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RECLAMATION

Technical Memorandum

Long-Term Operation of the Central Valley Project and State Water Project

Literature Review of Juvenile Survival/Mortality Effects on Adult Populations for California Central Valley Chinook Salmon and Steelhead

Introduction

The relationships connecting juvenile survival to adult populations are complex, and there are many studies that have evaluated Chinook salmon and steelhead survival at different life stages. However, studies that incorporate cumulative pressures experienced throughout their life cycle are less common. Most studies assess effects on juvenile survival (or mortality), but do not directly link juvenile survival to adult populations. This technical memorandum (TM) focuses on the key stressors affecting California Central Valley (CCV) Chinook salmon and steelhead survival and the effect of survival on adult populations.

Methods

Salmonid survival is based on a suite of factors that affect all life stages through multiple geographies. This literature review covered different environmental and anthropogenic stressors affecting juvenile survival. An initial literature search was conducted for peer-reviewed and grey literature, mostly published between 2001 and 2025. Studies in the Sacramento-San Joaquin Delta (Delta) and lower Sacramento and San Joaquin Rivers were prioritized, but other watersheds were included as appropriate. Around 180 articles were identified and reviewed, but only 55 met the screening criteria, based on the identified key stressors (Appendix A).

Weight-of-evidence for the body of literature was developed using a method outlined in the National Marine Fisheries Service 2019 Biological Opinion (NMFS 2019). A section with weight-of-evidence descriptions for the body of literature relative to each stressor synthesized in this TM is provided in Appendix B. The section's intent is to list the attributes of each reference. References are categorized by type and include salmonid(s) description, geography, and type of publication. After considering information presented in the weight-of-evidence section, a reader can evaluate the literature on that stressor as it relates to juvenile Chinook survival and, ultimately, adult populations.

Stressors Affecting Juvenile Survival

A synthesis of the literature is provided for each stressor—specifically, its effects on juvenile salmon and steelhead survival over varying geographic ranges. Each section highlights key studies, any similarities between studies, and their results.

Routing and Entrainment

In the literature, "routing" is often used interchangeably with "entrainment." However, for purposes of this TM, pathway selection is referred to as routing, and entrainment at fish facilities is categorized as entrainment. Appendix C provides more detailed summaries of each article reviewed for juvenile routing and entrainment. The pathway a juvenile salmonid travels to Chipps Island directly affects its survival. Survival is affected by routing that either continues through the mainstem Sacramento or San Joaquin rivers or is redirected at various junctions into the interior Delta.

Outmigration routing for juvenile Chinook salmon and steelhead in the Sacramento River can impact growth and survival. When salmonids are able to enter the Sutter, Yolo, or Sacramento bypasses, they have access to habitats with conditions that enable faster growth and have comparable survival rates to those in the Sacramento River, but are higher than those of the Georgiana Slough route (Sommer et al. 2001, Johnston et al. 2018, Pope et al. 2021). Larger salmonids have been shown to have higher survival in the Delta (Perry et al. 2012b, Reclamation 2018).

Downstream from Sacramento, salmonids encounter junctions that dictate their through-Delta pathway: Steamboat and Sutter sloughs, which return them to the Sacramento River near Rio Vista, or the Delta Cross Channel (DCC), Georgiana Slough, or Threemile Slough, which route them into the interior Delta (Perry et al. 2012a, 2012b, 2015, 2018; Romine et al. 2021; Jensen et al. 2025). Routing is affected by both river flow and tidal flow, with the predominant effect being location specific. Export operations at the Central Valley Project (CVP) and State Water Project (SWP) facilities do not appear to play a role in routing at junctions along the Sacramento River. Survival is substantially higher for fish that remain in the Sacramento River (including Steamboat and Sutter sloughs) than for those that are routed through the interior Delta.

Juvenile salmonids migrating from the San Joaquin River are at greater risk of entrainment into the interior Delta and generally have lower survival rates than those from the Sacramento River Basin (Buchanan et al. 2013 and 2018, Cavallo et al. 2015, ESA and AECOM 2018, Reclamation 2018, Buchanan et al. 2019). They navigate heavily modified channels with barriers and diversions, high water temperatures, and poor water quality and have an increased number of predator interactions. They experience more junctions leading toward export facilities, agricultural barriers, or other conditions in which predator interactions are increased (Buchanan et al. 2013, 2018, ESA and AECOM 2018, Buchanan and Skalski 2019). Winter-run Chinook salmon routed into the south Delta experienced increased entrainment at the export facilities with increased exports and increasingly negative Old and Middle River flows (Jensen et al. 2025). Studies show that Chinook salmon salvaged at the CVP salvage facility and transported to the west Delta near Chipps Island have higher survival rates than those that continue through the interior Delta (Buchanan et al. 2013, 2018).

Additional studies on entrainment at the export facilities evaluated the efficacy of the facilities and determined the location and extent of fish loss (Zeug and Cavallo 2014, Karp et al. 2017, Jahn and Keir 2020, Jensen et al. 2025, Zeug et al. 2025). These studies looked at survival through the Clifton Court Forebay, different stages of the structural components (e.g., intake, louvers, holding tanks), loss to predation, and loss during transport. Predation is a known strong influence on survival rates at the facilities.

Environmental Suitability

Environmental conditions during juvenile rearing and outmigration influence growth and survival, with subsequent effects on adult returns. Stressors affecting juveniles include hydrology, water temperature and quality, habitat, and climate change. Appendix D provides more detailed summaries of each article reviewed on environmental suitability.

Hydrology influences salmonid survival by affecting habitat availability, migration efficiency, and exposure to stressors. Michel et al. (2021) demonstrated a non-linear threshold-based flow-to-survival relationship where survival increases sharply above minimum and historical mean flow thresholds, suggesting moderate to high flows disproportionately benefit juvenile survival by encouraging spring outmigration. Del Rosario et al. (2013) found that pulse flows strongly influence the timing and movement of juvenile winter-run Chinook salmon through the Delta, with entry and exit closely associated with elevated Sacramento River discharge.

Streamflow is identified as a natural predictor of juvenile salmonid survival across spatial and temporal scales (Crozier and Zabel 2006, Iglesias et al. 2017, Michel et al. 2021). Higher flows increase downstream transport efficiency, reduce residence time and predation exposure, and enhance turbidity and habitat complexity. Reduced spring flows decrease outmigration survival and compress favorable migration windows (Friedman et al. 2019, Michel et al. 2021). In regulated systems, diversion structures and dams increase mortality through entrainment, with survival of entrained juveniles decreasing, particularly survival as the proportion of the flow diverted is increased (Zeug and Cavallo 2014, Kock et al. 2024). Flow-related migration cues are critical and help synchronize downstream movement with environmental conditions that enhance migration efficiency and, potentially, survival. These conditions include reduced residence time in the Delta and limited exposure to poor water quality and predation (Del Rosario et al. 2013, Bosch et al. 2023).

Temperature affects aquatic fishes' metabolic demand, respiration, growth, and smoltification and is directly associated with survival rates (Crozier and Zabel 2006, Perry et al. 2015, ESA and AECOM 2018, Buchanan and Skalski 2019, Friedman et al 2019, Michel et al. 2020). Water temperatures that increase prey availability can enhance juvenile salmonid growth and survival in productive habitats like floodplains (Sommer et al. 2001, Jeffres et al. 2008, Johnston et al. 2018). Elevated water temperatures increase physiological stress and can reduce swimming performance in juvenile salmonids while enhancing predator swimming performance, increasing predation risks (Lehman et al. 2017).

Water quality conditions affect juvenile salmonid growth, survival, and life-history expression, with effects that propagate to adult abundance. Flow-mediated water quality conditions, including temperature regulation, turbidity, and dissolved oxygen availability, are consistently associated with outmigration success in the CCV (Iglesias et al. 2017, Perry et al. 2018, Buchanan and Skalski 2019). Higher flows tend to improve water quality by reducing temperatures and may increase turbidity (more so if due to natural runoff, less so if due to managed reservoir releases). Higher flows also tend to shorten outmigrating juveniles' travel times and exposure to poor conditions. Higher flows can create some adverse conditions; for example, agricultural and urban pollutants that accumulate in sediments and are resuspended during high-flow or tidal events can elevate physiological stress (Iglesias et al. 2017, Friedman et al. 2019, Michel et al. 2021).

Access to diverse juvenile rearing habitats promotes life history diversity in juvenile Chinook salmon, critical for dynamic and highly variable environments (Maslin et al. 1998, Phillis et al. 2018).

Individuals that accessed multiple habitat types contributed disproportionately to the adult population, indicating that habitat diversity supports life-history variability and enhances population resilience (Maslin et al. 1998, Phillis et al. 2018).

Floodplain habitats, such as the Yolo Bypass, and non-natal tributaries support higher growth rates and improved conditions due to warmer temperatures, increased prey availability, and expanded rearing area, which reduce competition and enhance survival potential (Maslin et al. 1998, Sommer et al. 2001, Limm and Marchetti 2009). In contrast, highly regulated rivers expose juveniles to elevated temperatures and degraded water quality, and thus decrease survival potential (Perry et al. 2018, Kock et al. 2024).

Climate change is increasingly altering the thermal and hydrologic conditions that influence juvenile salmonid survival in the CCV, reshaping the suitability of migration strategies and rearing habitats (Buchanan 2021, Cordoleani et al. 2021). Juvenile salmon survival is much lower in warm, low-flow drought years compared to wet years with cooler temperatures and higher flows, highlighting the influence of climate-driven hydrologic conditions on survival (Notch et al. 2020). As droughts and warming become more frequent, suitable migration and rearing habitats are expected to decline, reducing life-history diversity and increasing long-term risks to population persistence and adult abundance. Phenotypic diversity is critical within populations to ensure that at least one portion of the population is successful as environmental conditions become more variable (Cordoleani et al. 2021).

