Appendix F, Modeling

Attachment F.7 Change in Abundance Estimate of Central Valley Chinook Salmon Available to Southern Resident Killer Whales

F.7.1 Introduction

This assessment evaluates abundance of Chinook salmon produced from the Central Valley watershed of California and available as adults in the ocean as prey for Southern Resident killer whales. The assessment assumes that age three and older (3+) Chinook salmon would be in the size range most suitable as prey, so the assessment focuses on age 3+ Chinook salmon. The scenarios evaluated are the No Action Alternative representing the last biological opinion operations (NAA) and the four alternatives analyzed in the Environmental Impact Statement with four phases of Alternative 2 that include or exclude TUCP and/or include or exclude the Voluntary Agreements (VA). The four phases of Alternative 2 assessed in this analysis are: without TUCP without VA (ALT2v1woTUCP), with TUCP and without VA (ALT2v1_wTUCP), without TUCP and with Delta VA (ALT2v2_woTUCP), and without TUCP and with systemwide voluntary agreements (ALT2v3_woTUCP).

F.7.2 Modeling Approach

Table F.7-1 depicts portions of life stages differentially affected by the Alternatives and other relevant scenarios that have quantitative models available and are compatible with the CalSim 3 water operations simulation. Unquantified effects are described but not bundled into the evaluation of abundance and assumed to apply equally across scenarios. The quantified freshwater mortality sources are aggregated into an overall change in freshwater survival attributable to the water operations scenarios.

Hatchery Chinook salmon releases are included in the analysis by using the average annual number of Chinook salmon released for all hatcheries and runs combined. Releases are separated by in-river and Bay releases using the proportion of release locations for each hatchery over approximately the past 15 years. Year to year variation in release location and numbers occurs in response to environmental conditions and hatchery management flexibility. For example, recently fry releases occurred in addition to the standard release numbers and these fry releases were not included here. In-river mortality based on the XT model and the Delta Passage Model was applied to the in-river released hatchery fish and these were then added to the Bay releases for a total number of hatchery fish in the Bay. The scenarios are assumed not to affect hatchery operations or fish so hatchery Chinook abundance entering the ocean is held constant through all scenarios. The past 18-year median ocean Chinook salmon abundance is divided by the hatchery and naturally produced Chinook salmon in the Bay to determine a baseline bay to ocean survival value. The hatchery proportion is based on coded wire tag recovery data in 2011 – 2020 from escapement surveys on the spawning grounds and proportions in the ocean are assumed to be the same. The past 20-year median ocean abundance along with differences in freshwater survival from the No Action Alternative (NAA) was used to calculate a point value of Chinook salmon available as prey to SRKW under each modeled scenario. The NAA was used as a point of reference to operations as they have occurred since the last Endangered Species Act consultation to obtain relative differences in survival between all the scenarios.

Table F.7-1. Rivers and Chinook salmon runs assessed, and models used in the assessment. The "Run" column refers to natural-origin (i.e., spawned in-river) fish unless stated otherwise. The proportions of Central Valley Chinook salmon is the mean 2001-2017 production from each tributary in USFWS 2018 and when summed adds up to 100% of the Central Valley Chinook production.

River	Run	Model	Proportion of Central Valley Chinook salmon	Reach shown in Figure F.7-1
Sacramento (spawning)	Fall	Salmort	0.097	1
Sacramento (RBDD to Delta Cross Channel)	Fall	XT	0.097	2
Sacramento (spawning)	Late Fall	Salmort	0.026	1
Sacramento	Late Fall (RBDD to Delta Cross Channel)	XT	0.026	2
Sacramento	Winter	CVPIA SIT	0.014	CV-wide
Central Valley	Spring	CVPIA SIT	0.02	CV-wide
Clear Creek	Fall	Upstream effects not included	0.023	-
Feather	Fall	Upstream effects not included	0.240	-
American	Fall	Salmort	0.223	3
American (mouth to Delta Cross Channel)	Fall	XT	0.223	4

River	Run	Model	Proportion of Central Valley Chinook salmon	Reach shown in Figure F.7-1
Stanislaus	Fall	Upstream effects not included	0.010	-
Delta	All Chinook salmon from Sacramento River basin	Delta Passage Model	0.936	5
Delta	Fall-run Chinook salmon from San Joaquin River basin and Delta Eastside streams [a]	Unquantified	0.065	-
Hatchery instream releases	All runs	XT model and Delta Passage Model NAA scenario	0.59 of hatchery releases	3,4,5
Hatchery Bay releases	All Bay releases	No project effects assumed	0.41 of hatchery releases	-

[a] "Delta Eastside streams" refers to the Cosumnes River, Mokelumne River, and Calaveras River.

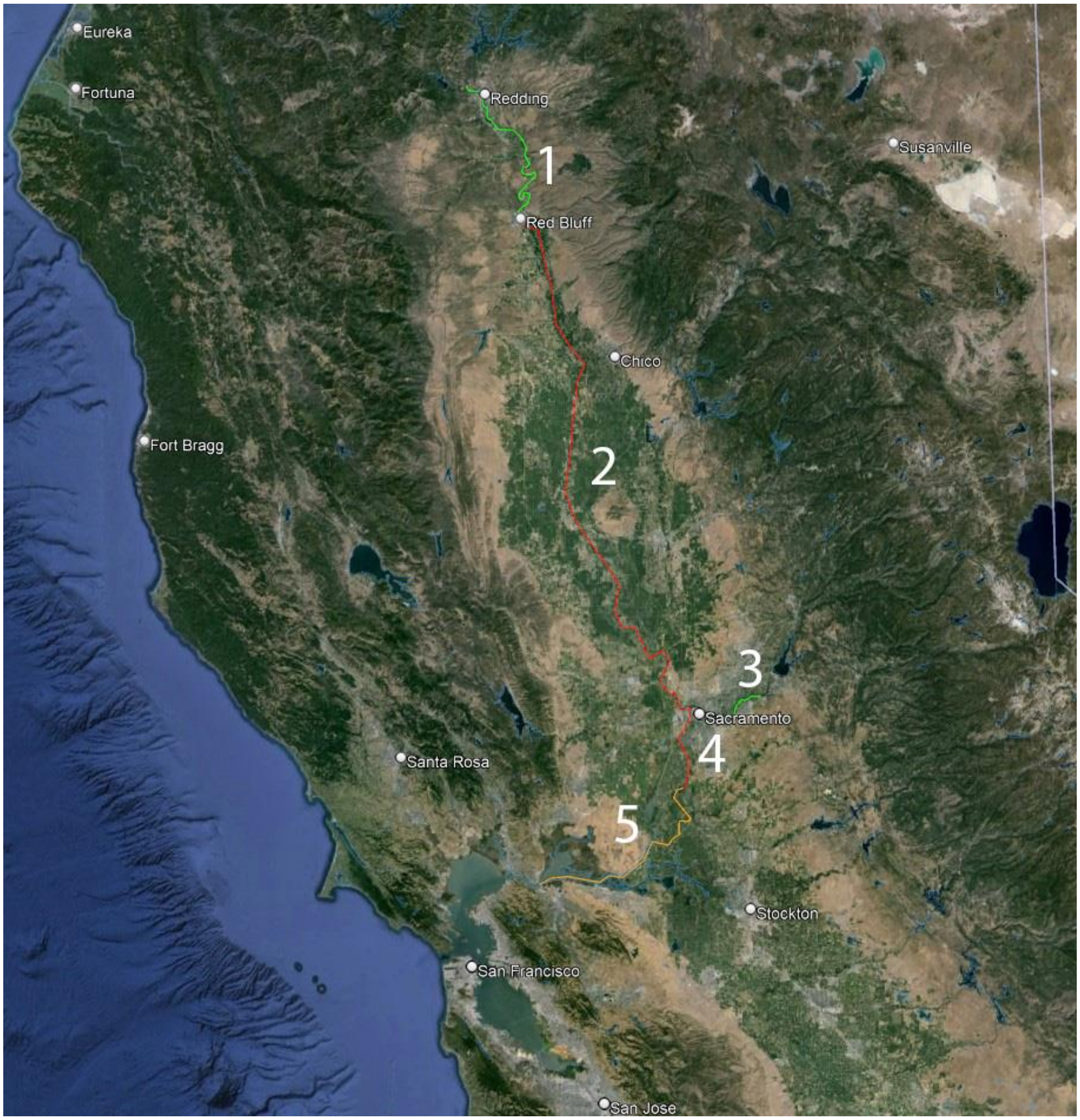


Figure F.7-1. Reaches covered by models in Table F.7-1.

F.7.3 Results

F.7.3.1 Changes in Chinook Salmon Survival and Production from the Upstream Areas

F.7.3.1.1 Sacramento River

The CVPIA Science Integration Team (SIT) Lifecycle models (Attachment F.2, *CVPIA SIT Winter-run LCM* and Attachment F.3 *CVPIA SIT Spring-run LCM*) were used to estimate abundance of juvenile winter-run Chinook salmon and spring-run Chinook salmon.

The Salmort egg mortality model (California Department of Water Resources and Bureau of Reclamation 2016) was used to estimate the change in survival in fall run and late fall-run Chinook salmon in the Sacramento River from changes in early life stage survival attributable to water temperature. This model uses the water temperature model outputs along with Chinook salmon spawning distribution and abundance to estimate water temperature effects on pre-spawned eggs, incubating eggs, and alevins.

