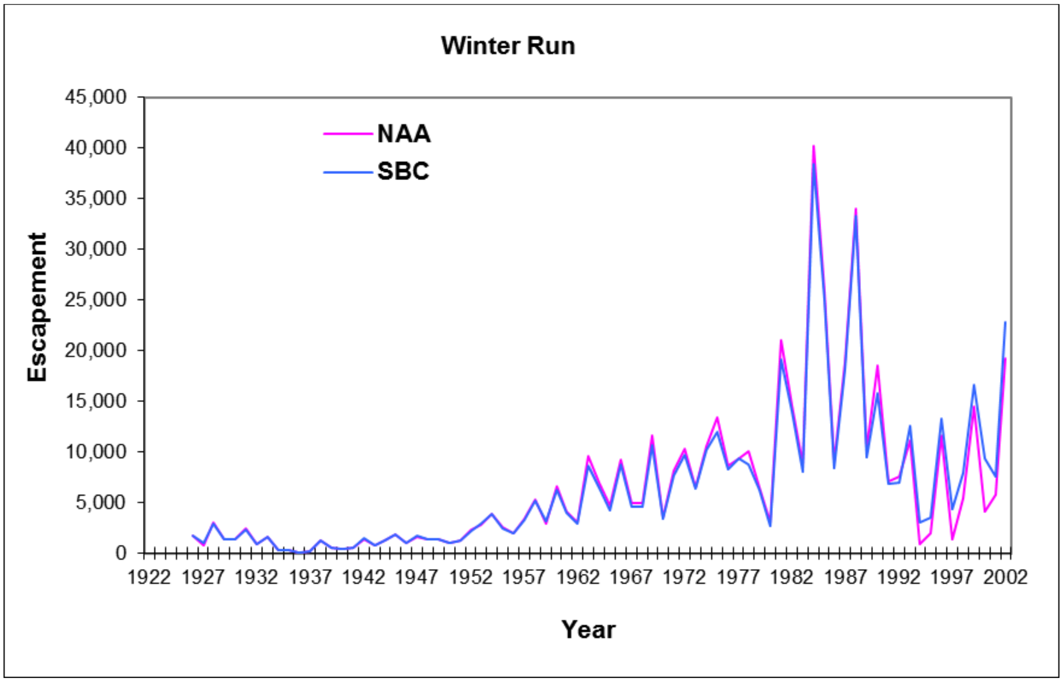

Figure 9H.2 Annual Adult Escapement for Winter-run Chinook Salmon under the No Action Alternative (NAA) compared to the Second Basis of Comparison (SBC) over 81 Water Years Estimated by the IOS Model

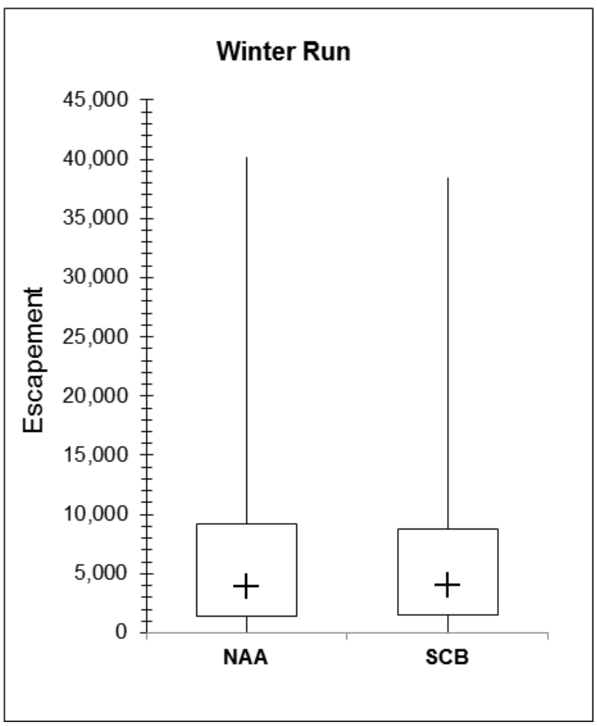

Figure 9H.3 Annual Adult Escapement for Winter-run Chinook Salmon under the No Action Alternative (NAA) compared to the Second Basis of Comparison (SBC) estimated by the IOS Model

Note: The plus symbol indicates median, box represents the interquartile range, and the whiskers represent the minimum and maximum values.