Predation

Predation impacts Chinook salmon and steelhead migration, growth, foraging, and ultimately survival, occurring across all salmonid life stages from egg incubation to adult returns (Wells et al. 2025). Juveniles may be more vulnerable compared to adults due to their smaller size and annual outmigration during a predictable window. Predation can be a proximate or ultimate cause of salmonid mortality and can be layered with other stressors and/or sources of mortality (e.g., facility entrainment, contaminants, food limitation, disease, parasites) (Grossman 2016). Additional details are provided in Appendix E.

Ocean Rearing

There is a body of evidence to suggest salmonid survival is influenced by the timing of juvenile ocean entry and is a function of the marine conditions that juveniles experience in their early days in the ocean. Ocean survival for juveniles and adults alike can be influenced by multiple stressors. West Coast salmon ocean survival has been associated with large-scale climate indices, like the Pacific Decadal Oscillation (PDO) (Burke et al. 2013), smaller-scale local physical indicators, like the biological spring transition date (Wilson et al. 2021), and individual fish body condition (Wilson et al. 2021, Adase et al. 2026). Not all stressors operate independently, and each represents either a direct relationship to juvenile survival or correlates to adult returns. Decreased survival during the ocean stage of their life cycle may result in fewer salmonids leaving the Pacific Ocean to spawn. Additional details are provided in Appendix E.

Effects on Adult Populations

The literature reviewed directly addresses survival of juvenile Chinook salmon and steelhead as a function of one or more stressors across varying geographies as juveniles emigrate toward the ocean to mature. Logically, it follows that reduced survival of juveniles at any stage (e.g., traveling in the upper watershed, floodplain feeding, migrating through a river plume at the edge of the ocean) decreases the total number of juveniles in a population, and that decrease results in fewer returning adults. However, most studies do not link individual juvenile stressors directly to adult abundance.

The smolt-to-adult return (SAR) metric estimates survival of fish leaving freshwater and returning as adults to spawn, incorporates cumulative pressures (e.g., freshwater and marine pressures on juveniles, pressures on returning adults) versus focusing on a single pressure as reported by most studies. Highlighted studies provide SAR or juvenile-to-adult survival estimates across the salmonid lifecycle in the CCV (Adase et al. 2026) or the northwestern U.S. and Canadian coast (Columbia River Basin: Wilson et al. 2021, Bosch et al. 2023; multiple British Columbia basins: James et al. 2023). These provide evidence that hatchery fish body condition at time of release, release timing, and ocean conditions juveniles encounter within the first few months of ocean entry impact survival (Appendix F). To achieve a management goal of increasing adult abundance, there are actions to take which could impact survival probabilities at multiple spatiotemporal points in the salmonid lifecycle.

At least five lifecycle models (and variations of the models) have been developed for Sacramento River winter-run Chinook salmon, however only the Interactive Object-Oriented Simulation Model (IOS) is discussed in more detail. The life cycle models simulate survival estimates for each life stage from spawning to adult escapement. For example, IOS estimates survival at each modeled life stages (e.g., spawning, incubation, river rearing and migration, Delta passage) based on either specific equations or normally distributed or uniform random variables; and includes parameters (e.g., water year, smolt-to-age-2 survival) and environmental data (e.g., temperature, flow, exports, Wells index of ocean productivity) that explain variation in adult escapement. The IOS model supports water year type as a significant driver of variability in age-2 escapement (accounting for interactions), and age-2 accounted for 8% of the total (Zeug et al. 2012) (Appendix G). Delta survival was the only significant driver in age-3 escapement (accounting for interactions), which accounted for 88% of the total (Zeug et al. 2012). Water year drives variability and impacts the adult winter-run Chinook salmon population, but not as much as Delta survival. The IOS model also suggests water temperature significantly affected escapement. In particular, an increase in temperature had a much greater effect than a decrease in temperature (10% increase led to 95.7% reduction in escapement; 10% decrease led to 11% increase in escapement (Zeug et al. 2012). Management of variables influencing juvenile Delta survival and temperature could impact adult populations.

Results from life cycle models can be examined in conjunction with empirical data and other studies to understand the impacts of manipulating one or multiple stressors on juvenile salmonid survival and the returning adult population.

Appendix A

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Appendix A References

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Appendix B

Weight of Evidence

Appendix B
Weight of Evidence

Table B1 provides the weight of evidence for the literature reviewed to identify the effects of Central Valley Chinook salmon and steelhead juvenile survival/mortality on adult populations.

Table B1. Weight of Evidence

Author	Primary Stressor	Secondary Stressor(s)	Weight of Evidence
Adase et al. 2026	Ocean Rearing, SAR[1]	Environmental Suitability	Quantitative, species-specific (hatchery juvenile fall-run Chinook salmon), location-specific (Sacramento watershed), published in peer-reviewed scientific journal
Bosch et al. 2023	SAR[1]	Environmental Suitability	Quantitative, species-specific (hatchery spring-run Chinook salmon), not location-specific (Yakima River, Columbia River Basin), published in peer-reviewed scientific journal
Brosnan et al. 2014	Ocean Rearing	--	Quantitative, species-specific (hatchery yearling Chinook salmon), not location-specific (Columbia River basin, Columbia River plume waters off Willapa Bay), published in peer-reviewed scientific journal
Buchanan 2021	Environmental Suitability	--	Article is a synthesis of Cordoleani's et al. (2021) – quantitative, species-specific (Chinook salmon), location-specific (California Central Valley, upper Sacramento River), published in peer-reviewed scientific journal
Buchanan and Skalski 2019	Routing	Environmental Suitability	Article is quantitative, species-specific (hatchery fall-run/spring-run hybrid and fall-run Chinook salmon), location-specific (Delta), published in peer-reviewed scientific journal
Buchanan et al. 2013	Routing	--	Article is quantitative, species-specific (hatchery fall-run/spring-run hybrid and fall-run Chinook salmon), location-specific (lower San Joaquin River and Delta), published in peer-reviewed scientific journal

Author	Primary Stressor	Secondary Stressor(s)	Weight of Evidence
Buchanan et al. 2018	Routing	--	Article is quantitative, species-specific (hatchery fall-run/spring-run hybrid and fall-run Chinook salmon), location-specific (lower San Joaquin River and Delta), published in peer-reviewed scientific journal
Burke et al. 2013	Ocean Rearing	--	Quantitative, species-specific (spring-run Chinook salmon), not location-specific (Columbia River), published in peer-reviewed scientific journal
Cavallo et al. 2015	Routing	--	Article is quantitative, species-specific (hatchery fall-run Chinook salmon), location-specific (lower Sacramento and San Joaquin Rivers and Delta), published in peer-reviewed scientific journal
Chasco et al. 2021	Ocean Rearing	--	Article is quantitative, species-specific (hatchery/wild spring-summer Chinook salmon), not location-specific (Columbia River basin, Snake River), published in peer-reviewed scientific journal
Cordoleani et al. 2021	Environmental Suitability	--	Article is qualitative, species-specific (spring-run Chinook salmon), location-specific (California Central Valley), published in peer-reviewed scientific journal
Crozier and Zabel 2006	Environmental Suitability	--	Article is quantitative, species-specific (spring-summer Chinook salmon), not location-specific (Salmon River Basin, Idaho), published in peer-reviewed scientific journal
Crozier et al. 2021	Ocean Rearing	--	Article is quantitative, species-specific (8 wild spring-summer Chinook salmon populations), not location-specific (Snake River), published in peer-reviewed scientific journal
Del Rosario et al. 2013	Environmental Suitability	--	Report is quantitative, species-specific (winter-run Chinook salmon), location-specific (Sacramento River, Delta), published in peer-reviewed scientific journal
ESA and AECOM 2018	Routing	Environmental Suitability	Report is quantitative, species-specific (hatchery steelhead and fall-run Chinook salmon), location-specific (lower San Joaquin River, Delta), grey literature

Author	Primary Stressor	Secondary Stressor(s)	Weight of Evidence
Fiechter et al. 2015	Ocean Rearing	--	Article is quantitative, species-specific (modeled juvenile Chinook salmon), location-specific (California Current area, e.g., Gulf of the Farallones, Monterey), published in peer-reviewed scientific journal
Freidman et al. 2019	Environmental Suitability	--	Article is quantitative, species-specific (fall-run Chinook salmon), location-specific (Central Valley fish), published in peer-reviewed scientific journal
Gingras and McGee 1997	Predation	--	Article is quantitative, species-specific (adult and subadult striped bass), location-specific (Clifton Court Forebay in south Delta), article is a technical report for Interagency Ecological Program)
Grossman 2016	Predation	--	Article is a review of theory and data, species-specific (Delta fishes), location-specific (Sacramento and San Joaquin Delta), published in a peer-reviewed scientific journal
Hayes et al. 2017	Predation	--	Article is quantitative, species-specific (Chinook salmon and predator fish species), location-specific (San Joaquin River), grey literature
Iglesias et al 2017	Environmental Suitability	--	Article is quantitative, species-specific (hatchery fall-run Chinook salmon), location-specific (Battle Creek then mainstem Sacramento River), grey literature
Jahn and Kier 2020	Entrainment	--	Article is both synthesis and quantitative, species-specific (all runs of Chinook salmon, not hatchery/wild specific), location-specific (Sacramento River, San Joaquin River, Delta), published in peer-reviewed scientific journal
James et al. 2023	SAR[1]	--	Article is quantitative, species-specific and not specific (hatchery Chinook salmon and coho salmon), not location-specific (British Columbia), published in peer-reviewed scientific journal
Jeffries et al. 2008	Environmental Suitability	--	Article is quantitative, species-specific (hatchery fall-run Chinook salmon), location-specific (Cosumnes River Floodplain), published in peer reviewed scientific journal
Jensen et al. 2025	Routing	Entrainment	Article is both synthesis and quantitative, species-specific (all runs of Chinook salmon), location-specific (Central Valley Project (CVP) and State Water Project (SWP) Export Facilities), published in peer-reviewed scientific journal