The XT model (Attachment J.4 *XT Survival Model (Red Bluff to Delta Survival)*) was used to estimate survival of juvenile fall-run and late fall-run migrating down the Sacramento River between Red Bluff and the Delta Cross Channel. The model estimates survival based on estimated travel time and predation rates from acoustic tagged and tracked hatchery late fall-run Chinook releases.

Central Valley Fall-run Chinook Salmon

Figure F.7-2 shows the Salmort results for modeled fall-run Chinook salmon temperature dependent egg mortality in the Sacramento River. Median mortality is around 40% in all of the Alternatives but slightly higher in ALT2v1_woTUCP and ALT2v2_woTUCP and Alternative 1 had the lowest median mortality. Alternative 2 phases show variation with different precipitation patterns and storage levels between years.

Table F.7-2. Fall-run Chinook temperature dependent egg mortality in the Sacramento River from the Salmort Model.

Statistic	NAA	ALT1	Alt2v1 wo TUCP	Alt2v1 wTUCP	Alt2v2 wo TUCP	Alt2v3 wo TUCP	ALT3	ALT4
Median	41.2	40.0	40.9	40.8	41.2	40.7	40.2	40.7
Maximum	70.7	74.3	71.1	71.1	71.2	70.5	71.7	71.8
Minimum	21.0	19.9	20.1	20.1	20.4	20.3	18.4	20.2

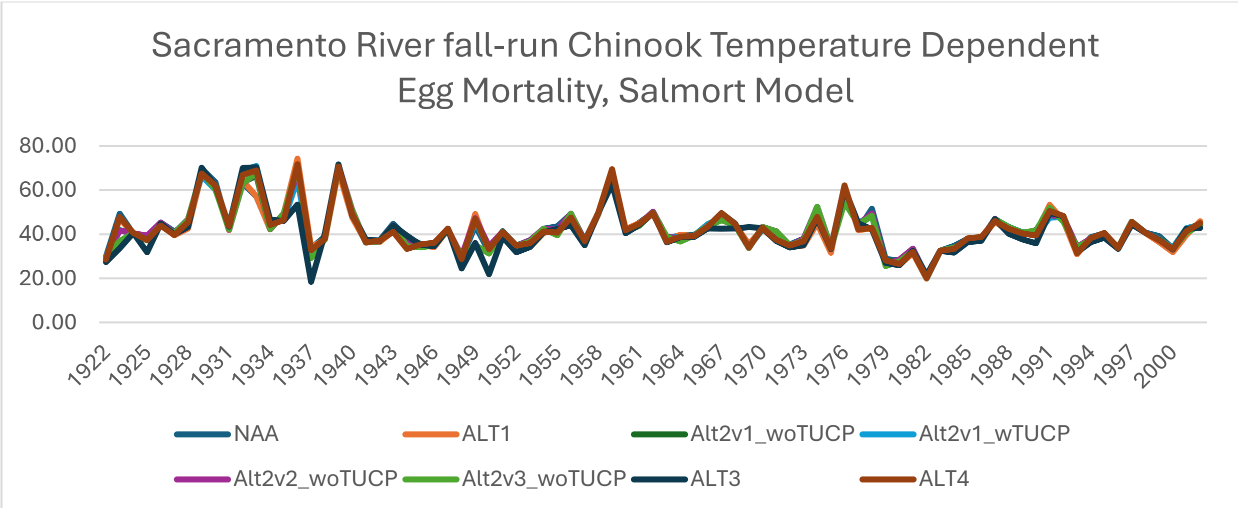
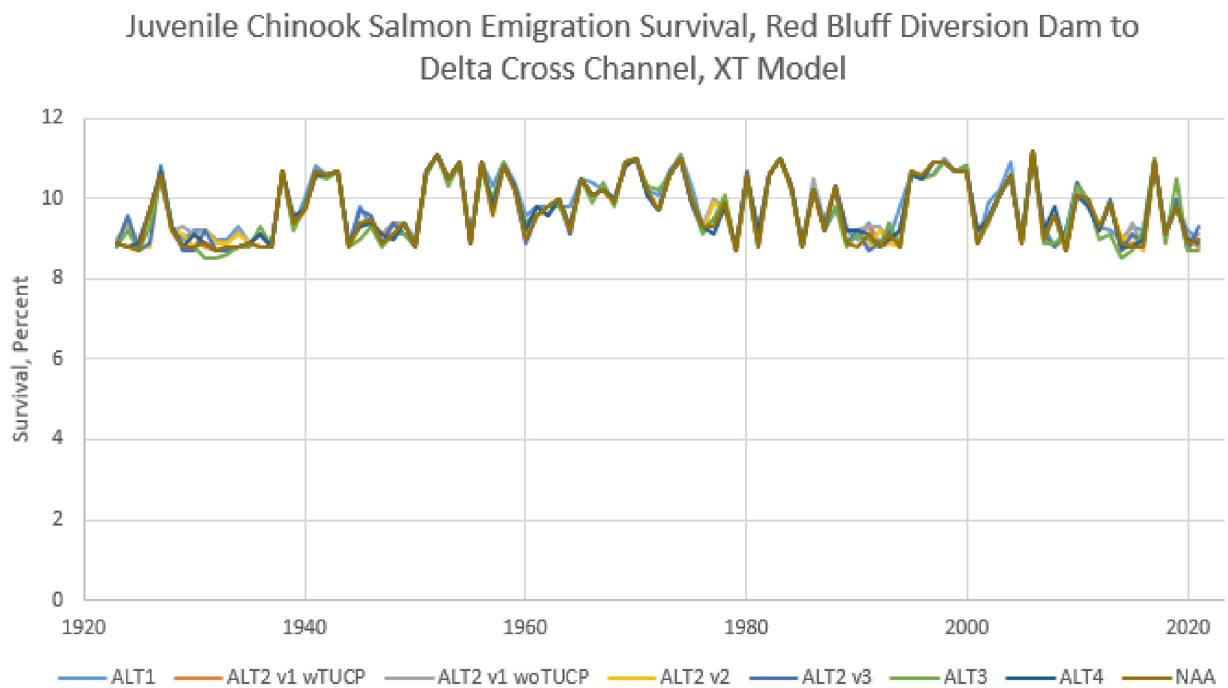


Figure F.7-2. Fall-run Chinook temperature dependent egg mortality in the Sacramento River from the Salmort Model.

Figure F.7-3 shows modeled fall-run Chinook salmon migration survival from Red Bluff downstream to the Delta Cross Channel from the XT model. The XT model estimates the probability of predator-prey encounters as a function of the predator density and the movement patterns of predators and prey. Survival estimates were similar between high and low flow conditions while fish travel time had a higher variability. Median survival was modeled to be between 9 and 10 percent in all of the Alternatives but slightly higher in Alternative 1 slightly lower Alternative 3 had the lowest median mortality. Alternative 2 all had a modeled median survival of 9.6 percent except ALT2v1woTUCP which was slightly higher at 9.7 percent.



	ALT1	ALT2 v1 wTUCP	ALT2 v1 woTUCP	ALT2 v2	ALT2 v3	ALT3	ALT4	NAA
Median	9.8	9.6	9.7	9.6	9.6	9.4	9.7	9.6
Maximum	11.2	11.2	11.2	11.2	11.2	11.2	11.2	11.2
Minimum	8.8	8.7	8.7	8.7	8.7	8.5	8.7	8.7

Figure F.7-3. Fall-run and late fall-run Chinook salmon survival between Red Bluff and the Delta Cross Channel from the XT model.

Central Valley Late fall-run Chinook Salmon

Temperature dependent egg mortality for late fall-run Chinook salmon in the Sacramento River from the Salmort model was similar across alternatives with a median mortality rate between 6 and 7 with ALT2v1_wTUCP being the highest and Alternative 1 and ALT2v3_woTUCP being the lowest.

Table F.7-3. Late fall-run Chinook temperature dependent egg mortality in the Sacramento River from the Salmort model.

Statistic	NAA	ALT1	Alt2v1_ woTUCP	Alt2v1 wTUCP	Alt2v2 woTUCP	Alt2v3_ woTUCP	ALT3	ALT4
Median	6.5	6.4	6.5	6.7	6.6	6.4	6.6	6.6
Maximum	17.6	17.8	17.1	16.8	17.2	16.7	16.3	17.7
Minimum	2.9	2.5	2.9	2.9	2.9	2.9	2.8	2.5

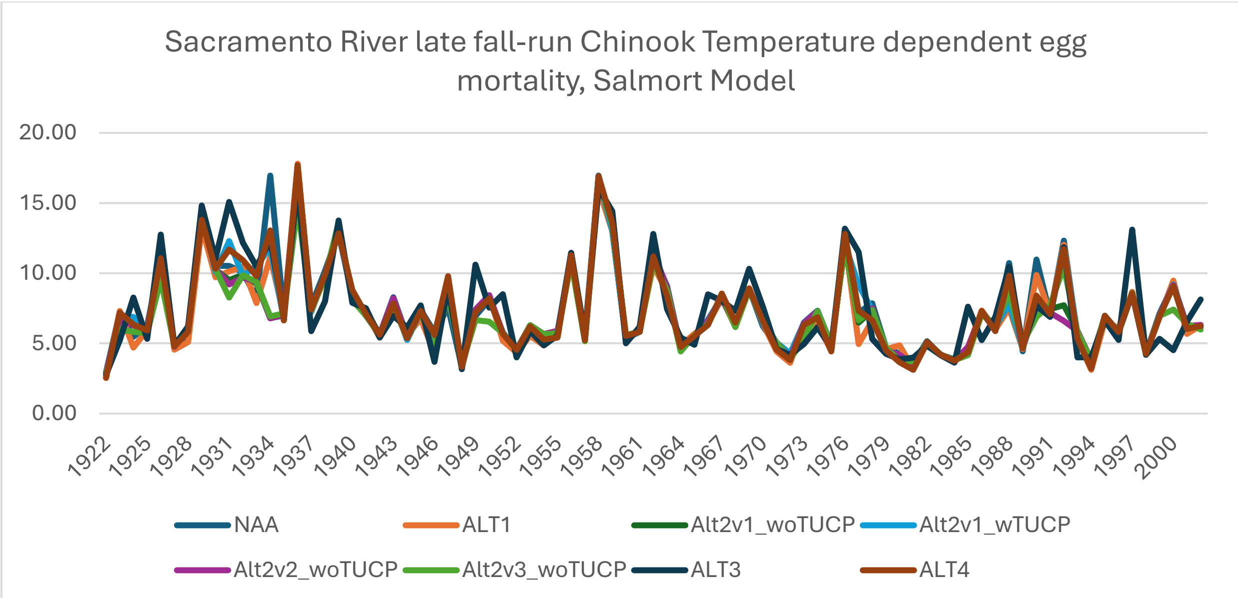


Figure F.7-4. Late fall-run Chinook temperature dependent egg mortality in the Sacramento River from the Salmort model.