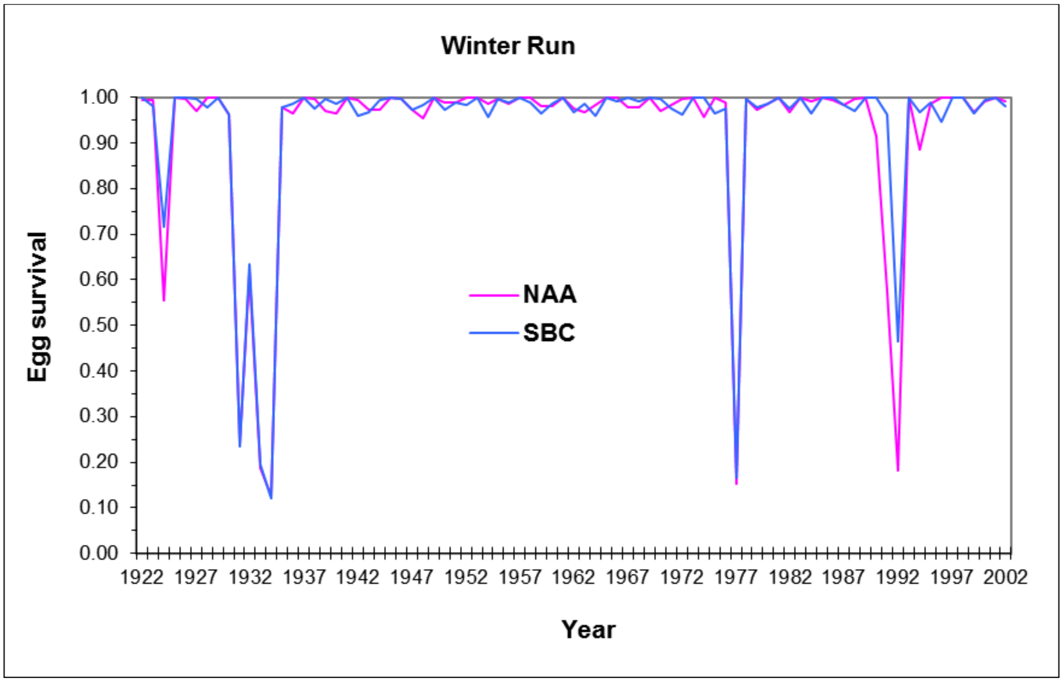

Figure 9H.4 Annual Egg Survival for Winter-run Chinook Salmon under the No Action Alternative (NAA) compared to the Second Basis of Comparison (SBC) over 81 Water Years Estimated by the IOS Model

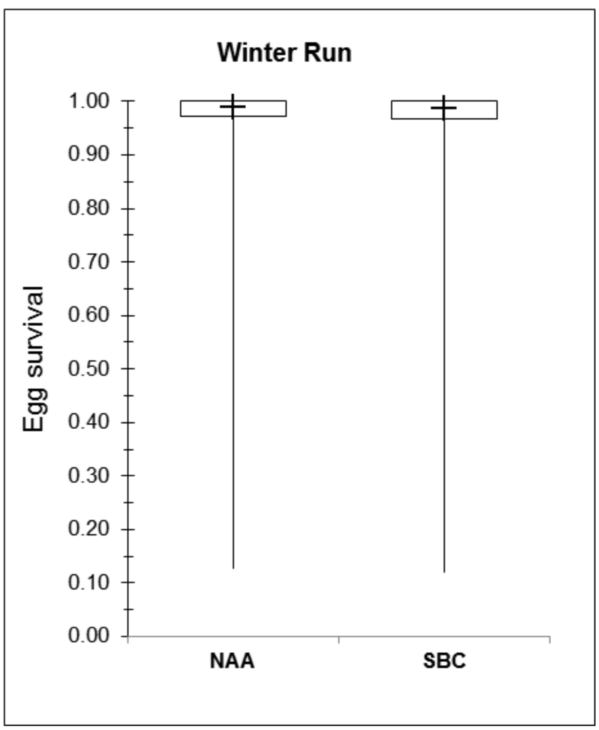

Figure 9H.5 Annual Egg Survival for Winter-run Chinook under the No Action Alternative (NAA) compared to the Second Basis of Comparison (SBC) estimated by the IOS Model

Note: The plus symbol indicates median, box represents the interquartile range, and the whiskers represent the minimum and maximum values.

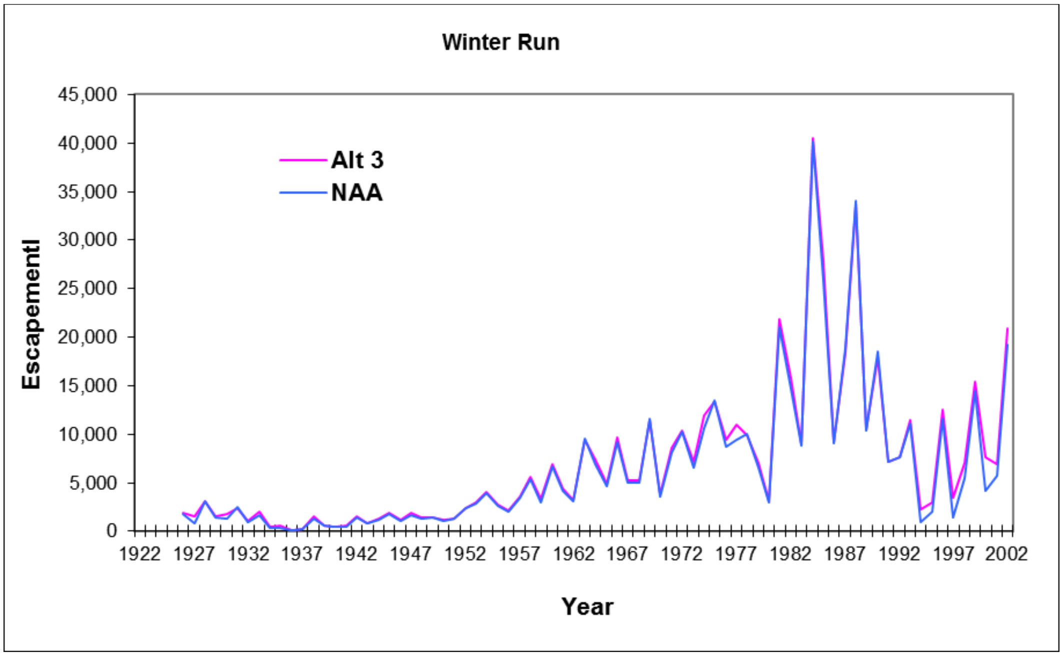

Figure 9H.6 Annual Adult Escapement for Winter-run Chinook Salmon under Alternative 3 (Alt 3) as compared to the No Action Alternative (NAA) over 81 Water Years Estimated by the IOS Model