Author	Primary Stressor	Secondary Stressor(s)	Weight of Evidence
Johnston et al. 2018	Routing	Environmental Suitability	Article is quantitative, species-specific (hatchery late fall-run Chinook salmon), location-specific (Yolo Bypass, Lower Sacramento River), published in a peer-reviewed scientific journal
Karp et al. 2017	Entrainment	Predation	Report is an annual report/technical bulletin, species-specific (Chinook salmon, steelhead, and adult striped bass), location-specific (Tracy Fish Collection Facility), grey literature
Kock et al. 2024	Environmental Suitability	--	Article is quantitative, species-specific (hatchery Chinook salmon, wild steelhead), not location-specific (lower Yakima River, WA), published in peer-reviewed scientific journal
Lehman et al. 2017	Environmental Suitability	Predation	Article is quantitative, species-specific (hatchery fall-run Chinook salmon), location specific (Lower San Joaquin River), published in a peer-reviewed scientific journal
Limm and Marchetti 2009	Environmental Suitability	Predation	Article is quantitative, species-specific (wild juvenile fall-run Chinook salmon), location-specific (Sacramento River), published in a peer-reviewed scientific journal
Lindley and Mohr 2003	Predation	--	Article is quantitative, species-specific (winter-run and spring-run Chinook salmon, striped bass), location-specific (Sacramento River), published in a peer-reviewed scientific journal
Maslin et al. 1998	Environmental Suitability	Predation	Report is quantitative, species-specific (Chinook salmon), location-specific (Sacramento River), grey literature
McInturf et al. 2022	Predation	--	Article is quantitative, species-specific (Chinook salmon and predator fish species), location-specific (San Joaquin River and Delta), published in peer-reviewed scientific journal
Michel 2010	Environmental Suitability	--	Document is quantitative, species-specific (hatchery late fall-run Chinook salmon), location-specific (Upper Sacramento River tracked through-Delta), Master's Thesis

Author	Primary Stressor	Secondary Stressor(s)	Weight of Evidence
Michel et al. 2015	Environmental Suitability	--	Article is quantitative, species-specific (hatchery late fall-run Chinook salmon), location-specific (Sacramento River, Delta, San Francisco Bay), published in peer-reviewed scientific journal
Michel et al. 2020	Predation	Environmental Suitability	Article is quantitative, species-specific (hatchery Chinook salmon), location-specific (Delta, with a focus on southern Delta), published in peer-reviewed scientific journal
Michel et al. 2021	Environmental Suitability	Predation	Article is quantitative, species-specific (hatchery and wild fall-run, spring-run and winter-run Chinook salmon), location-specific (Sacramento River), published in peer-reviewed scientific journal
Notch et al. 2020	Environmental Suitability	--	Article is quantitative, species-specific (wild spring-run Chinook salmon), location-specific (Mill Creek to lower Sacramento River), published in peer-reviewed scientific journal
Perry et al. 2012a	Routing	Predation	Article is quantitative, species-specific (hatchery late fall-run Chinook salmon), location-specific (Sacramento River; Steamboat, Sutter, and Georgiana Sloughs; and Delta Cross Channel), published in peer-reviewed scientific journal
Perry et al. 2012b	Routing	Predation	Article is quantitative, species-specific (hatchery late fall-run Chinook salmon), location-specific (Sacramento River; Steamboat, Sutter, and Georgiana Sloughs; and Delta Cross Channel), published as a USGS open-file report
Perry et al. 2015	Routing	Environmental Suitability	Article is quantitative, species-specific (juvenile hatchery late fall-run Chinook), location-specific (Sacramento River; Steamboat, Sutter, and Georgiana Sloughs; and Delta Cross Channel), published in a peer-reviewed scientific journal
Perry et al. 2018	Routing	Environmental Suitability	Article is quantitative, species-specific (juvenile hatchery late fall-run Chinook), location-specific (Sacramento River; Steamboat, Sutter, and Georgiana Sloughs; and Delta Cross Channel), published in a peer-reviewed scientific journal

Author	Primary Stressor	Secondary Stressor(s)	Weight of Evidence
Phillis et al. 2018	Environmental Suitability	--	Article is quantitative, species-specific (winter-run Chinook salmon), location-specific (Sacramento River, Delta), published in a peer-reviewed scientific journal
Pope et al. 2021	Routing	--	Article is quantitative, species-specific (hatchery late fall-run Chinook salmon), location-specific (Lower Sacramento River, Delta), published in a peer-reviewed scientific journal
Reclamation 2018	Routing	--	Report is quantitative, species-specific (juvenile hatchery steelhead), location-specific (Lower San Joaquin River, Delta), grey literature
Romine et al. 2021	Routing	--	Article is quantitative, species-specific (hatchery late fall-run Chinook salmon), location-specific (Sacramento River; Steamboat, Sutter, and Georgiana Sloughs; and Delta Cross Channel), published in a peer reviewed scientific journal
Sabal et al. 2016a	Predation	--	Article is quantitative, species-specific (striped bass, juvenile hatchery Chinook salmon), location-specific (Lower Mokelumne River), article is published in a peer-reviewed scientific journal
Sabal et al. 2016b	Ocean Rearing	--	Article is quantitative, species-specific (hatchery fall-run Chinook salmon), location-specific (release locations and hatcheries all California Central Valley, recapture locations in California Current off the California coast with few in the northern California Current), published in peer-reviewed scientific journal
Satterthwaite et al. 2014	Ocean Rearing	--	Article is quantitative, species-specific (fall-run Chinook salmon), location specific (San Francisco Estuary, Pacific Ocean), published in peer-reviewed article
Sommer et al. 2001	Environmental Suitability	Routing	Article is quantitative, species-specific (Chinook salmon), location specific (Sacramento River and Yolo Bypass), published in peer-reviewed article

Author	Primary Stressor	Secondary Stressor(s)	Weight of Evidence
Wells et al. 2025	Predation	--	Article is a synthesis paper, species-specific (Atlantic and Pacific salmon), is both location-specific and not location-specific (North American examples of salmon, some are California Central Valley), published in a peer-reviewed scientific journal
Wilson et al. 2021	Ocean Rearing, SAR[1]	--	Article is quantitative, not species-specific (summer-run steelhead), not location-specific (Lower Columbia River and Wind River Basin), published in peer-reviewed scientific journal
Zeug et al. 2012	Life Cycle Model [1]	--	Article is quantitative, species-specific (winter-run Chinook salmon), location-specific (California Central Valley), published in peer-reviewed scientific journal
Zeug and Cavallo 2014	Entrainment	--	Article is quantitative, species-specific (hatchery Chinook salmon), location-specific (Sacramento and San Joaquin Rivers and Delta), published in peer-reviewed scientific journal
Zeug et al. 2025	Entrainment	--	Article is quantitative, species-specific (hatchery late fall-run Chinook salmon), location-specific (Delta), published in peer-reviewed scientific journal

Note: [1]SAR, or Smolt-to-Adult Return rates or metrics are not considered a stressor, but are identified in the Technical Memorandum as an important factor to consider in the link between juvenile survival and adult populations. Additionally, Life Cycle Model (LCM) is not considered a stressor but is discussed in the Technical Memorandum.

Appendix C

Routing and Entrainment

Appendix C
Routing and Entrainment

This Appendix provides a summary of each of the articles used in the literature review to identify potential effects to adult populations resulting from changes in juvenile survival caused by the use of different routes in the Delta and by entrainment at the CVP and SWP export facilities. In literature, routing is often used interchangeably with entrainment. For the purposes of this TM entrainment into a particular pathway is categorized as routing while entrainment into the fish facilities or diversions is categorized as entrainment.

The most common source of information on juvenile survival caused by routing and travel time comes from acoustic telemetry studies. Acoustic telemetry studies estimate juvenile survival as a function of routing and travel time using hatchery fish. Hatcheries have more readily available fish and facilities where tags can be surgically implanted. While hatchery fish likely behave differently than wild fish, their use as a proxy is a generally accepted practice in the Delta.

Sacramento River Routing

Multiple studies looked at salmon and steelhead movement in the Sacramento River and the pathways or routes that are used. Salmonids can leave the Sacramento River and be routed upstream into bypass habitats (Pope et al. 2020), or farther downstream through Steamboat and Sutter Sloughs, which then returns them to the Sacramento River just upstream from Rio Vista. They can also be routed through the Delta Cross Channel (DCC) or Georgiana Slough into the interior Delta (Perry et al. 2012a, 2012b, 2015, 2018, Romine et al. 2021). Steamboat and Sutter Sloughs are important migration routes because fish using these routes remain in the Sacramento River where survival is higher and avoid entering the interior Delta where survival is lower compared with other routes.

Johnston et al. (2018) evaluated the survival of juvenile Chinook salmon to Chipps Island that used the Yolo Bypass as they migrated downstream compared to those that remained in the lower Sacramento River. Both sample years (2012 and 2013) were below normal water year types with higher water temperatures. This resulted in a large reduction in flow in the Yolo Bypass Toe Drain compared to the Sacramento River, and had correspondingly higher water temperatures, both of which are connected to higher mortality in the Delta. They found no significant difference between the estimate of cumulative probability of survival to Chipps in the Yolo Bypass system and the mainstem Sacramento River in either year (2012: 0.312 to 0.629 versus 0.37 to 0.682; 2013: 0.111 to 0.408 versus 0.243 to 0.456). Estimates of cumulative probability of survival in the Georgiana Slough route ranged from 0.136 to 0.681 (2012) and from 0.043 to 0.323 (2013). In both sample years, fish had a higher probability of remaining in the mainstem Sacramento than of diverting into either the Yolo Bypass or Georgiana Slough.