Central Valley Spring-run Chinook Salmon

Populations of spring-run Chinook salmon are primarily in the cooler Sacramento River tributaries and spawning in the mainstem Sacramento River has become a rarely documented event despite regular aerial spawning surveys. Since the gates at RBDD were permanently lifted, population estimates for spring-run Chinook salmon in the mainstem are based primarily on redds observed in September during aerial redd surveys. The temperature management focus on winter-run Chinook salmon, which generally ends by the end of October, usually results in a water temperature increase during the spring-run Chinook salmon incubation period in the fall, which may limit the ability of spring-run Chinook salmon to successfully reproduce in the mainstem. In many years no spawning is documented during the spring-run spawning period (considered to be September in the Sacramento River). The CVPIA SIT model was used to estimate spring-run Chinook salmon juvenile abundance leaving San Francisco Bay (Figure F.7-5); sources of mortality are not partitioned out for specific tributaries, life stages, or locations. Juvenile abundance was summed with the other runs in San Francisco Bay. Results were generally similar across alternatives. Alternative 3 had the highest modeled median juvenile abundance and the NAA had the lowest modeled median juvenile abundance but differences are likely negligible.

Table F.7-4. Spring-run Chinook juvenile abundance at the Golden Gate from the CVPIA-SIT model.

Statistic	Alt1	Alt2wTUCP woVA	Alt2wo TUCPwoVA	Alt2wo TUCP DeltaVA	Alt2wo TUCPAllVA	Alt3	Alt4	NAA
Median	73168	73118	73139	73199	73487	74395	73130	73040
Maximum	74760	74798	74830	74872	75156	76238	74805	74697
Minimum	73964	73958	73984	74035	74321	75317	73968	73868

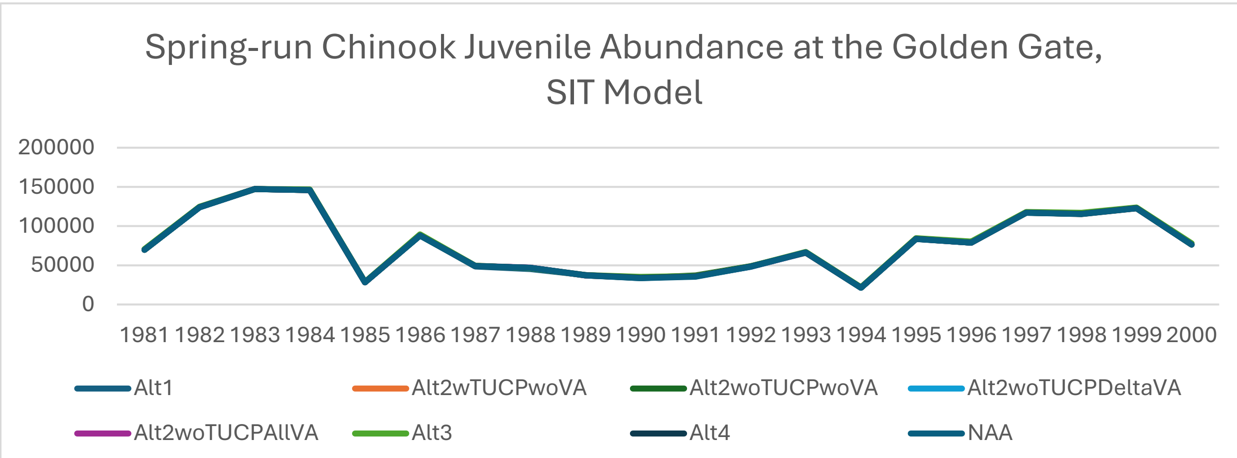


Figure F.7-5. Spring-run Chinook juvenile abundance at the Golden Gate from the CVPIA-SIT model

Central Valley Winter-run Chinook Salmon

Effects of the Alternatives on winter-run Chinook salmon relative abundance throughout their lifecycle were quantified using the CVPIA SIT winter-run Chinook salmon model. Reclamation ran the winter-run Chinook salmon model, both deterministically (i.e., no variability in parameters) and stochastically, to estimate demographic parameters, spawner abundances, and population trends for the period from 1980-1999 using flow and temperature inputs for each modeled alternative. In the upper Sacramento River, the model integrates the effects of water temperature, flow, fish abundance, and habitat availability to arrive at production of juvenile winter-run Chinook salmon emigrating from the Sacramento River, through the Delta to the ocean. Ocean survival factors are included through the range of years in the ocean until the fish come back and spawn. Figure F.7-6 shows how the juvenile abundance responds to the water operations and other factors over the 20-year period, 1981 – 2000, used in the model. The abundance displayed is that of juveniles exiting at the Golden Gate Bridge (Figure F.7-5). Results are generally similar for the Alternatives. Alternative 3 again had the highest modeled median juvenile abundance and the NAA again had the lowest modeled median juvenile abundance but difference are likely negligible. The juvenile abundance was added to the juvenile abundance for the other Chinook runs in the Bay.

Table F.7-5. Winter-run Chinook salmon juvenile abundance at the Golden Gate Bridge from the CVPIA SIT model.

Statistic	Alt1	Alt2wTUCP woVA	Alt2woTUCP woVA	Alt2woTUCP DeltaVA	Alt2woTUCP AllVA	Alt3	Alt4	NAA
Median	29665	31352	31297	31424.5	31764	31928.5	31213.5	31397
Maximum	96225	107606	107615	107330	109691	102787	106010	105948
Minimum	9382	11389	559	3556	3854	10390	11190	9367
Mean	38806	41333	40248	40304	41312	40768	41663	41404

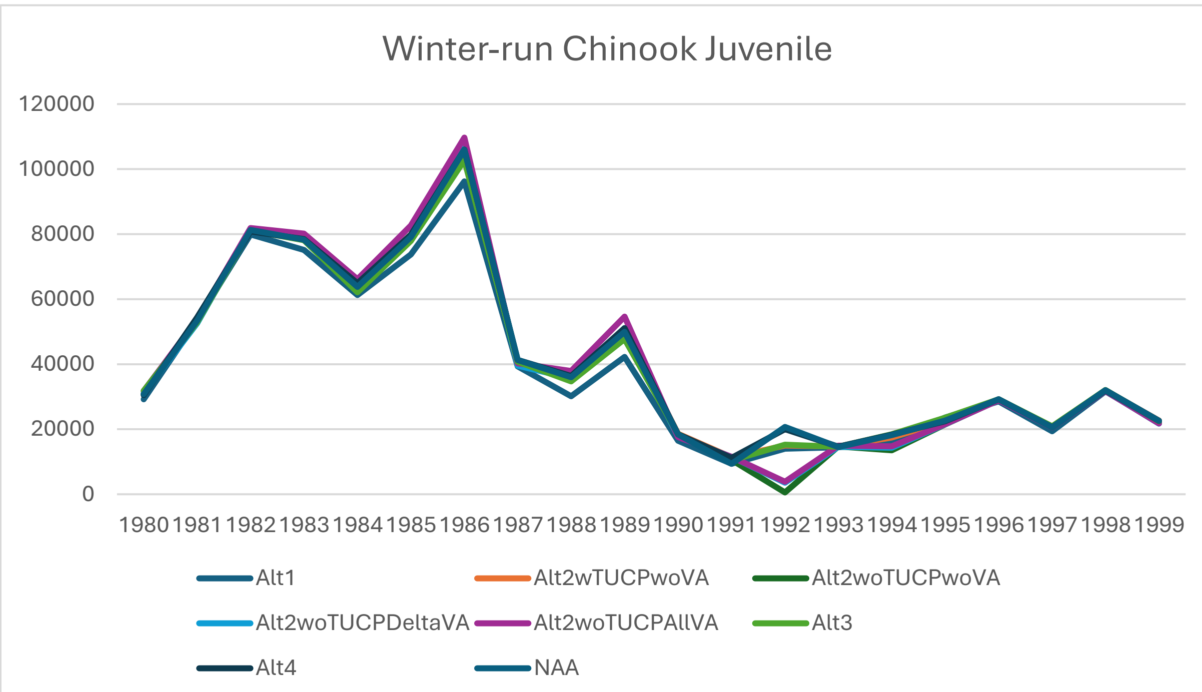


Figure F.7-6. Winter-run Chinook salmon juvenile abundance at the Golden Gate Bridge from the CVPIA SIT model.