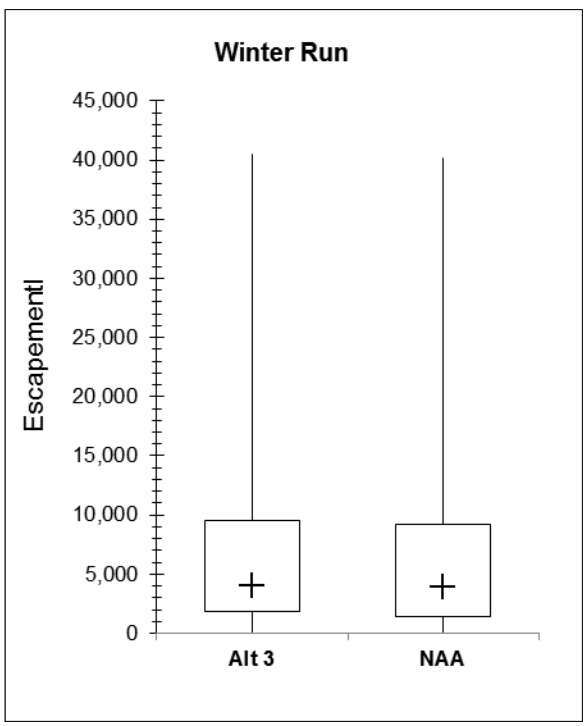

Figure 9H.7 Annual Adult Escapement for Winter-run Chinook Salmon under Alternative 3 (Alt 3) as compared to the No Action Alternative (NAA) estimated by the IOS Model

Note: The plus symbol indicates median, box represents the interquartile range, and the whiskers represent the minimum and maximum values.

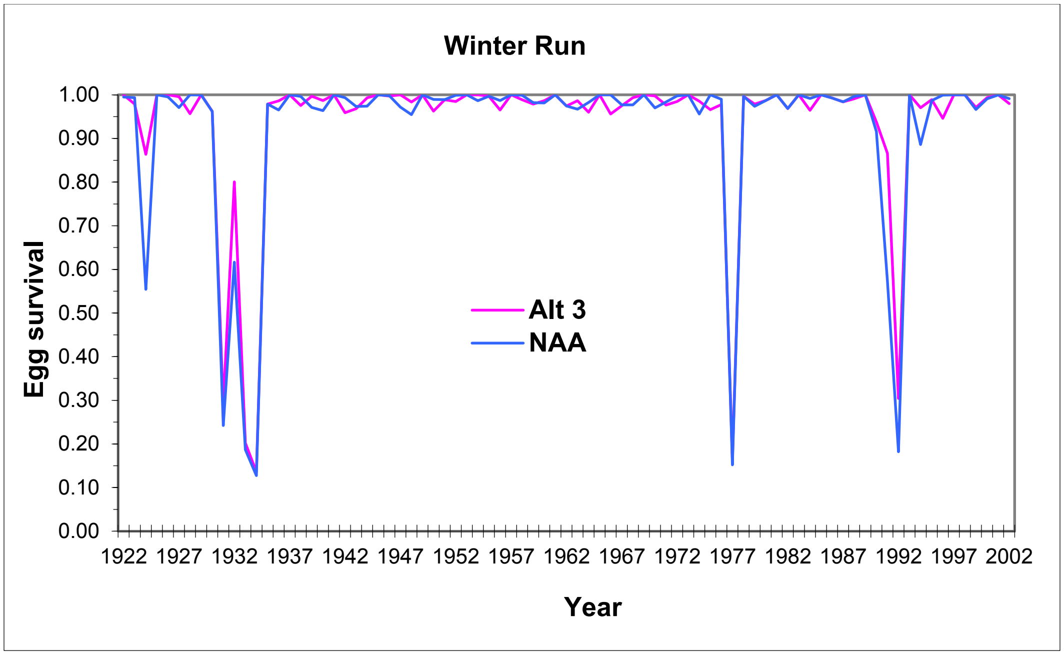

Figure 9H.8 Annual Egg Survival for Winter-run Chinook Salmon under Alternative 3 (Alt 3) as compared to the No Action Alternative (NAA) over 81 Water Years Estimated by the IOS Model