Pope et al. (2021) compared the travel time and survival of juvenile hatchery late fall-run Chinook salmon that utilize floodplain habitat (i.e., Yolo Bypass) versus those that remain in the Sacramento

River. Their study area covered the Sacramento River from just above the Fremont Weir, downstream to near Rio Vista, Yolo Bypass, Steamboat, Sutter, and Georgiana sloughs, the DCC, and the interior Delta. They found that over 80% of the fish released during peak flooding entered the Yolo Bypass, compared to less than 5% released either before or after peak flooding. The proportion of fish that migrated through the Yolo Bypass varied between the three release groups from three locations (Tisdale, Yolo Bypass, and Verona; one week apart in March 2016) from 0.21 to 0.801. The proportion was highest for the group released nearest Fremont Weir. The proportion of juveniles that migrated through the Sacramento River ranged from 0.115 to 0.458. The proportions of juveniles migrating into the alternate routes were lower, with estimates for Sutter and Steamboat sloughs ranging from 0.05 to 0.361 and for Georgiana Slough and the interior Delta ranging from 0.031 to 0.223. They identified survival rates from Fremont Weir to Chipps Island varied between the different routes and three release groups with estimates ranging from 0.564 to 0.843. Survival rates of the fish that remained in the Sacramento River ranged from 0.704 to 0.843, and survival for Georgiana Slough ranged from 0.564 to 0.695. While survival for the fish that did not route through the Yolo Bypass was slightly higher for two release groups, these differences were not significant. Juvenile salmon survival for the Yolo Bypass route ranged from 0.659 to 0.689. Route-specific estimated mean travel time ranged from 2.7 to 6.4 days from Freemont Weir to Chipps Island. Those that remained in the Sacramento River had mean travel times from 2.7 to 3.16 days; those that travelled through Steamboat and Sutter sloughs had average travel times ranging from 4.19 to 5.08 days; those that traveled through Georgiana Slough and the interior Delta to Chipps Island took approximately 5.41 to 6.4 days. This study focused on smolts which are actively migrating downstream and minimizing their residence times.

Perry et al. (2012a) assessed the sensitivity of survival to the migration route used in the Sacramento River using data from acoustically tagged hatchery late fall-run Chinook salmon. They noted that routes selected could be affected or altered in three ways: 1) the use of physical barriers, 2) behavioral responses to the changes in the hydrodynamics at each junction, and 3) structural changes in channel geometry at the river junctions, even without changing the flow distribution. Physical barriers, like the DCC gates, can alter the distribution of flow and affect the hydrodynamic conditions. Additionally, closing the DCC gates can result in increased salinity intrusion into the interior Delta, which results in a reduction or ceasing of exports at the CVP and SWP export facilities to comply with salinity standard requirements. However, closing the gates also blocks access to the DCC, providing Chinook salmon and steelhead a chance to remain in the Sacramento River. They also found that diverting fish away from a low-survival route (DCC and Georgiana Slough) did not increase population survival by as much as they expected. This is because part of the population used different migration routes at the upstream river junction (i.e., Steamboat and Sutter sloughs). At each secondary (and tertiary or beyond) river junction, the juvenile population is divided into a smaller proportion of the population. Therefore, management actions centered on the flows or operations at these junctions will have less population-level effects than at primary river junctions because a smaller fraction of the population will be influenced. Finally, they noted the effects of routing on predation. By changing the migration route, the abundance of juvenile salmonids in each route is altered, which could lead to a density-dependent predator response. If the prey density is low in a specific route, increasing the number of salmonids could increase the predation rate. However, if a high number of salmonids enter the same route, predation rates could be decreased through predator swamping. They estimated average through-Delta survival greater than 0.33 between December 2006 and January 2009, though the estimated survival rate for 2008 was less than 0.2.

In an extension of a previous study, Perry et al. (2012b) used acoustically tagged hatchery late fall-run Chinook salmon in 2009 and 2010 to assess survival and route probabilities. Two groups of fish were released in December and January. They noted that fish entering Sutter and Steamboat sloughs had lower survival than fish remaining in the Sacramento River in December, but fish entering the two sloughs had similar survival to fish remaining in the Sacramento River in February. They also found that the December release groups had a higher proportion entering the interior Delta. Route-specific survival in the Sacramento River, and Steamboat and Sutter sloughs was positively correlated to fish size and Sacramento River flow. The fish released in February were larger and exposed to higher flows, so they had shorter travel times to Chipps Island than those released in December. The mortality rate per unit of distance was higher for the interior Delta than for the Sacramento River. They also noted that predator encounters were driven more by the distance traveled than the time traveled. This is consistent with tidal effects which may cause fish to move both upstream and downstream, increasing predator encounter opportunities relative to the overall distance traveled. Survival for the fish released in December for all routes combined ranged from 0.374 to 0.464. Survival for fish remaining in the Sacramento River between the two years was 0.51 and 0.584. Sutter and Steamboat sloughs survival for each year averaged 0.446 and 0.346. Survival in the DCC was recorded for 2009 at 0.236, but the gates were closed in 2010 during the study so no fish were routed into the DCC. Survival in Georgiana Slough was 0.248 in 2009 and 0.233 in 2010.

Perry et al. (2015) studied how reduced Sacramento River inflows result in an increase in the frequency of reverse flows at the junction of the DCC and Georgiana Slough. They found that the probability of fish (acoustically tagged hatchery late fall-run Chinook salmon) routing into both DCC and Georgiana Slough was highest during the reverse-flow flood tides (flows below 12,713 cfs at the DCC/Georgiana Slough junction), whereas the probability of salmonids remaining in the Sacramento River was near zero during the flow reversals (around 20,000 cfs at Freeport). They noted that fish routing in the Delta is dependent on the actual timing of their presence at the specific junctions, given the hourly variations in river flows affected by tidal forcing. Diel activity patterns that shift towards either a more nocturnal, diurnal, or crepuscular migration pattern may separate the entrainment probabilities from the proportion of flow entering a specific route. This would shift the routing towards a more time-specific condition experienced by the majority of the cohort. In the release groups, 75% of the juveniles detected were moving at night (ranging between 55% and 86%). Increased nighttime behavioral activity during decreasing water temperatures results in lower metabolic requirements, thus reducing the need to feed during the day when the risk of predation is high. However, diel patterns can change from night to day in response to trade-offs between predation risk, physiological condition, and environmental cues.

Flow direction has a strong influence on the migration route selected. Perry et al. (2018) analyzed acoustic data for hatchery late fall-run Chinook salmon between 2007 and 2011. In their study, they defined three reaches based on flow: riverine reaches with a unidirectional flow; transitional reaches where flows transition from unidirectional to bidirectional; and tidal reaches where flows are bidirectional and not affected by river inflows. They found that juvenile survival through riverine reaches was high, regardless of travel time and inflows, and they also noted that increases in river flows decreased the median travel times. However, survival significantly decreased and routing into the interior Delta significantly increased when Delta inflows declined below roughly 35,314 cfs, the condition at which transitional reaches change from bidirectional to unidirectional flow. They found that as the influence of inflow declines and tidal influence moves upstream into the transitional reaches, both travel distance and travel time increase since juvenile salmonids may be transported upstream during flood tides. This may increase predation encounter rates. Seasonal variations in location-specific conditions, such as water temperatures, turbidity, predator densities, and spring-neap tidal cycles also regulates how travel time and survival of salmonids are affected by changes in inflow. There was no relationship identified between survival and inflow in tidal reaches. However, there was a strong relationship between inflow and travel time.

Romine et al. (2021) studied the effects of tidally varying river flow on the routing of acoustically tagged juvenile hatchery late fall-run Chinook salmon in 2014. Their results showed that the highest proportion of juvenile Chinook salmon are likely to be routed into Steamboat and Sutter sloughs as flow changes from positive to negative, on both the ascending and descending tidal cycles. Individual fish pass a routing junction in a matter of minutes so the hydrodynamic condition at the time of passing dictates whether or not they are entrained into a channel divergence. When flows in the Sacramento River and Steamboat Slough have reversed, then Sutter Slough becomes negative, which increases the proportion of flow into Sutter Slough. This increases the likelihood that fish will be routed into Sutter Slough. Fish are more likely to be rapidly routed into Steamboat Slough, but for a short duration, on the ascending limb of a tidal stage. Additionally, fish that arrive at the mid-ebb and mid-flood stages during low flow conditions may experience a brief period of high routing into Sutter Slough and Steamboat sloughs. They also found that fish in the Sacramento River that transported upstream by reverse flows are likely to remain in the Sacramento River when flows are simultaneously reversed in both Sutter and Steamboat sloughs. Additionally, the proportion of fish remaining in the Sacramento River was higher than the proportion of flow remaining in the Sacramento River. The opposite is the case for Sutter and Steamboat sloughs, that is, a lower proportion of fish enter the sloughs relative to the proportion of flow entering the sloughs. They estimated that fish remaining in the Sacramento River had the highest survival, with through-Delta survival ranging from 10% to 80% depending on the flow and route selected.