F.7.3.1.2 Clear Creek

No models were available to assess survival in Clear Creek. Clear Creek fall -run Chinook salmon are added in with other Sacramento River runs and survival included with them down the Sacramento River from the XT model.

F.7.3.1.3 American River

American River Fall-run Chinook Salmon

The Salmort egg mortality model (California Department of Water Resources and Bureau of Reclamation 2016) was used to estimate the change in survival in the American River from changes in early lifestage survival attributable to water temperature. This model uses the water temperature model outputs along with Chinook salmon spawning distribution and abundance to estimate water temperature effects to pre-spawned eggs, incubating eggs, and alevins. The American River is a temperature-challenged system for salmonids and maintaining a balance in management for steelhead, fall-run Chinook salmon, and other water management needs results in tradeoffs in temperatures and flows for the maintenance of habitat conditions hospitable to salmonids. Modeled median mortality is around 25% in Alternative 1, about 27% in all the Alternative 2 phases, Alternative 3, and Alternative 4 (Figure F.7-7).

Table F.7-6. Annual temperature related mortality of Chinook Salmon eggs in the American River from the Salmort model.

Statistic	NAA	ALT1	Alt2v1_woTUCP	Alt2v1_wTUCP	Alt2v2_woTUCP	Alt2v3_woTUCP	ALT 3	ALT 4
Median	27.5	24.9	27.3	27.3	27.6	27.3	27.3	26.4
Maximum	68.1	70.0	68.1	68.1	68.9	68.9	68.1	68.1
Minimum	8.9	8.2	8.9	8.9	9.1	8.9	8.5	8.8

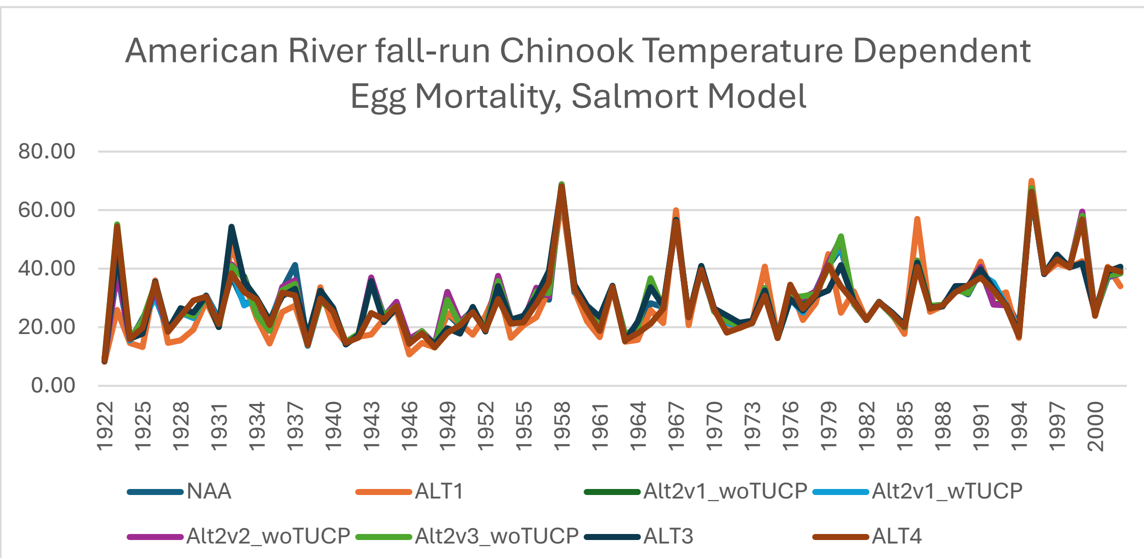


Figure F.7-7. Annual temperature related mortality of Chinook Salmon eggs in the American River from the Salmort model.

Pre-spawning mortality of fall-run Chinook salmon in the American River is the highest measured in any of the Central Valley rivers (Figure F.7-8). This is partially depicted in the annual egg mortality estimates in Figure F.7-7.

but not fully. Water temperatures are in a stressful range for adult holding (mid 60 degrees) in most years and the fall-run Chinook salmon congregate near the dam starting in summer and peaking in October to November when spawning starts. During wetter years, such as 2011, when flows are higher and water is cooler throughout the fall, the fish are distributed more evenly throughout the river and are more actively moving around and redistributing in advance of spawning in comparison with most years when the majority hold at Nimbus Dam. Water temperatures are relatively unchanged between Alternatives so appreciable changes in the extent of pre-spawning mortality are not expected (

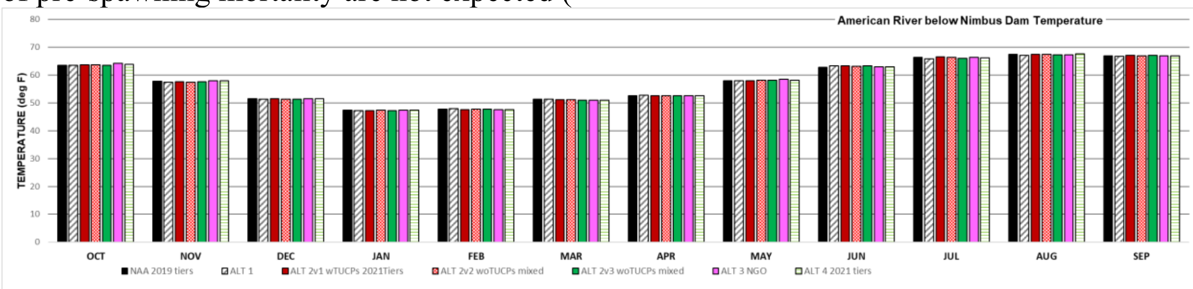


Figure F.7-9).

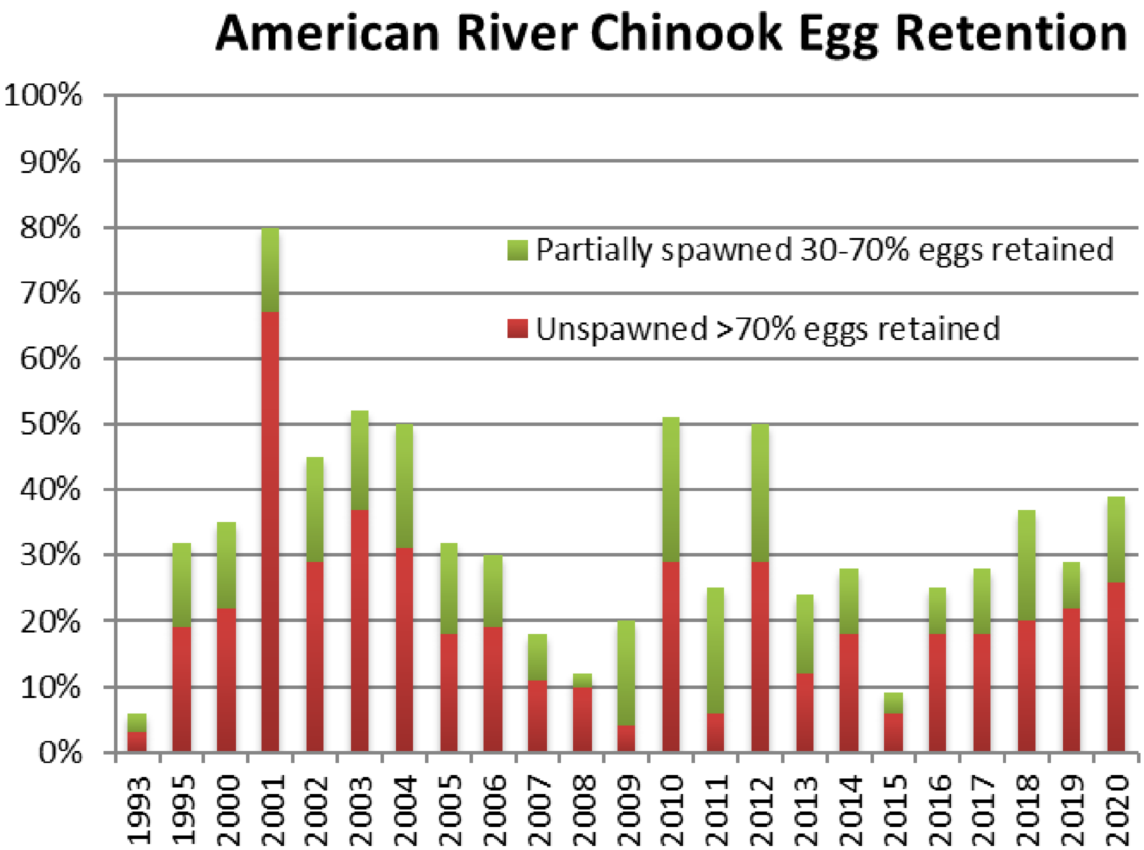


Figure F.7-8. Egg retention in American River Chinook salmon, 1993-2020. Note, no data for 1996-1999. Data compiled from annual CDFW escapement reports.