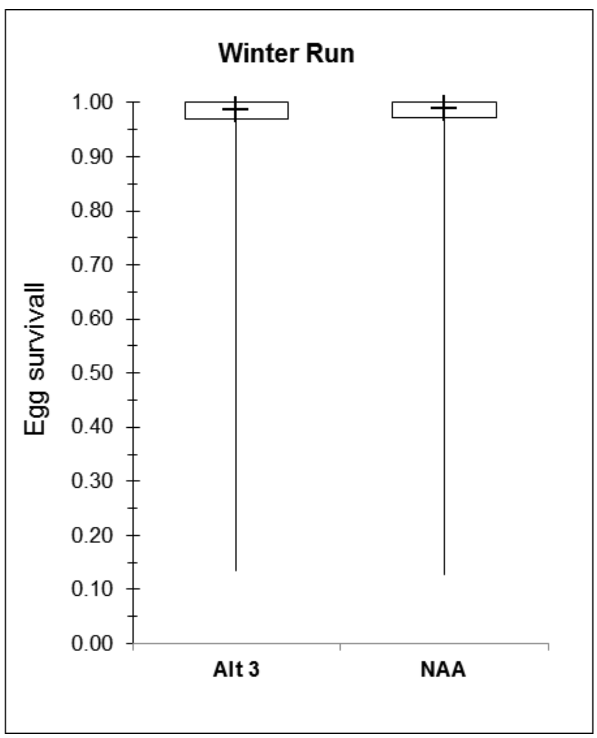

Figure 9H.9 Annual Egg Survival for Winter-run Chinook under Alternative 3 (Alt 3) as compared to the No Action Alternative (NAA) estimated by the IOS Model

Note: The plus symbol indicates median, box represents the interquartile range, and the whiskers represent the minimum and maximum values.

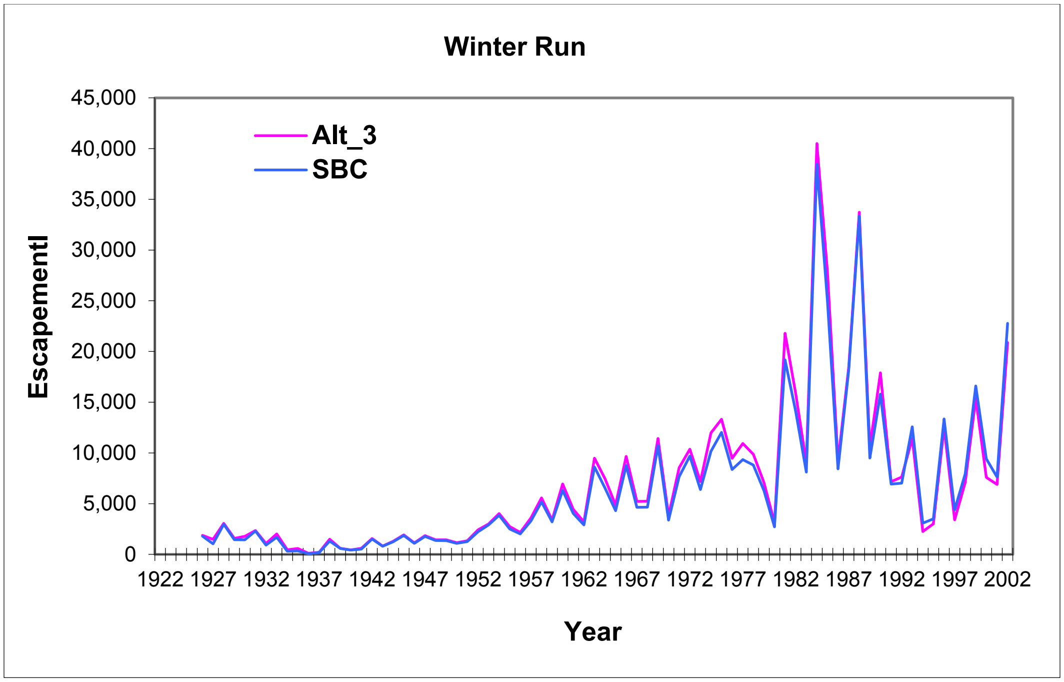

Figure 9H.10 Annual Adult Escapement for Winter-run Chinook Salmon under Alternative 3 (Alt 3) as compared to the Second Basis of Comparison over 81 Water Years Estimated by the IOS Model

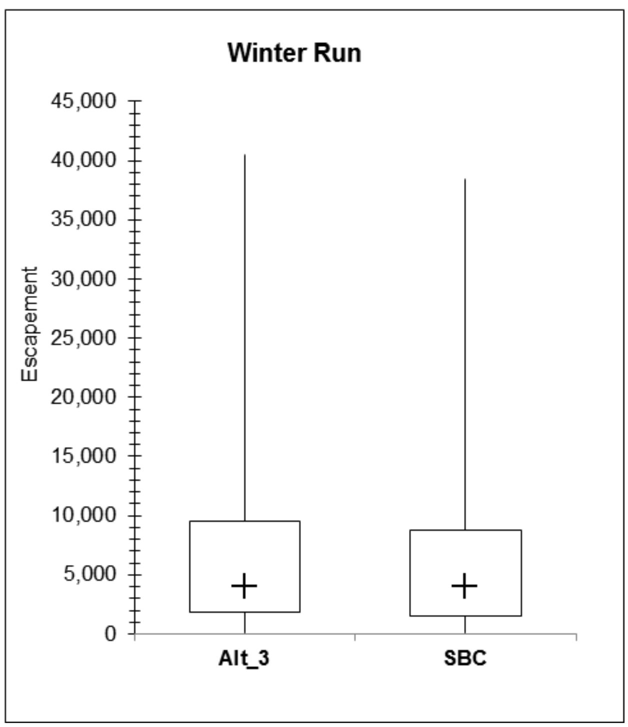

Figure 9H.11 Annual Adult Escapement for Winter-run Chinook Salmon under Alternative 3 (Alt 3) as compared to the Second Basis of Comparison (SBC) estimated by the IOS Model

Note: The plus symbol indicates median, box represents the interquartile range, and the whiskers represent the minimum and maximum values.