Jensen et al. (2025) addressed uncertainties on efficacy of recovery actions by synthesizing information from multiple studies on winter-run Chinook salmon through-Delta migratory survival. They developed a new conceptual model that characterizes the effects of Delta hydrology on winter-run Chinook survival, addresses the current state of science, and then identifies data gaps using simulation modeling. The conceptual model separately considered the effects of water operations on the routing of fish into the interior Delta; the survival of juveniles routed into the interior Delta; and the survival of juveniles not routed into the interior Delta. To assess water and fish movement affected by hydrologic modifications in the Delta as a function of exports, they utilized both the particle tracking model (PTM) and the ecological particle tracking model (ECO-PTM). Routing into the interior Delta via the DCC when the gates are open increases with decreasing Sacramento River flow. Routing into Georgiana Slough is roughly proportional to the proportional volume of flow entering the slough, which is affected by both Sacramento River flow and tidal flows. Model simulations using DSM2 HYDRO showed minor effects of exports on the flow at the Georgiana Slough junction, ranging between 2,000 and 10,000 cfs. PTM results showed that simulated routing through Threemile Slough varied from 2% to 23%, and, like Georgiana Slough, decreased with increasing Sacramento River flow. ECO-PTM results showed that Sacramento River flows affect migratory survival in Georgiana Slough, Threemile Slough, and possibly through the interior Delta; and exports do not appear to affect survival of fish routed through the interior Delta.

San Joaquin River and Interior Delta Routing

Juvenile Chinook salmon and steelhead migrating down the lower San Joaquin River are exposed to multiple junctions that may route them into the interior Delta. These fish can be exposed to more unsuitable conditions than those in the Sacramento River and often experience lower survival rates unless salvaged at the export facilities.

Buchanan et al. (2013) studied the survival of acoustically tagged juvenile hatchery fall/spring-run hybrids from the Feather River Fish Hatchery and fall-run Chinook salmon from the Merced River Fish Hatchery migrating through the lower San Joaquin River and Old River in April and May of 2009 and 2010. They found no significant difference in estimated survival rates between the mainstem San Joaquin River and Old River in 2009. The average probability of juveniles using the Old River was 0.47 for both study years. The average survival in the Old River route was substantially higher than in the entire Delta to Chipps Island in 2010 (0.77 and 0.05, respectively), while the average survival estimate for the San Joaquin River route was 0.32. No direct estimates of survival for the entire Delta were made for 2009, but the decrease in survival in 2010 from the South Delta (0.56) to the entire Delta (0.05) may indicate that the total survival through the entire Delta in 2009 may have been as low as 0.005. The Old River route ends at the export facilities, which is likely the reason for the higher survival rates, as the fish were salvaged and transported to release sites near Chipps Island. As fish move downstream, they are more affected by tidal actions, and their migration rates tend to decrease. The slower migration may result in a decreased ability to evade predators and increased predation encounters.

Buchanan et al. (2018) tracked juvenile hatchery fall-run Chinook salmon from the Mokelumne and Merced River Fish Hatcheries between 2010 and 2015 through lower San Joaquin River and southern Delta to evaluate the route-selection and survival of outmigrating juveniles. Similar to Buchanan et al. (2013), the estimated survival in the southern Delta routes tended to be higher than through-Delta survival. Predators that ingested tagged Chinook may have appeared in the acoustic record as they passed over the telemetry receiver. This phenomenon may have artificially increased the route survival predictions. In the 2010–2015 studies, a predator filter identified a minimum of 20% to 64% of the tagged fall-run Chinook salmon detected between Mossdale and Chipps Island as being preyed upon. Survival was higher when fish passed through the CVP, except in years when the temporary rock barrier at the head of Old River blocked the direct path to the CVP. In years without the rock barrier (2010, 2011, 2013), the probability of selecting the San Joaquin River route (Mossdale to Chipps Island) ranged from 0.23 to 0.58, but years with the rock barrier (2012, 2014, 2015), the probability of selecting the route was between 0.92 and 0.98. The probability of survival in the San Joaquin Route in the years without the barrier ranged from 0.01 to 0.04, while survival in the Old River route in the same years ranged from 0.01 to 0.07. The probability of survival in the years with the rock barrier in the San Joaquin route ranged from 0 to 0.03, and in the Old River route from 0 to 0.11. Overall, release-specific Delta survival estimates for the San Joaquin River had a maximum of 0.1 and an average of around 0.025, that the survival probability per kilometer for the San Joaquin Route was 0.97. They hypothesized that if a smolt-to-adult ratio (SAR) greater than or equal to 0.02 is required for population persistence, then a minimum survival probability of 0.2 (SAR estimate/estimated survival, 0.02/0.1) is required through the remainder of the life history. At the low survival rate of 0.25, a SAR of 0.02 would require a post-Delta survival rate of 0.8. They cited a study (Sturrock et al. 2015) that found that a chemical analysis of otoliths from wild adult fall-run Chinook from the Stanislaus River suggest that juveniles that rear in the lower San Joaquin River or Delta sometimes have higher survival rates than those that exit the Stanislaus River as smolts. However, low survival estimates observed in various acoustic telemetry studies are more likely representative of the Delta survival of the smolt-sized migrants of the naturally spawned population, to the extent to which hatchery fish may serve as a proxy for natural-origin fish.

Buchanan and Skalski (2019) examined survival of fall-run Chinook salmon through the Delta as a function of San Joaquin River flow. Their goal was to determine if there are flow conditions at locations within the Delta that are associated with higher survival, and what spatial and temporal scales are appropriate for relating survival to specific environmental conditions. They reviewed five years of acoustic telemetry data from juvenile hatchery fall-run Chinook salmon released at Durham Ferry in the lower San Joaquin River. Juveniles that migrate throughout the lower San Joaquin River and the interior Delta experience both instantaneous and cumulative effects of varying hydrodynamic conditions over multiple days, which affect travel time and movement patterns. Higher river flows increase available rearing and migrating habitat and can be associated with lower water temperatures, higher dissolved oxygen levels, lower concentrations of contaminants, and lower predator densities. The amount of water in the Delta is affected not just by river inflow, but by exports (Federal, state, and private). Salinity is affected by flows, and salinity may influence the distribution and relative densities of predators. This study found that while a higher average net Delta flow is associated with higher survival of juveniles at the Turner Cut junction, a lower X2 has a stronger relationship and a greater effect on survival. The study noted that the average net flow in the interior Delta (as well as the flow direction) is less associated with the variability in Delta survival as is the volume of flow. They found that survival was higher when the average net flow was more negative, which is counter to the Old and Middle River- (OMR) based management actions. The installation of the Head of Old River Barrier (HORB) prevented juveniles from entering the Old River, but with the limitations established by US Fish and Wildlife Service (USFWS) in the spring for the protection of Delta smelt, Chinook juveniles are more likely to enter Old River. Survival from the San Joaquin River at Lathrop to Chipps ranged from 0 to 0.08. Survival in the Old River route ranged from 0.05 to 0.17. Survival from San Joaquin River at Lathrop to Turner Cut Junction ranged from 0 to 0.55. Survival of juveniles from the head of Old River to Chipps Island was predicted to be higher when Old River flows were higher. They found that 89% of the tagged fish from the Old River route that were detected at Chipps Island had passed through the CVP holding tanks avoiding most of the interior Delta. They found that the spatial complexity of the survival-flow relationship indicated that management actions to maximize Delta survival should focus on sequencing tailored strategies on smaller regions rather than a single strategy for the entire Delta.

Cavallo et al. (2015) examined the drivers of travel route selection in the Delta. Juvenile encounters at junctions lead to migration routes which affect survival probability because of their difference in quality (e.g., floodplain habitat, screened and unscreened diversions). They looked at data from 2010 and 2011 of 41 estimates of acoustically-tagged juvenile hatchery fall-run released in April and May of both years, in the lower San Joaquin River near Durham Ferry and the City of Stockton, and late fall-run Chinook salmon released in December and January for both years, near the City of Sacramento in the lower Sacramento River at six different routing junctions. They predicted the proportion of juveniles that would enter the distributary routes and found the proportion of flow entering a distributary explained 70% of the route selection. There were more fish entering distributaries at junctions where there was a strong river inflow influence (e.g., Georgiana Slough and Old River), and that junctions with that were more tidally dominated had lower routing (Middle River and interior Delta). They noted that it may be difficult to alter fish routing by manipulating river inflows or water diversions. At tidally dominant flow junctions, the volume of water entering the junctions from tidal action is large compared to the volume of water influenced by either river inflow or diversions and exports. Channel morphology at the junctions may have substantial effects on the specific pattern of proportional flow into different routes as inflows increase, thus affecting predicted fish entry. Chinook salmon and steelhead may primarily actively migrate at night or only on ebb tides, which further restricts the range of potential route use probabilities.

ESA and AECOM (2018) prepared a report for the California DWR's Temporary Barriers Project. This study looked at multiple factors that affected the survival of juvenile salmonids including diversions, flow, predator density, and water year. The goal of the study was to estimate the following effects of three seasonal south Delta agricultural barriers (SDAB) and the HORB: 1) survival of outmigrating juvenile salmonids; 2) the time a juvenile salmonid spends in the vicinity of a barrier; 3) predation rates on juvenile salmonids; and 4) predatory density near barriers before, during, and after installations. The three seasonal barriers – Old River at Tracy (ORTB), Middle River (MRB), and Grant Line Canal (GLCB) - are typically operated between April and November acting as control structures to retain tidal freshwater behind each barrier following a flood tide. However, the GLCB did not close until early to mid-July in both 2010 and 2011. The HORB is installed in the spring and fall, but the spring installation is restricted to protect Delta smelt. Many smaller water diversions in the Delta are unscreened and represent a potential mortality source for juvenile salmonids. These diversions complicate the hydrodynamics in the southern Delta by exacerbating flow conditions that salmonids must navigate during their out-migration. They found very few juvenile Chinook salmon or steelhead utilized the Middle River route. Grant Line Canal was the most heavily used juvenile migration route among the three studied, used by 98.9% of the steelhead. In 2010, 26.5% of the steelhead successfully passed the OTBR and 69.2% in 2011; 94.5% of the juvenile Chinook salmon successfully passed the OTBR in 2011. No fish were observed at the MRB. Increased spring and summer export rates were higher after the ORTB installation, which should have decreased travel time and predation rates, but instead decreased survival. They concluded, however, that export flow changes did not cause the decreased survival to the study end points. Increased water temperatures (often exceeding 24°C) in the south Delta impair smoltification, decrease growth rates, and increase predation risks. Temperatures in late June may cause direct mortality from high temperatures. Predator fish density at the ORTB increased from 3.6% (downstream of the barrier) to 67.3% (upstream of the barrier) between April 1 and May 9 compared to the densities between June 4 and July 7. The study found that there was a higher predation probability on juvenile Chinook Salmon was associated with higher density of small fish < 30 cm (< 11.8 in) in the study area. There is substantial diversion capacity from individual water users in the southern Delta.