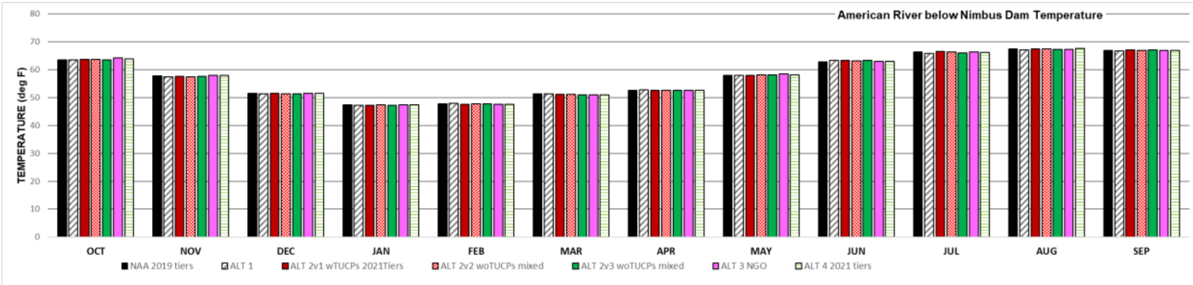


Figure F.7-9. American River below Nimbus Dam monthly water temperature at the 50% exceedance probability.

F.7.3.1.4 Feather River

Upstream effects were not evaluated for the Feather River because operations are governed by the FERC license within that project area. Migration for Feather River salmon through the Delta is assessed with the Delta Passage Model described in the Delta section below.

F.7.3.1.5 Stanislaus River

Fall-run Chinook salmon

Survival from the Stanislaus River was not included because no models are available to assess survival from the San Joaquin system to the San Francisco Bay. The proportion of Central Valley Chinook abundance from the San Joaquin tributaries and Mokelumne River was added into the juveniles in the bay and included in the adult ocean abundance estimate.

Through-Delta survival of juvenile Chinook salmon emigrating from the San Joaquin basin has been estimated to be less than five percent (Buchanan 2017). This low migratory survival is likely a key factor limiting natural populations in the Stanislaus River and other San Joaquin tributaries. Releases cause stable and similar March through June flows in the Stanislaus River between the Alternatives so estimated survival should be similar. Stanislaus River Chinook salmon production composes about one percent of the Central Valley total.

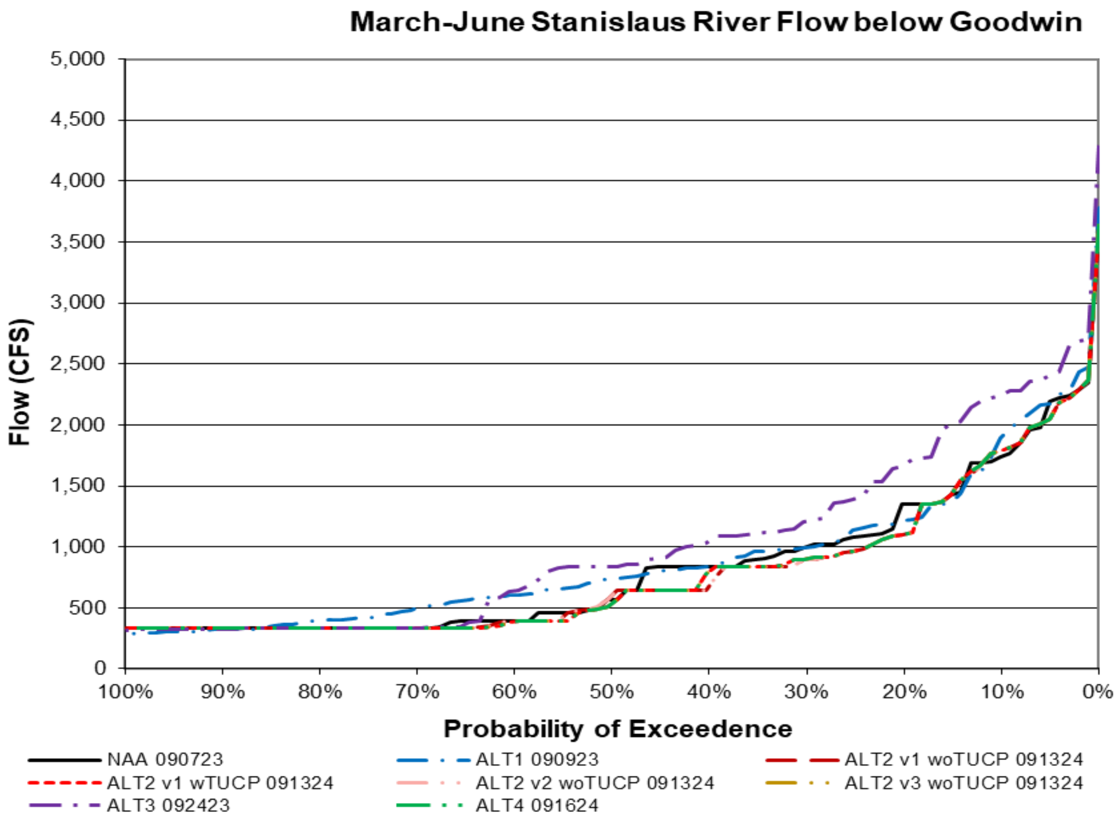


Figure F.7-10. March through June Stanislaus River flow below Goodwin Dam.

Spring-run Chinook salmon

Because few spring-running Chinook salmon are expected on the Stanislaus River, no assessment of the effect of the Alternatives on Stanislaus River Spring-run Chinook salmon was conducted as part of this evaluation of Chinook salmon production for southern resident killer whale prey.

F.7.3.1.6 Delta

Sacramento River basin Chinook salmon

The Delta Passage Model (Cavallo et al. 2011) was used to estimate survival of Chinook salmon from the Sacramento River basin emigrating through the Delta. This model uses results from acoustic tagged salmon survival studies along with relationships between flow through delta channels and survival to estimate through-Delta smolt survival. Figure F.7-11 and Figure F.7-12 show Delta Passage Model results for fall-run and late fall-run Chinook salmon from the Sacramento River basin. Results for both runs show median survivals of 0.17 or 0.18 across all alternatives.

Table F.7-7. Delta Passage Model results for fall-run Chinook salmon.

Statistic	Alt1	Alt2woTUCPAllVA	Alt2woTUCPDeltaVA	Alt2woTUCPwoVA	Alt2wTUCPwoVA	Alt3	Alt4	NAA
Median	0.17	0.17	0.17	0.17	0.17	0.18	0.17	0.17
Maximum	0.32	0.33	0.33	0.33	0.33	0.35	0.33	0.33
Minimum	0.12	0.11	0.11	0.12	0.12	0.12	0.12	0.12

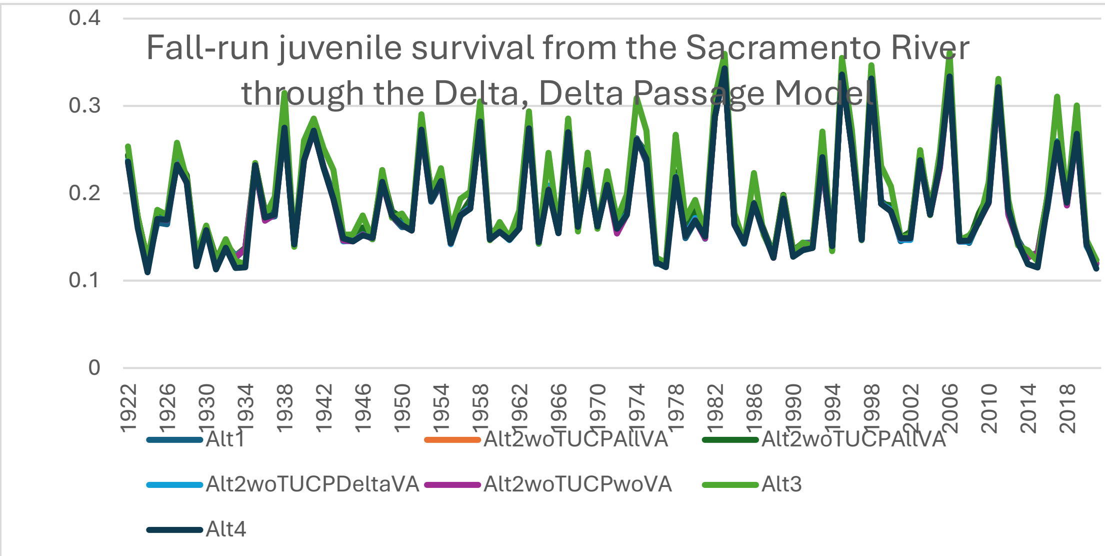


Figure F.7-11. Delta Passage Model results for fall-run Chinook salmon.

Table F.7-8. Delta Passage Model results for late fall-run Chinook salmon.