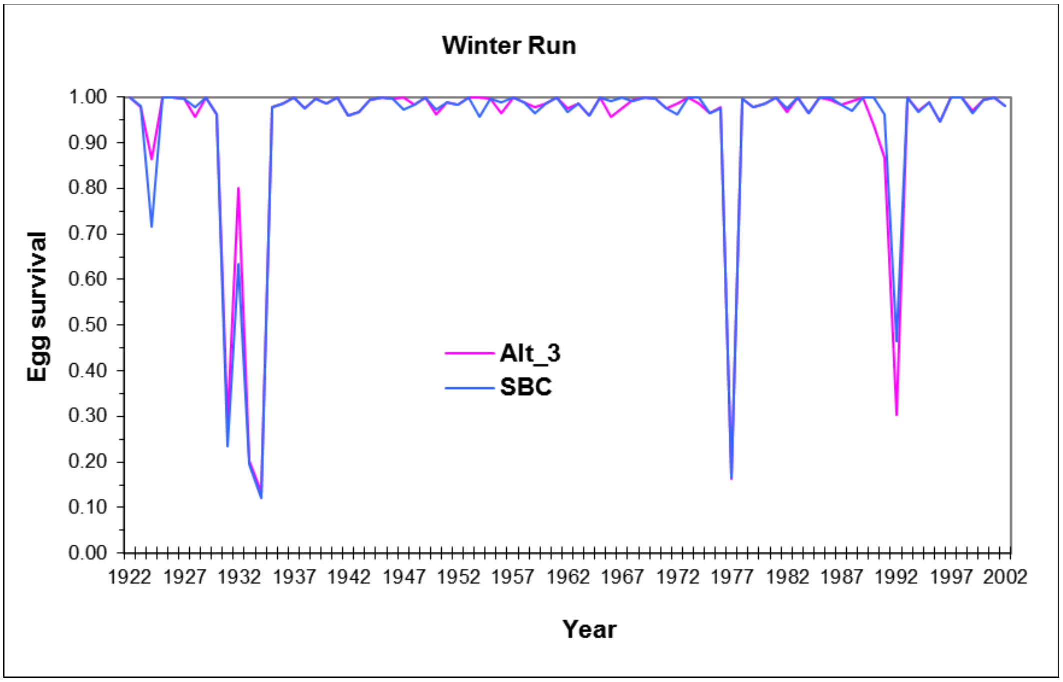

Figure 9H.12 Annual Egg Survival for Winter-run Chinook Salmon under Alternative 3 (Alt 3) as compared to the Second Basis of Comparison (SBC) over 81 Water Years Estimated by the IOS Model

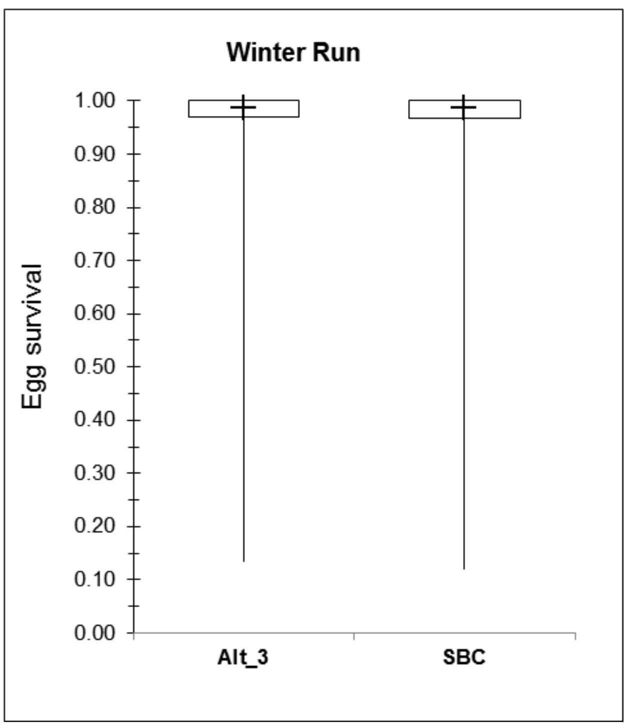

Figure 9H.13 Annual Egg Survival for Winter-run Chinook under Alternative 3 (Alt 3) as compared to the Second Basis of Comparison (SBC) estimated by the IOS Model

Note: The plus symbol indicates median, box represents the interquartile range, and the whiskers represent the minimum and maximum values.