The Bureau of Reclamation (2018) conducted a 6-year telemetry study on steelhead in compliance of the 2009 NMFS Biological Opinion to identify proportional causes of mortality triggered by project and non-project related effects. Examples include changes in OMR reverse flows, San Joaquin River pulse outflows, and exports on emigrating hatchery steelhead smolts from the San Joaquin Basin and through the Delta. They found a correlation between flow at Vernalis and survival in the San Joaquin River route: survival increased as flow increased. Vernalis flows affected the variation in survival more than other variables, such as exports, I:E (inflow:export ratio), flow at the head of Old River, and OMR flows. In 2013, exports did not appear to be related the route selection at the head of Old River junction, nor were there significant effects of any measure of exports on the probability of remaining in the San Joaquin River at the head of Old River or at Turner Cut. Fish arriving at the Old River junction with higher flow or river stage were less likely to enter Old River than fish that arrived at lower flows or stages. The pattern observed at Turner Cut had too few observations to adequately test its significance but was consistent with an incoming tide being associated with entry to Turner Cut. Outmigrating steelhead would likely survive better than juvenile Chinook salmon because the steelhead are much larger and larger-sized fish usually have higher survival. Travel time through the Delta (Mossdale to Chipps Island) averaged approximately 11.3 days in 2013, for both the San Joaquin River route and the Old River route.

Entrainment

Zeug and Cavallo (2014) examined the effects of the export facilities on juvenile survival and predicted that salvage would be negatively associated with recovery at Chipps Island and in the ocean. They looked at data for coded-wire tagged (CWT) hatchery Chinook salmon (all runs) and acoustic telemetry data for Chinook salmon. Diversions at the exports may result in mortality caused by impingement on the intake screens or entrainment into the fish facilities, export facilities, or canals. Some of the entrained fish were salvaged and returned to the west Delta near Chipps Island. Estimating the population loss caused by the exports is difficult to quantify, so Zeug and Cavallo created a statistical model of salvage to estimate the total loss using 15 years of CWT data. They defined loss as fish entrained but did not survive to release after salvage and transport. San Joaquin River Chinook salmon had a higher salvage rate than Sacramento River fish, and San Joaquin River Chinook experienced a higher loss than Sacramento River fish. Fish released in the Sacramento River and fish released into the interior Delta had similar losses at the CVP, but fish released in the interior Delta had higher losses at the SWP. Additionally, there was a significant increase in salvage of Sacramento River Chinook salmon at the CVP facilities with decreasing Sacramento River flow. However, salvage of San Joaquin River fish occurs when fish are abundant near the export facilities, regardless of flow. They found no significant relationship between salvage and the distance travelled for the San Joaquin River fish. The relative loss of the Sacramento and San Joaquin origin populations at the export facilities during migration was low. Less than half of the San Joaquin River juveniles are likely to route into channels that lead to the export facilities, and even less Sacramento-origin juveniles are likely to enter the channel. Late fall-run Chinook juveniles were the largest of the runs and were salvaged more than any other run. For Sacramento River fall-run Chinook salmon, the combined loss at both the CVP and SWP export facilities was always less than 1% of the total migration mortality, or relative loss, no matter how much water was diverted nor the fish release location. Most late fall-run Chinook salmon had less than 2.5% total migration mortality for fish released into the Delta. Winter-run Chinook salmon total migration mortality was typically less than 2% but never exceeded 5.5%. Most San Joaquin River fall-run Chinook juvenile releases experienced a total migration loss that was less than 5% but did have losses as high as 17.5%. Their analysis showed that salvage at the export facilities reduced the contribution of juvenile loss at the diversion to the total mortality (relative loss) for fall-run and late fall-run Chinook salmon released in the Sacramento River by 42% and 41% respectively, and in the San Joaquin River for fall-run Chinook salmon by 24%. The authors predicted that there would be a negative association between salvage and recoveries at Chipps Island and the ocean because when fewer fish are entrained, there are more fish available to be caught at a later date. They found a significant negative relationship between ocean recoveries and salvage at the SWP (-0.297, $p=0.032$) and a positive non-significant relationship between ocean recoveries and salvage at the CVP (0.02, $p=0.827$).

Karp et al. (2017) conducted a study for the Bureau of Reclamation to estimate the efficiency and pre-screen losses at the Tracy Fish Collection Facility (TFCF), and to understand fish behavior in the facility. They used acoustically tagged juvenile Chinook salmon, juvenile steelhead, and adult striped bass across varying Jones Pumping Plant (JPP) flow conditions. Facility efficiency describes the efficiency of the TFCF louver system to detect and divert fish where collected and held. Pre-screen loss is the mortality of individuals occurring before they encounter the primary louver screens. This loss is largely attributed to predation by both aquatic and avian predators in the intake channel. Chinook and steelhead exhibited different fates with the majority of steelhead fish falling in the "unknown" category (Chinook: 40.6% recovered in holding tanks, 24.6% lost to predation, 11.6% lost to louvers; steelhead: 14.8% recovered in holding tanks, 8.2% lost to predation, 3.3% lost to louvers, 73.8% unknown). 37 Chinook and steelhead (28.5% of tagged salmonids) were collected in holding tanks and most moved through the facility within the first hour post-release (high flows: 13 Chinook, 6 steelhead; intermediate flows: 11 Chinook, 2 steelhead; low flows: 4 Chinook, 1 steelhead. TFCF generally was more efficient with an increase in JPP pumps in operation from 1 to 5 (minimum operating pumps occurs at 1, maximum operating pumps occurs at 5) and for both species travel time, predation and pre-screen loss to predation decreased with increasing flow. Most tagged striped bass remained in the primary channel for months and one fish traveled north up the Sacramento River to Red Bluff, CA.

Jahn and Keir (2020) examined existing studies of juvenile salmon survival near the SWP and CVP facilities, assessing the efficiency of fish salvage operations at the CVP and SWP export facilities. Both export salvage facilities use louvers as behavioral barriers that exclude large fish and direct small fish into holding areas from which they are then trucked and released in the west Delta. Salvage efficiency is affected by intake velocity, debris on the louvers and trash racks, and by predator species in front of and within the screen guidance structures. Their conceptual model was developed based on fish moving with the tides, but with a mean southward drift approach an increased probability of entrainment as the fish approach the export facilities. Survival is substantially affected by predation near the export facilities and the failure of the behavioral barriers to divert the predators from the export canals. They did not find a convincing argument for the near-field survival at the CVP being greater than at the SWP.

While most of the Jensen et al. (2025) paper discussed survival among different through-Delta pathways (See San Joaquin River and Interior Delta Routing section), they also reviewed particle tracking results simulating entrainment at the CVP and SWP facilities. They found that entrainment of winter-run Chinook at the facilities increased with increasing exports and decreasing Sacramento River flow. Fewer simulated particles were entrained at the facilities with increased Sacramento River flow, but more were entrained with an increasingly negative Old and Middle River Index (OMRI). Modeling results were the same when entrainment at the facilities was considered compared to the proportion of particles routed through the interior Delta. Both OMRI and inflow affected the entrainment of particles already located in the region. Model results also indicated that entrainment loss at the export facilities and migration survival may be inversely related as a function of inflow, such that entrainment decreases and migration survival increases with increasing inflow. While exports on their own do not appear to affect migration survival through the interior Delta and the overall Delta, increased hydrologic alterations may result in exports increasing entrainment at the export facilities.

Through data review of a 6-year telemetry study to identify survival in specific sections of the SWP, Zeug et al. (2025) depicted variations in survival over time and related survival probabilities to the characteristics of individual juvenile hatchery late fall-run Chinook salmon and steelhead (Coleman National Fish Hatchery) and fall-run Chinook salmon (Mokelumne Fish Hatchery). The fish were tagged at the Skinner Delta Fish Protective Facility (SDFPF), with late fall-run Chinook released between January and March; fall-run Chinook released between March and June; and steelhead released between March and May of all years. They established three SWP routes, all with a starting point just inside the Clifton Court Forebay (CCF) near the radial gates: 1) travelling across the CCF through the salvage facility, and transported to west Delta release sites; 2) travelling upstream through the radial gates out of the CCF and back into the interior Delta; and 3) travelling across the CCF into the intake canal and primary bays, bypassing the louvers and entering the California Aqueduct to the pumping plant instead of entering secondary/salvage tanks. They found that late fall-run Chinook had higher survival rates than fall-run Chinook, particularly from route 1 (i.e., trash rack and primary louver to salvage release), as it appeared that larger individuals had higher probability of survival. Smaller fish (i.e., fall-run Chinook) were more susceptible to predators. Late fall-run Chinook also outmigrate earlier in year so they are exposed to conditions with higher turbidity and cooler water temperatures which typically equates to lower predation risk. Fall-run Chinook outmigrate in later spring during warmer water temperatures and lower turbidity, and experience increased predator interactions. Winter-run Chinook and yearling spring-run Chinook are affected similarly to late fall-run Chinook, in that they also move earlier in the migration season (January through March) and are a similar size to the late fall-run Chinook. Median survival between the radial gates to the intake canal was lowest for fall-run Chinook at 0.393, 0.459 for late fall-run

Chinook, and 0.621 for steelhead. Median survival between the intake canal and the debris boom and trash rack was 0.756 for fall-run Chinook, 0.931 for late fall-run Chinook, and 0.883 for steelhead. Median survival from the trash rack to the release sites was 0.379 for fall-run Chinook, 0.881 for late fall-run Chinook, and 0.484 for steelhead. The median travel time from the radial gates to a salvage release site for fall-run Chinook was 3.12 days, 2.25 days for late fall-run Chinook, and 4.42 days for steelhead. This time included time spent in the holding tanks, which could last up to 24 hours. No study fish that exited CCF volitionally were later detected at sites in the West Delta, and it was assumed that their migration was unsuccessful.