Statistic	Alt1	Alt2woTUCPAllVA	Alt2woTUCPDeltaVA	Alt2woTUCPwoVA	Alt2wTUCPwoVA	Alt3	Alt4	NAA
Median	0.168488	0.17693	0.170626	0.169295	0.170161	0.177059	0.170127	0.170694
Maximum	0.342654	0.342712	0.34314	0.343	0.3428	0.360878	0.343052	0.342118
Minimum	0.117912	0.121186	0.118502	0.118351	0.11259	0.118868	0.109605	0.112595

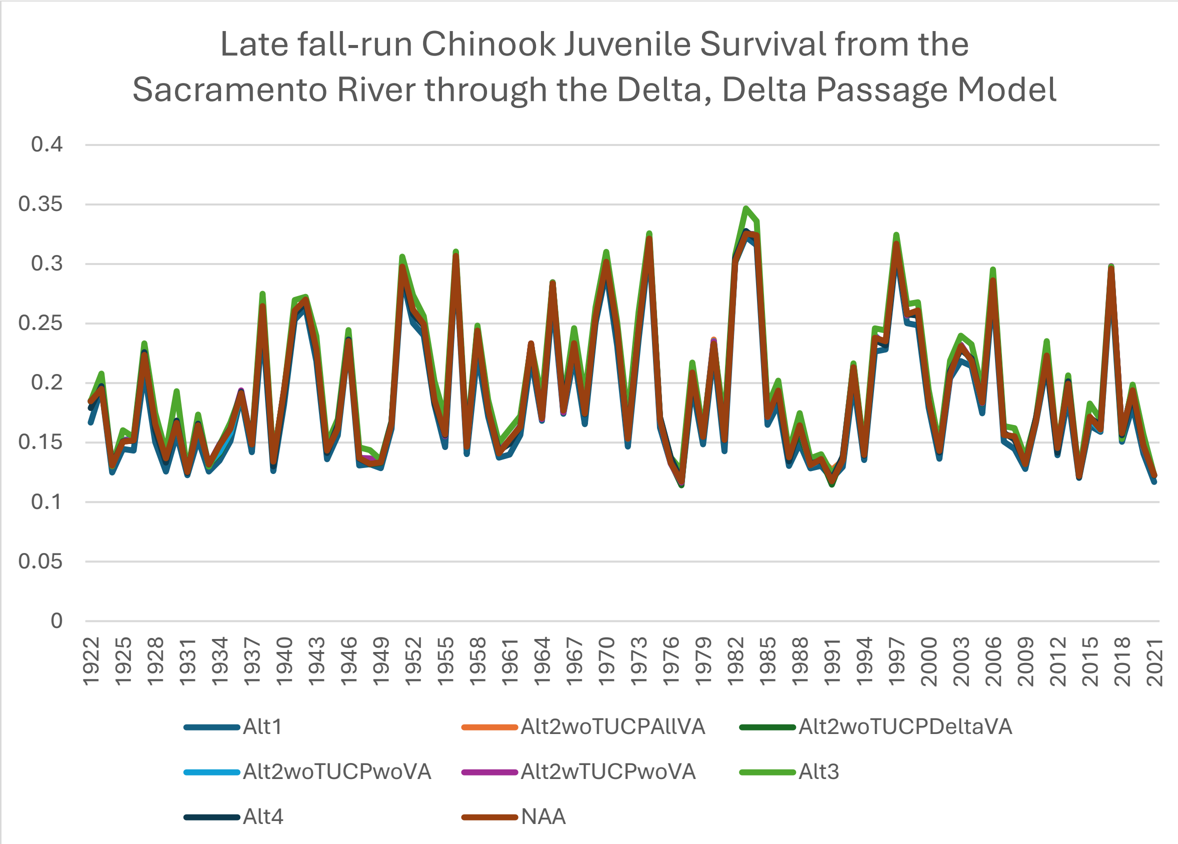


Figure F.7-12. Delta Passage Model results for late fall-run Chinook salmon.

San Joaquin River basin and Mokelumne River Chinook Salmon

No Delta survival changes were incorporated for Chinook salmon from the San Joaquin or Mokelumne rivers. Chinook salmon from the San Joaquin tributaries compose 2.6 percent and from Mokelumne about 2.8 percent of the Central Valley total Chinook salmon.

Naturally produced Chinook Salmon Survival to the Delta

Table F.7-9 summarizes the survival values of each Alternative as a proportion of the NAA for each river and model presented previously and used in the quantitative assessment. Values greater than 1.0 indicate higher upstream survival relative to the NAA and values less than 1.0 indicate lower survival than NAA. The survival value in each watershed and each run is scaled to the total Central Valley abundance by using the proportion that each river and run composes of the total Central Valley Chinook salmon abundance in the ocean over the 2001 – 2017 period (mean value) as estimated by USFWS (2018).

Table F.7-9. Upstream survival in each alternative as a proportion of survival in the NAA.

River and run	Upstream effects - Egg Mortality Model								Upstream effects (Migration; mean difference) - XT Model								Proportion of CV Abundance
	NAA	ALT1	Alt2v1_woTUCP	Alt2v1_wTUCP	Alt2v2_woTUCP	Alt2v3_woTUCP	ALT3	ALT4	NAA	ALT1	Alt2v1_woTUCP	Alt2v1_wTUCP	Alt2v2_woTUCP	Alt2v3_woTUCP	ALT3	ALT4	
Sacramento River winter-run	Uses SIT lifecycle model																0.014
Sacramento River spring-run	Uses SIT lifecycle model																0.000
Sacramento River fall-run	1.000	1.014	1.005	1.005	1.002	1.005	1.021	1.007	1.0000	1.0010	1.0008	1.0004	1.0001	1.0002	0.9998	1.0003	0.097
Sacramento River late fall-run	1.000	1.002	1.001	1.001	1.000	1.001	1.002	1.001	1.0000	1.0010	1.0008	1.0004	1.0001	1.0002	0.9998	1.0003	0.026
Clear Creek fall-run									1.0000	1.0010	1.0008	1.0004	1.0001	1.0002	0.9998	1.0003	0.023
American River fall-run	1.000	1.008	1.000	1.000	0.999	1.000	0.996	1.005	1.0000	0.9999	1.0000	1.0000	1.0000	0.9999	0.9999	1.0001	0.223
Stanislaus River fall-run	not evaluated																0.010
Feather River fall-run									1.0000	0.9999	1.0000	1.0000	1.0000	0.9999	0.9999	1.0001	0.240
Other Sac Runs (spring)	included in SIT spring-run model																0.022
Other Sac Runs (fall)	only Delta passage evaluated																0.292
San Joaquin Basin	not evaluated																0.026
Mokelumne	not evaluated																0.028

Survival through the Delta

The Delta Passage Model results from Figure F.7-11 and Figure F.7-12 are aggregated for all rivers and runs from the Sacramento Basin passing through the delta (Table F.7-10). Results are multiplied by the upstream survival for each river for an aggregate freshwater survival. Results from each river are scaled by the proportion of Central Valley production from each area to allow summing results across rivers for an aggregate freshwater survival as a proportion of NAA survival (Table F.7-11).

Table F.7-10. Survival through the delta from the Delta Passage Model for fall and late fall-run and lifecycle effects from the SIT model for winter-run and spring-run.

River and run	Delta effects - Delta Passage Model								Lifecycle effects - SIT Model								Proportion of CV Abundance
	NAA	ALT1	Alt2v1_woTUCP	Alt2v1_wTUCP	Alt2v2_woTUCP	Alt2v3_woTUCP	ALT3	ALT4	NAA	ALT1	Alt2v1_woTUCP	Alt2v1_wTUCP	Alt2v2_woTUCP	Alt2v3_woTUCP	ALT3	ALT4	
Sacramento River winter-run									1.0000	0.9595	1.0002	1.0030	0.9923	1.0075	0.9976	1.0022	0.014
Sacramento River spring-run									1.0000	1.0021	1.0016	1.0009	1.0013	1.0033	1.0125	1.0014	0.000
Sacramento River fall-run	1.0000	1.0002	0.9988	0.9989	0.9996	1.0027	1.0118	0.9989									0.097
Sacramento River late fall-run	1.0000	0.9929	1.0002	1.0004	1.0002	1.0003	1.0077	0.9993									0.026
Clear Creek fall-run	1.0000	1.0002	0.9988	0.9989	0.9996	1.0027	1.0118	0.9989									0.023
American River fall-run	1.0000	1.0002	0.9988	0.9989	0.9996	1.0027	1.0118	0.9989									0.223
Stanislaus River fall-run	not evaluated																0.010
Feather River fall-run	1.0000	1.0002	0.9988	0.9989	0.9996	1.0027	1.0118	0.9989									0.240
Other Sac Runs (spring)	included in SIT spring-run model																0.022
Other Sac Runs (fall)	1.0000	1.0002	0.9988	0.9989	0.9996	1.0027	1.0118	0.9989									0.292
San Joaquin Basin	not evaluated																0.026
Mokelumne	not evaluated																0.028

Table F.7-11. Freshwater survival by run scaled by proportion of Central Valley abundance and then summed to aggregate freshwater survival relative to a survival of 0.97826 for the NAA. For each alternative, values greater than 0.97826 have higher abundance and survival than the NAA and values less than 0.97826 are lower than NAA.

River and run	NAA	ALT1	Alt2v1_woTUCP	Alt2v1_wTUCP	Alt2v2_woTUCP	Alt2v3_woTUCP	ALT3	ALT4
Sacramento River Winter-run	0.01411	0.01354	0.01412	0.01416	0.01401	0.01422	0.01408	0.01415
Sacramento River Spring-run	0.00031	0.00031	0.00031	0.00031	0.00031	0.00031	0.00031	0.00031
Sacramento River Fall-run	0.09699	0.09846	0.09743	0.09740	0.09715	0.09776	0.10016	0.09759
Sacramento River Late Fall-run	0.02594	0.02584	0.02599	0.02599	0.02595	0.02598	0.02618	0.02595
American River Fall-run	0.22327	0.22507	0.22300	0.22303	0.22296	0.22385	0.22497	0.22416
San Joaquin and Mokelumne	0.08645	0.08645	0.08645	0.08645	0.08645	0.08645	0.08645	0.08645
Feather River Fall-run	0.23969	0.23970	0.23940	0.23943	0.23959	0.24032	0.24248	0.23945
Other Sac Tribs - Fall	0.29150	0.29155	0.29115	0.29118	0.29139	0.29229	0.29493	0.29119
Upstream survival of all populations	0.97826	0.98092	0.97785	0.97794	0.97780	0.98118	0.98956	0.97926

F.7.3.1.7 Hatchery Produced Chinook Salmon

Hatchery produced Chinook salmon releases are included in the analysis by using the average release of hatchery juveniles for 2007 – 2013 (from Palmer-Zwahlen et al. 2019 and 2018, and Palmer Zwahlen and Kormos 2015) as the number of hatchery produced fish released each year for all Central Valley Chinook salmon runs combined (average total of 35,059,237 and range of 30,455,664 to 38,510,728). The proportion of hatchery fish released in-river and in San Francisco Bay varies from year to year based on water year conditions and other factors. The general release goals and release locations based on recent trends over the last 15 years (Table F.7-12) were used to estimate an average in-river release proportion of 0.59.