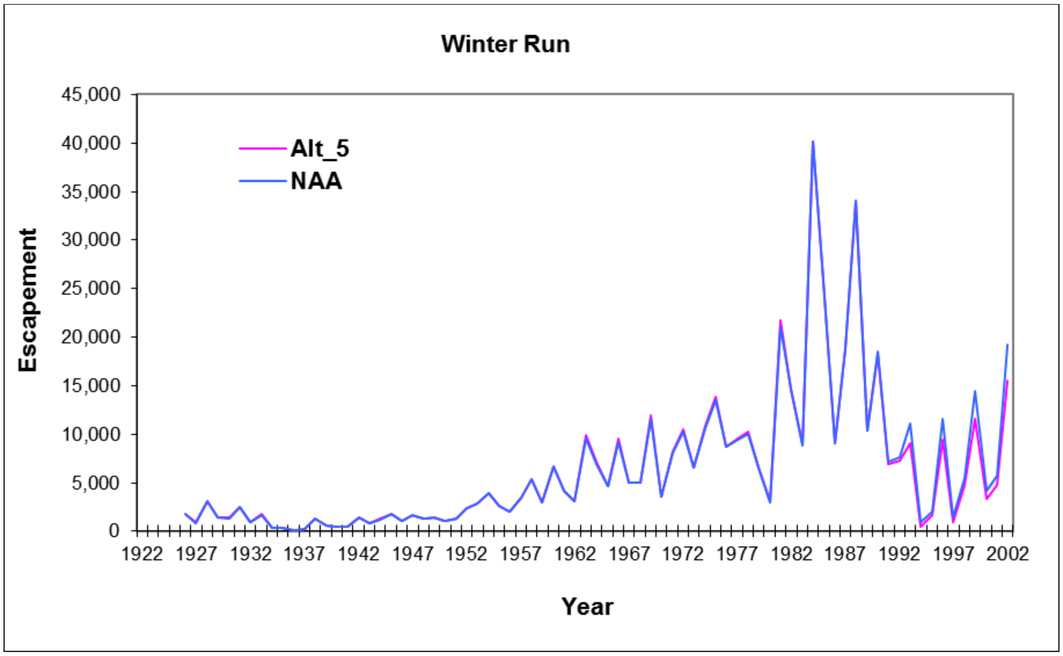

Figure 9H.14 Annual Adult Escapement for Winter-run Chinook Salmon under Alternative 5 (Alt 5) as compared to the No Action Alternative (NAA) over 81 Water Years Estimated by the IOS Model

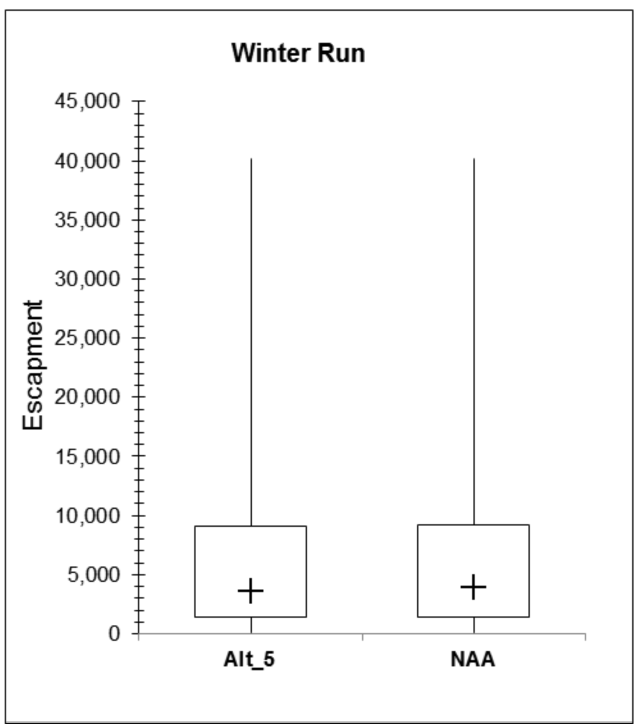

Figure 9H.15 Annual Adult Escapement for Winter-run Chinook Salmon under Alternative 5 (Alt 5) as compared to the No Action Alternative (NAA) estimated by the IOS Model

Note: The plus symbol indicates median, box represents the interquartile range, and the whiskers represent the minimum and maximum values.

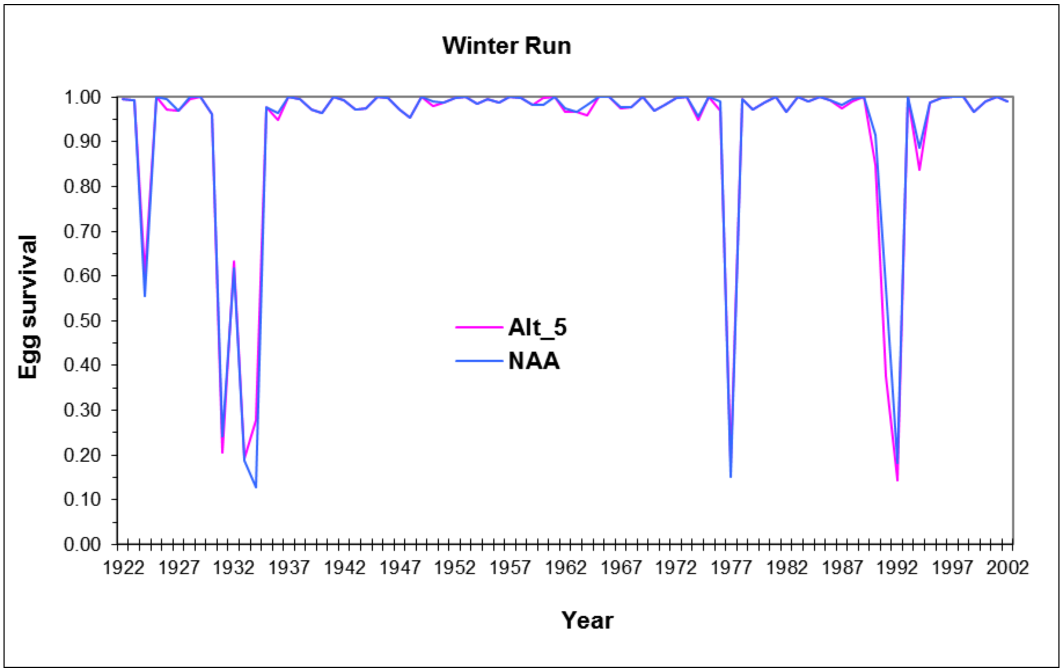

Figure 9H.16 Annual Egg Survival for Winter-run Chinook Salmon under Alternative 5 (Alt 5) as compared to the No Action Alternative (NAA) over 81 Water Years Estimated by the IOS Model