Summary of Survival

Table C1 provides a summary of estimated survival, routing, and entrainment identified in the literature. Literature sources that did not provide estimates of all three parameters are not included in the table.

Table C1. Estimates of Survival, Routing, and Entrainment Identified in the Literature Reviewed

Author/Reference	Stressor	Estimated Survival, Routing, and Entrainment
Buchanan and Skalski 2019	Routing – San Joaquin River and Delta, 2010-2014 Fall-run Chinook salmon	Survival San Joaquin (Lathrop) to Chipps: 0 to 0.08, averaged over all years 0.02
		Survival Old River to Chipps: 0 - 0.7, averaged over all years 0.05
		Survival: SJL to Turner Cut: 0 - 0.55
Buchanan et al. 2013	Routing – San Joaquin River and Delta, 2009-2010 Fall-run Chinook salmon	Average Southern Delta survival: 0.06 - 0.56
		• Route entrainment probability in San Joaquin River: 0.05 - 0.32
		• Route entrainment probability into Old River: 0.08 - 0.77
		Average Delta survival: 0.05
		• Route entrainment probability in San Joaquin River: 0.04
		• Route entrainment probability into Old River: 0.07
Buchanan et al. 2018	Routing - San Joaquin River and Delta, 2010 - 2015 Fall-run Chinook salmon	Survival Mossdale - Chipps: 0 - 0.05; survival probability per km = 0.97
		Survival Southern Delta: 0.02 - 0.56
ESA and AECOM 2018	Routing - Delta, All runs of Chinook salmon and steelhead	2010 steelhead survival 0.893 before installation of Old River at Tracy barrier
		2010 steelhead survival 0.577 after installation of Old River at Tracy
Jensen et al. 2025	Routing - Delta All runs of Chinook salmon	Routing probability for late fall-run into interior Delta via DCC or Georgiana Slough: 0.3-0.57
		Survival (fall-run) routed through Georgiana Slough: 0.35-0.44
		Entrainment at export facilities contributed less than 5.5% of total winter-run juvenile and ocean mortality
		Late fall-run survival outside of interior Delta: 0.3 - 0.8

Author/Reference	Stressor	Estimated Survival, Routing, and Entrainment
Johnston et al. 2018	Routing - Sacramento River, 2012-2013 Late fall-run Chinook salmon	Cumulative probability of survival for all routes combined: 0.322 - 0.47
		Cumulative probability of survival Yolo route: 0.24 - 0.469
		Cumulative probability of survival Sacramento River route: 0.348 - 0.528
		Cumulative probability of survival Sutter/Steamboat/Miner Slough: 0.364 - 0.392
		Cumulative probability of survival Georgiana Slough route: 0.172 - 0.423
Perry et al. 2012a	Routing – Sacramento River, 2006-2009 Late fall-run Chinook salmon	Survival through Delta ranged from 0.195 to 0.543
		Survival in mainstem in 2009 was >0.235 than in interior Delta
Perry et al. 2012b	Routing - Sacramento River, 2009-2010 Late fall-run Chinook salmon	Survival in Delta, all routes: 0.374 - 0.524
		Survival in mainstem route: 0.485 - 0.584; probability of remaining in mainstem: 0.392 - 0.6
		Survival in Sutter Slough route: 0.302 - 0.508; probability of Sutter Slough route: 0.134 - 0.243
		Survival in Steamboat Slough route: 0.483 - 0.616; probability of Steamboat Slough route: 0.076 - 0.205
		Survival in Georgiana Slough route: 0.179 - 0.314; probability of Georgiana Slough route: 0.104 - 0.289
		Survival in DCC route (2009 only): 0.236; probability of DCC route: 0.0.038

Author/Reference	Stressor	Estimated Survival, Routing, and Entrainment
Perry et al. 2018	Routing - Sacramento River, 2007-2011 Late fall-run Chinook salmon	Survival Sacramento River, Freeport to DCC: between 0.95 and 1
		Survival Steamboat and Sutter Slough: around 0.45 at 500 cfs to 1 at 1,500 cfs
		Survival Sacramento River, DCC to Rio Vista: 0.75 at 500 cfs to 1 at 1,000 cfs
		Survival Georgiana Slough: 0.45 at 500 cfs to 1 at 2,000 cfs
		Survival Sacramento River, Rio Vista to Chipps: 0.75 for all Sac River flows
		Survival Interior Delta: 0.39 - 0.4 for all flows
		Survival DCC: 0.35 at 500 cfs to 0.55 at 750 cfs (gates closed at all other times)
		Route-specific survival Sacramento River: ~0.5 - 0.7 (500 to 2,500 cfs)
		Route-specific survival Sutter and Steamboat Slough: ~0.5 - 0.75 (500 - 2,500 cfs)
		Route-specific survival Georgiana Slough: ~0.17 - 0.37 (500 - 2,500 cfs)
Pope et al. 2021	Routing – Sacramento River, 2016 Late fall-run Chinook salmon	Survival: Average Freemont Weir – Chipps Island = 0.564-0.843
		Survival Sac River to Chipps route: 0.704-0.843. Probability of route selection: 0.115-0.458. Travel time (median days): 2.696-3.163
		Survival Yolo Bypass route: 0.695-0.689. Probability of route selection: 0.659-0.689. Travel time (median days): 4.186-5.084
		Survival Sutter/Steamboat Slough route: 0.614-0.716. Probability of route selection: 0.614-0.716. Travel time (median days): 2.712-2.885
		Survival Georgiana Slough route: 0.564-0.613. Probability of route selection: 0.564-0.695. Travel time (median days): 5.405-6.401

Author/Reference	Stressor	Estimated Survival, Routing, and Entrainment
Reclamation 2018	Routing - San Joaquin River and Delta, 2013 Focus on steelhead, some Chinook salmon data	2011 Survival Mossdale to Chipps (SJR and OR combined): 0.38 - 0.69
		2011 Survival Mossdale to Chipps, San Joaquin River Route: 0.32 - 0.69
		2011 Survival Mossdale to Chipps, Old River Route: 0.44 - 0.68
		2012 Survival Mossdale to Chipps (SJR and OR combined): 0.26 - 0.35
		2012 Survival Mossdale to Chipps, San Joaquin River Route: 0.28 - 0.36
		2012 Survival Mossdale to Chipps, Old River Route: 0.05 - 0.1
		2013 Survival Mossdale to Chipps (SJR and OR combined): 0.02 - 0.2
		2013 Survival Mossdale to Chipps, San Joaquin River Route: 0 - 0.2
		2013 Survival Mossdale to Chipps, Old River Route: 0.03 - 0.2
		Chinook 2011 Survival Mossdale to Chipps (SJR and OR combined): 0.01 - 0.03
		Chinook 2011 Survival Mossdale to Chipps, Old River Route: 0.02 - 0.07
		2012 Survival Mossdale to Chipps (SJR and OR combined): 0.26 - 0.35
		Chinook 2012 Survival Mossdale to Chipps, San Joaquin River Route: 0 - 0.05
		Chinook 2015 Survival Mossdale to Chipps, Old River Route: 0 - 0.16
		Chinook 2013 Survival Mossdale to Chipps (SJR and OR combined): 0 - 0.02
		2011 Survival Mossdale to Chipps, San Joaquin River Route: 0.32 - 0.69
		Chinook 2013 Survival Mossdale to Chipps, Old River Route: 0 - 0.03
Romine et al. 2021	Routing – Sacramento River, 2014 Late fall-run Chinook salmon	Through-Delta survival from Sac River = 10% to 80% to Chipps, depending on flow and route
		Eliminating routing through Georgiana or DCC could increase survival by up to 7%

Author/Reference	Stressor	Estimated Survival, Routing, and Entrainment
Jahn and Keir 2020	Entrainment	95% survival between salvage facilities and release sites
		Survival at Clifton Court Forebay: 0.01 - 0.37
Karp et al. 2017	Entrainment, CVP Tracy Fish Facility, 2013 Chinook salmon, steelhead	Pre-screen loss Chinook average 17.8% -31.6% (including predation)
		Pre-screen loss steelhead average 8.8% - 76.3% (including predation)
Zeug and Cavallo 2014	Entrainment - CVP/SWP Export Facilities, 1993-2007 All runs Chinook salmon	Entrainment at export facilities contributed less than 5.5% to total winter-run juvenile and ocean mortality
		Late fall-run salvage reduced relative loss by 19% at hatchery release, and 41% for Sacramento River release
		Winter-run salvage reduced relative loss by 15% for hatchery release
		Fall-run salvage reduced relative loss by 41% for Sacramento River release
		Fall-run salvage reduced relative loss by 24% for San Joaquin River release
Zeug et al. 2025	Entrainment – SWP Export Facilities, 2019, 2021 Late fall-run Chinook salmon, steelhead	Steelhead median survival from radial gates to holding tanks/west Delta ≈0.19
		Fall-run Chinook median survival from radial gates to holding tanks/west Delta ≈0.081
		Late fall-run Chinook survival from radial gates to holding tanks/west Delta ≈0.27

Key:
Cfs = cubic feet per second
CVP = Central Valley Project
DCC = Delta Cross Channel
SWP = State Water Project