Table F.7-12. Central Valley Chinook salmon hatchery release goals and proportion released in-river and in Bay areas.

Hatchery Annual Chinook Releases	General Goal	Proportion Bay	Proportion In-River	Number In-River
Coleman Fall	12,000,000	0	1	12,000,000
Coleman Late Fall	1,000,000	0	1	1,000,000
LSNFH Winter	200,000	0	1	200,000
Feather Fall	6,000,000	0.7	0.3	1,800,000
Feather Spring	2,000,000	0.5	0.5	1,000,000
Feather Enhancement	2,000,000	1	0	0
Nimbus	4,000,000	0.33	0.67	2,680,000
Mokelumne	5,000,000	0.7	0.3	1,500,000
Mokelumne Enhancement	2,000,000	1	0	0
Merced	300,000	0	1	300,000
Total Release	34,500,000			
In-River Release	20,480,000			
Proportion Released In-River	0.59			

In-river mortality was applied to all the in-river released hatchery fish using a static river survival value across all alternatives. We assumed no difference in hatchery fish survival between alternatives because hatcheries have ability to modify practices as needed to meet their performance measures. A survival of 0.096 from the median NAA scenario of the XT model was applied to Coleman and Livingston Stone hatchery in-river releases. A survival of 0.96 from the XT model difference between RBDD to DCC and RBDD to American River was applied to in-river releases for the American River, Mokelumne River, Feather River, and Merced River hatcheries. The Delta Passage Model survival of 0.17 was applied to all the hatchery fish passing through the Delta. We assumed that the Mokelumne and Merced hatchery survival through the Delta (along with their in-river survival) would be similar to the Delta Passage Model survival for Sacramento River origin Chinook salmon. The in-river released hatchery Chinook salmon surviving through the Delta were added to the Bay releases for a total number of hatchery fish in the Bay (Table F.7-13).

Table F.7-13. Calculation of hatchery Chinook salmon in the San Francisco Bay under the NAA scenario.

Total Hatchery Release	35,059,237
Proportion Released In-River	0.59
Coleman and LSNFH Hatchery Survival to Delta from XT Model NAA	0.096
Feather, American, Mokelumne, and Merced River Hatchery Survival to Delta (using interpolated value for American River from XT model)	0.96
Hatchery Fish Surviving to Delta	8,263,280
NAA DPM Survival	0.17
NAA Hatchery Fish to Bay	1,410,488
Hatchery Bay Release	14,247,261
Hatchery Total in Bay NAA	15,657,749
Hatchery Proportion	0.74
Total Fish in Bay	21,159,121
Natural Fish in Bay NAA	5,501,371

F.7.3.1.8 Hatchery and Natural Proportions and Ocean Abundance

Because release and recovery coded wire tag data are available and more reliable for the hatchery component of the runs, the smolt to adult survival rate was estimated for the hatchery component and applied to the whole population (hatchery and natural) of smolts in the bay. First it was necessary to estimate ocean abundance of all the central valley Chinook runs and then apply a hatchery proportion. This is because the ocean abundance estimates for the largest Central Valley run, Sacramento River fall-run Chinook, is estimated for the combined natural and hatchery origin fish.

The hatchery and natural area escapement proportions of Central Valley Chinook salmon were estimated using data from the Central Valley coded wire tag recovery reports for run years 2011-2022 (Palmer-Zwahlen et al. 2019, Palmer-Zwahlen et al. 2018, and Palmer-Zwahlen and Kormos 2015, 2020, Letvin et al. 2021a, Letvin et al. 2021b, Dean and Lindley 2023). The hatchery proportion over the eleven years of available data averaged 0.74 (range 0.57 – 0.88). A separate analysis of Chinook salmon otoliths in 1999 and 2002 found that the contribution of hatchery-produced fish made up approximately 90 percent of the ocean fishery off the central California coast from Bodega Bay to Monterey Bay (Barnett-Johnson et al. 2007), however the more recent Central Valley coded wire tag-derived value of 0.74 overall Central Valley hatchery proportion was used for this analysis.

The ocean abundance, hatchery releases, and hatchery proportions are values regularly estimated with greater confidence than the abundance of naturally produced Chinook salmon entering the ocean from the Central Valley. Therefore, the median ocean abundance for the period 2001 – 2022 of 233,349 (Table F.7-14) along with the hatchery proportion of 0.74 and median number of hatchery produced fish in San Francisco Bay in the NAA scenario (15,657,749 from Table F.7-13) was used to estimate the smolt in the bay-to adult survival rate of 0.011[1]. Mortality sources other than that quantified in the fisheries (e.g. predation on adults by marine mammals) are not included in this estimate. Back calculating using the median ocean abundance, smolt to adult survival, and 0.74 hatchery proportion gives a NAA value for estimated number of naturally produced juvenile Chinook salmon in the San Francisco Bay of 5,501,371 juveniles (Table F.7-13).

F.7.3.2 Ocean Abundance and Biomass of Adult (Age 3+) Chinook Salmon

The Sacramento River Index was used as the annual production of fall-run Chinook salmon from the Central Valley. This index is the sum of the annual (September 1 to August 31) Sacramento River fall-run Chinook salmon ocean harvest South of Cape Falcon (~Columbia River mouth), fall-run Chinook salmon impacts from non-retention (released fish), recreational harvest of Sacramento River fall-run Chinook salmon in the Sacramento River Basin, and the Sacramento River fall-run Chinook salmon spawner escapement (Pacific Fishery Management Council 2023a). The ocean abundance of late fall-run, San Joaquin fall-run Chinook salmon, Sacramento River winter-run Chinook salmon, and Central Valley spring-run Chinook salmon was estimated from annual escapement estimates as presented in PFMC (2023b) plus an estimated ocean harvest. Each year's ocean harvest rate for late fall-run and spring-run Chinook salmon was assumed to be the same as the year's rate for fall-run Chinook salmon. Winter-run Chinook salmon abundance assumed an annual harvest rate of 8.5 percent based on harvest management goals. Jacks, as enumerated in PFMC (2023b), were excluded from the ocean abundance estimate for all runs because they were assumed to be too small to contribute significantly to Southern Residents killer whale prey.

The average size of adult Chinook salmon in the ocean varies from year to year and is likely a function of the prey availability and current age distribution. The seasonal average dressed weight at the time of harvest in the commercial troll fishery ranged from 9.6 to 15.1 pounds from 2001 through 2022 (Pacific Fishery Management Council 2023b). The dressed weight (assumed to be gutted, head off) was converted to live weight using a 1.33 conversion factor (National Marine Fisheries Service 1980) resulting in live weight range of 14.4 to 20.1 pounds. Abundance and biomass have varied substantially from year to year with cohort replacement rates for all runs combined ranging from 0.28 to 3.58 (Figure F.7-13 and Table F.7-14).

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[1] (233,349 adult Chinook in the ocean *0.74 hatchery proportion)/ 15,657,749 hatchery fish in the bay = 0.011 bay smolt to ocean adult survival (not including enumerated jacks)