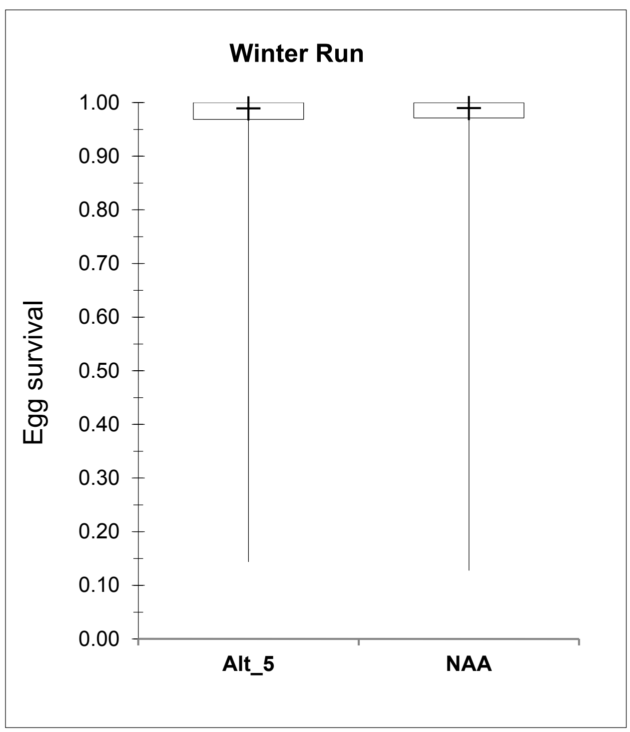

Figure 9H.17 Annual Egg Survival for Winter-run Chinook under Alternative 5 (Alt 5) as compared to the No Action Alternative (NAA) estimated by the IOS Model

Note: The plus symbol indicates median, box represents the interquartile range, and the whiskers represent the minimum and maximum values.

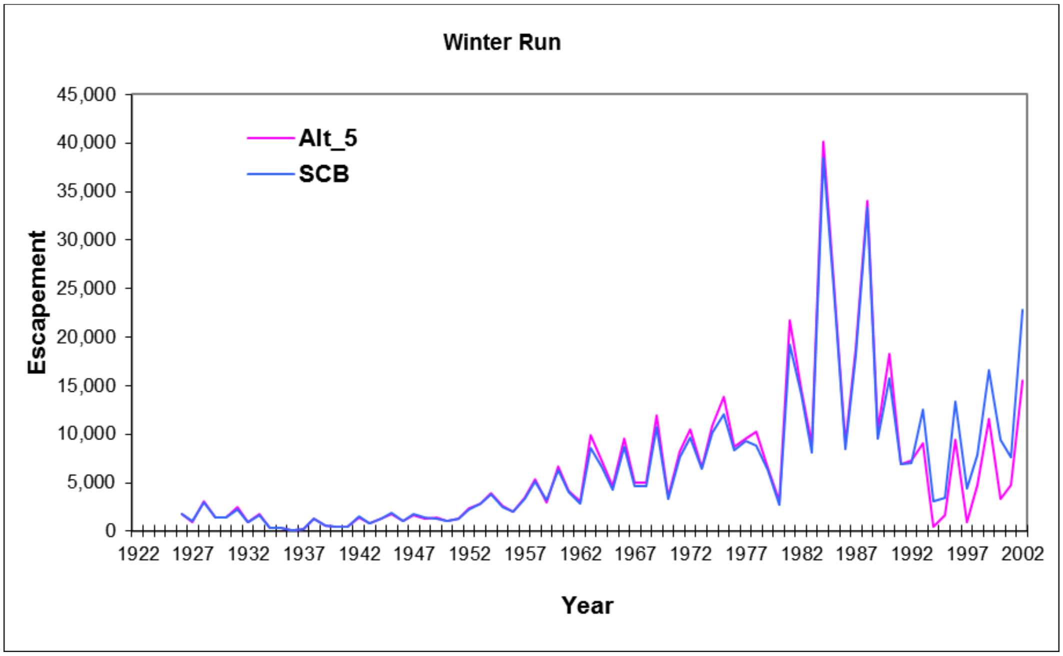

Figure 9H.18 Annual Adult Escapement for Winter-run Chinook Salmon under Alternative 5 (Alt 5) as compared to the Second Basis of Comparison over 81 Water Years Estimated by the IOS Model