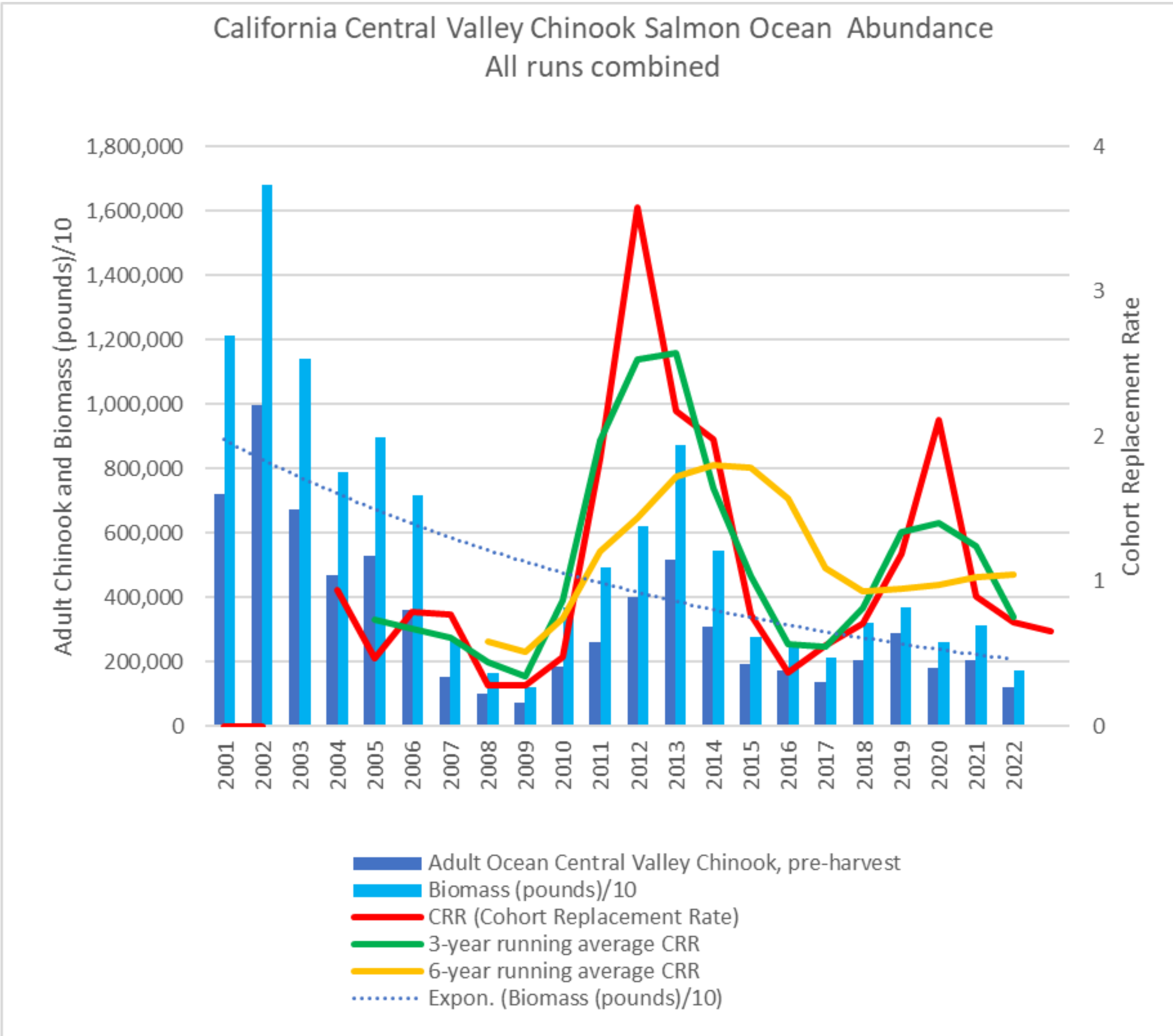

Figure F.7-13. Ocean abundance, biomass, and cohort replacement rates for Central Valley Chinook salmon, all runs combined. Abundance is pre-harvest in the ocean fisheries and jacks are excluded. Source: abundance calculated from data in PFMC 2023b.

Table F.7-14. Annual Central Valley Chinook salmon ocean abundance, all rivers and runs combined pre-harvest and estimated biomass of Chinook salmon from the Central Valley. Jacks are excluded. Ocean abundance is calculated from data in PFMC 2023b.

Year	**Fall**	**Late Fall**	**Spring**	**Winter**	**Adult Ocean Central Valley Chinook, pre-harvest**	**CRR (Cohort Replacement Rate)**			**Dressed Weight Statewide Season**	**Live Weight***	**Total Biomass (pounds)**
2001	639,896	31,411	38,395	8,923	718,625	CRR			12.7	16.9	12,138,292
2002	890,798	59,801	37,064	8,073	995,736		6-year running average CRR		12.7	16.9	16,818,979
2003	603,250	13,945	48,194	8,917	674,305	0.94		3-year running average CRR	12.7	16.9	11,389,693
2004	404,451	24,763	30,013	8,538	467,764	0.47			12.7	16.9	7,901,004
2005	449,963	25,888	36,718	17,185	529,755	0.79		0.73	12.7	16.9	8,948,088
2006	298,396	22,935	19,617	18,766	359,714	0.77		0.67	15	20.0	7,176,301
2007	99,007	31,091	18,388	2,757	151,242	0.29		0.61	13.4	17.8	2,695,442
2008	71,420	10,994	14,190	3,071	99,675	0.28	0.59	0.44	12.8	16.5	1,644,634
2009	53,079	10,298	4,490	4,923	72,790	0.48	0.51	0.35	12.8	16.5	1,201,029
2010	164,951	11,686	5,411	1,732	183,780	1.84	0.74	0.87	15.1	20.1	3,690,848
2011	236,807	11,996	11,042	897	260,742	3.58	1.21	1.97	14.2	18.9	4,924,382
2012	352,348	9,278	34,760	2,898	399,285	2.17	1.44	2.53	11.7	15.6	6,213,270
2013	459,123	13,776	36,429	6,603	515,932	1.98	1.72	2.58	12.7	16.9	8,714,601
2014	266,444	21,011	15,953	3,271	306,680	0.77	1.80	1.64	13.4	17.8	5,465,644
2015	166,970	14,586	7,742	3,732	193,030	0.37	1.79	1.04	10.8	14.4	2,772,681
2016	148,061	8,756	12,687	1,681	171,186	0.56	1.57	0.57	11.2	14.9	2,549,985
2017	124,099	8,138	2,673	1,062	135,972	0.70	1.09	0.55	11.8	15.7	2,133,952
2018	185,403	7,884	7,535	2,863	203,685	1.19	0.93	0.82	11.9	15.8	3,223,721

Year	Fall	Late Fall	Spring	Winter	Adult Ocean Central Valley Chinook, pre-harvest	CRR (Cohort Replacement Rate)			Dressed Weight Statewide Season	Live Weight*	Total Biomass (pounds)
2019	225,795	19,191	33,998	8,819	287,802	2.12	0.95	1.34	9.6	12.8	3,674,658
2020	160,759	8,292	5,303	8,059	182,413	0.90	0.97	1.40	10.8	14.4	2,620,187
2021	140,559	6,512	47,440	11,445	205,955	0.72	1.03	1.24	11.4	15.2	3,122,688
2022	88,372	12,625	12,082	6,583	119,661	0.66	1.05	0.76	10.8	14.4	1,718,806
Average	**283,180**	**17,493**	**21,824**	**6,400**	**328,897**				**12.40**	**16.45**	**5,488,131**
Median	**205,599**	**13,200**	**17,171**	**5,753**	**233,349**				**12.70**	**16.70**	**3,682,753**

*2001 - 2005 was an average, 2008 and 2009 when no fishery occurred used 2001-2022 average
Assumes 55% harvest for SJ fall, late fall, and CV spring-run and 8.5% for winter-run
Note: the analysis uses the average 2011 - 2022 weight of 15.015 pounds

F.7.3.3 Abundance of Central Valley Chinook Salmon Available as Prey for Southern Resident Killer Whales

The estimated natural and hatchery juvenile Chinook salmon abundance in the Bay from Table F.7-13 were combined for a total juvenile Chinook salmon in the Bay estimate (Table F.7-15). A static Bay smolt to adult survival rate of 0.011 was applied to all scenarios to arrive at an estimate of age 3+ adults present in the ocean and available as prey for southern resident killer whales. The adult abundance under the NAA of 232,750 comes from the estimated juvenile abundance in the San Francisco Bay in the NAA multiplied by the smolt to adult survival of 0.011. Ocean adult abundance under the alternatives ranged from 232,722 in Alt2v2_woTUCP to 232,931 under Alternative 3, an abundance range of 728 adult Chinook among all alternatives. Based on an adult weight of 15.015 pounds the Chinook biomass ranges from 3,494,314 pounds to 3,505,241 pounds.

The year to year Chinook salmon abundance and biomass fluctuations shown in Figure F.7-13 and Table F.7-14 are significantly greater than the within year potential differences estimated to be attributable to changes in water operations. The hatchery proportion of 0.74, potentially a low estimate, and the higher contribution of hatchery Bay releases in comparison with instream releases and naturally produced Chinook salmon suggests that naturally produced Chinook salmon from the Central Valley, in aggregate, are in a depressed state in all scenarios. Hatchery-produced Chinook salmon likely supply the bulk of the Chinook salmon available to SRKW. Given the hatchery release scenarios (i.e. Bay releases and high fish numbers) that seem to be needed to support desired harvests of Chinook salmon in the fisheries, unquantified behavioral and genetic effects to naturally produced Chinook salmon (e.g. age at return, stray rates, hatchery/wild fish spawning together) (Davison and Satterthwaite 2017) may continue to exacerbate the depressed state of naturally produced Chinook salmon with potential consequent effects on distribution and abundance of southern resident killer whale prey in the ocean. Based on this analysis the operational alternatives have little difference in effect on abundance and biomass. The difference in quality of the Chinook salmon, nutrition wise, by the time they reach a size usable by killer whales is likely negligible between hatchery and naturally produced Chinook.

Table F.7-15. Abundance of Central Valley Chinook salmon available as prey for SRKW under the LTO scenarios. Biomass is converted using a median adult weight of 15.015 pounds.

Statistic	NAA	ALT1	Alt2v1_woTUCP	Alt2v1_wTUCP	Alt2v2_woTUCP	Alt2v3_woTUCP	ALT3	ALT4
Natural Chinook (all runs combined) in Bay by scenario	5,501,371	5,516,308	5,499,042	5,499,541	5,498,754	5,517,763	5,564,911	5,506,961
Hatchery Chinook in Bay = same in all scenarios	15,657,749	15,657,749	15,657,749	15,657,749	15,657,749	15,657,749	15,657,749	15,657,749
Total Juvenile Chinook in Bay	21,159,120	21,174,058	21,156,792	21,157,291	21,156,503	21,175,512	21,222,661	21,164,710
Bay to ocean adult survival	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
Ocean Adult Chinook Abundance	232,750	232,915	232,725	232,730	232,722	232,931	233,449	232,812
Ocean Adult Chinook Biomass**	3,494,746	3,497,213	3,494,361	3,494,444	3,494,314	3,497,453	3,505,241	3,495,669

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