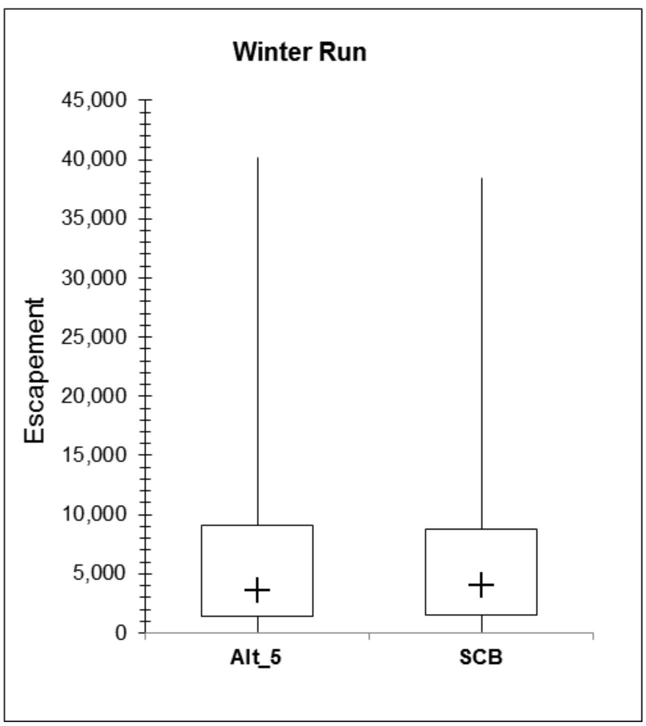

Figure 9H.19 Annual Adult Escapement for Winter-run Chinook Salmon under Alternative 5 (Alt 5) as compared to the Second Basis of Comparison (SBC) estimated by the IOS Model

Note: The plus symbol indicates median, box represents the interquartile range, and the whiskers represent the minimum and maximum values.

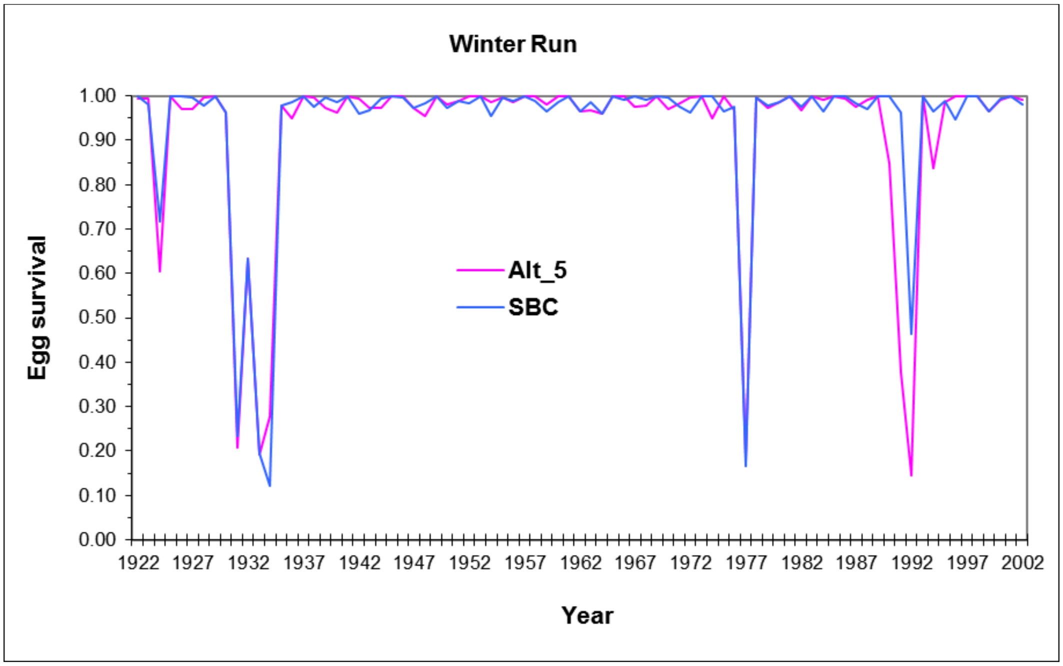

Figure 9H.20 Annual Egg Survival for Winter-run Chinook Salmon under Alternative 5 (Alt 5) as compared to the Second Basis of Comparison (SBC) over 81 Water Years Estimated by the IOS Model

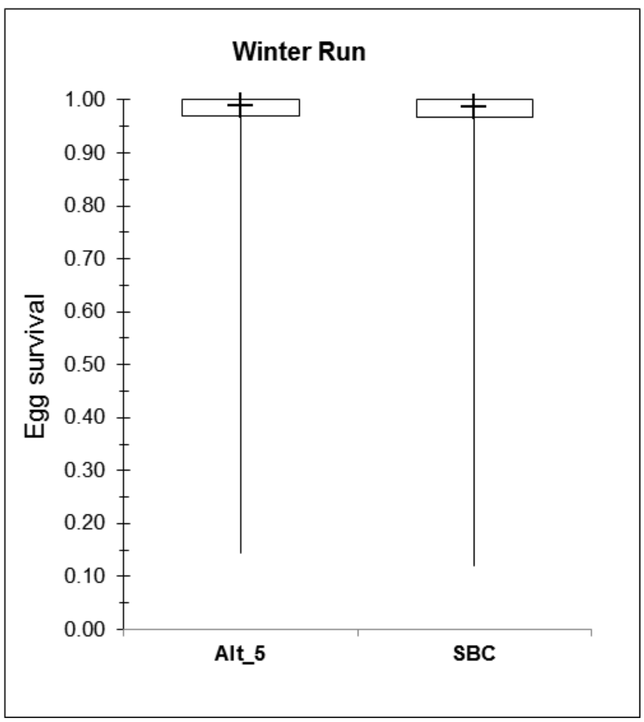

Figure 9H.21 Annual Egg Survival for Winter-run Chinook under Alternative 5 (Alt 5) as compared to the Second Basis of Comparison (SBC) estimated by the IOS Model

Note: The plus symbol indicates median, box represents the interquartile range, and the whiskers represent the minimum and maximum values.

This page left blank intentionally.