Appendix D

Environmental Suitability

Appendix D
Environmental Suitability

Multiple Environmental Conditions

Adase et al. (2026) looked at flow, spring temperature, and climate indices (e.g., Pacific Decadal Oscillation (PDO)) to compare the survival of juvenile hatchery (coded wire tagged (CWT)) fall-run Chinook salmon under different release strategies for 2016, 2017, 2019 and 2020. Early releases were in March with the average cohort fork length of 71 millimeters (mm), and standard release times were in April with the average fork length of 74 mm. Model results showed that mean cohort fork length showed a strong positive relationship with estimated smolt-to-adult return (SAR) probabilities when all other covariates were held constant. Each additional mm in cohort fork length was associated with an increased odds of SAR by 5.9%. Overall, the annual adult return rates for the early juvenile release time using the best-fit model estimates were similar to observed estimates, ranging from 0.07% to 0.19% for modeled estimates, and 0.09% to 0.22% for observed estimates. The annual adult return rates for the standard juvenile release time using the best-fit model estimates averaged 0.04% to 0.18%, with observed estimates ranging from 0.03% to 0.18% for the same four years, but 0.03% to 0.26% for 2001-2020. However, early released group was significantly more likely to return than were those in the standard release group, and the probability of SARs decreased by approximately 30.6% for every 10 days later that the fish were released. Environmental factors associated with SARs included river flow, air temperature, and ocean upwelling. Approximately 65.7% of the variation in SARs was explained by fish length and summer upwelling. They found that the day of the year, inverse flow, air temperature anomalies, and spring PDO negatively influenced the SARs, whereas water temperature, snow-water equivalent, precipitation anomalies, and sea surface temperatures did not significantly influence the SARs. They also found that when flow at Wilkins Slough increased from 5,000 cfs to 10,000 cfs, the SAR increased by 147%, and by 35.2% when flows increased from 10,000 cfs to 15,000 cfs. Using the modeled odds of SARs and the observed odds of SARs for 4 study years – modeled odds 1.98 times greater for early fish vs later ones AND observed odds 2.03 times greater for early vs late. Critical uncertainties: Complex and dynamic suite of biotic and abiotic factors, some of which themselves aren't fully understood and that the best fit was 65.7%.

Hydrology

Michel et al (2021) reviewed tagged fish from 2013 – 2019 and took an information theoretic approach to identify a flow survival relationship. Results consistent with other studies: flow is a strong driver of smolt spring outmigration survival. Presents a step function with 3 Wilkins Slough flow thresholds associated with survival. These thresholds are defined as follows: minimum (4,259 cfs), historic mean (10,712 cfs), and high (22,872 cfs). Results are as follows: 3% below the minimum, 18.9% between the minimum and historic mean thresholds, 50.8% between the historic mean and high thresholds, and 35.3% above the high threshold. These survival responses to flow are nonlinear which suggests different flows provide disproportionate benefits to survival. There are management implications for these results. For example, using the lower critical flow boundary in the spring could result in a 6.3-fold increase in survival, and applying flows above historical mean could result in a 2.7-fold increase. Heterogeneity of flows may lead to increased population diversity and taking advantage of higher releases could increase survival due to decreased travel time and predation risk. Link to adults: none directly. Juveniles, increased outmigrating survival translates to more possible adults all other factors held equal.

Michel et al. (2015) assessed travel time and survival of acoustic-tagged hatchery origin late fall-run Chinook salmon in the Sacramento River associated with river flow. They focused on both wet and dry water years. They found that juvenile survival was generally higher in the lower reiver compared to the Delta and Bays, even though the river is channelized with rip-rapped banks. As expected, survival throughout the entire migration route was lower during the low discharge (dry) years (2.8 – 5.9%), and higher for the high-discharge year (15.9%). They hypothesize that the increased survival in the lower river is because the channelization and riprap result in reduced prey abundance, minimal cover from predators with an increased risk of predation, and therefore, their rate of travel is increased. The increased travel speed along with the avoidance of channel margins and disproportionate use of the center of the channel decreases their exposure time to sources of mortality. They found survival through the both the Delta and San Francisco Bay ranged from 15.1% to 23.4%. Survival in the mainstem ranged from 15.5% to 62.2%.

Del Rosario et al. (2013) showed that juvenile winter-run Chinook salmon migrate through and reside in the Sacramento–San Joaquin Delta over an extended period, with timing and movement patterns closely tied to hydrologic conditions, including seasonal pulse flows that stimulate downstream emigration. These hydrologically driven migration patterns reflect how flow-mediated environmental suitability influences juveniles and their exposure to varying habitat conditions. This study found that higher flows that promote directed downstream movement tend to support more efficient migration and likely improve survival, whereas altered or low flows can prolong residence time in suboptimal habitats and increase exposure to stressors. Results show that ≥5% catch at the Knights Landing Rotary Screw Trap coincided with first day of flow of at least ~14,100 cfs at Wilkins Slough. The study also showed that residence time in the Delta can affect daily survival. Average residence time for winter-run between Knights Landing and Chipps Island averaged 87 days, though it ranged from 40 to 110 days.

Iglesias et al. (2017) identified mortality zones and factors that influence outmigration success. 2007 – 2011 tagged fish were used to identify environmental covariates (flow, temperature, depth and velocity), habitat features (riverine cover, off channel habitat, diversion structures, bank type) and individual fish covariates (fish condition, length, hatchery release strategy) on outmigration success (survival). Authors found that flow was strongest correlated with smolt survival (increased flow meant increased survival) and fish condition (increased length-to-weight ratio meant increased survival). The effects on adult populations were not directly addressed but assume increased early life stage survival translates to increased adult returns. Flow was most strongly correlated with out-migration success (increased flow meant increased smolt apparent survival) and with fish condition (increased length-to-weight ratio meant increased apparent survival). Authors discuss other important variables correlated with survival which included hatchery release strategy and swim speed. A general survival trend was reported: there was lower per-reach survival in the upper and middle Sacramento River compared with the lower Sacramento River.

Kock et al. (2024) assessed data from 2018-2021 to examine a flow survival relationship. 6-59% entrainment at 3 of 4 studied dams and probability of entrainment positively associated with proportion of streamflow diverted into canals. Fish that were entrained had average survival 10-37% lower than non-entrained fish, so entrainment reduced survival of outmigrating fish (increased survival with less flow diverted into canals). Additionally, authors hypothesize entrainment could delay outmigration possibly decreasing survival (predators, poor water quality, higher temperatures) but not directly tested. Link to adults: none directly. Juveniles, increased outmigrating survival translates to more possible adults all other factors held equal.

Perry et al. (2018) examined juvenile salmon survival through the Delta and found that fish entering the interior Delta south of the mainstem Sacramento River experienced lower survival than those migrating along more northerly routes, likely due to longer travel times and distances, elevated predation risk, and entrainment at pumping facilities. The authors characterized the Delta into three hydrodynamic zones: riverine reaches with unidirectional flow, transitional reaches where flow shifts with inflow conditions, and tidal reaches dominated by bidirectional flow. Survival was consistently high in riverine reaches regardless of inflow, while tidal reaches exhibited lower but relatively stable survival. In contrast, survival declined and became more variable in transitional and tidal reaches during low inflow conditions, when increased tidal influence prolonged travel time and distance by advecting juveniles upstream on flood tides. These findings indicate that flow regime and hydrodynamic complexity strongly shape environmental suitability during outmigration. In the Central Valley, altered flow patterns and reduced cold-water inputs may compress or shift migration timing, increasing the likelihood that juveniles encounter unfavorable tidal and predation conditions during downstream movement.

Notch et al. (2020) evaluated juvenile salmon survival from Mill Creek through the Sacramento River between 2013 and 2017, encompassing both drought and high-flow years. Mean cumulative survival from Mill Creek through the Sacramento River was 9.5%, with substantial interannual variability: survival was 0% in 2016, 4.9% in the drought year of 2015, and 42.3% in the high-flow year of 2017. Regional survival estimates increased downstream and were consistently higher in wetter years, ranging from 62.1% to 88.1% in Mill Creek, 86% to 96.5% in the Upper Sacramento River, and 92% to 98.1% in the Lower Sacramento River. Explanatory covariates included streamflow, water temperature, turbidity, and fish size, with top-performing models identifying flow and Mill Creek temperature as the strongest predictors. Higher flow conditions were associated with increased survival, whereas elevated water temperatures in Mill Creek corresponded to reduced survival. Although overall survival estimates were lower than those reported in other telemetry studies, such as Michel et al. and Cordoleani et al., the findings reinforce the importance of hydrologic and thermal conditions in shaping juvenile outmigration success. While adult returns were not directly evaluated, increased juvenile survival during outmigration would be expected to enhance the potential for adult recruitment, all else being equal.

Crozier and Zabel (2006) analyzed juvenile survival across 18 Chinook salmon populations and found that fall streamflow was the strongest predictor of survival, highlighting the importance of adequate flows for migration and habitat connectivity. Climate effects varied regionally, with high summer temperatures negatively affecting some populations and higher fall flows—often associated with snowpack—improving survival in others, demonstrating that local habitat conditions mediate climate impacts. Although adult returns were not directly assessed, greater juvenile survival increases the potential for adult recruitment. Systems with longer migration corridors and sustained flows, such as the Columbia River and Fraser River, exhibited higher juvenile survival, emphasizing the importance of hydrologic stability and climate-resilient habitats.

Temperature and Water Quality

Friedman et al. (2019) developed a life-cycle model to evaluate how freshwater and marine environmental processes jointly influence adult returns of CV fall run Chinook salmon. The model explained 68.3% of the variability in escapement from 1988 to 2016, demonstrating that population dynamics are driven by cumulative environmental effects experienced across multiple life stages rather than by any single factor. This study also found that egg incubation temperature significantly affected early survival through temperature-dependent mortality, and juvenile outmigration flow influenced survival directly and indirectly by altering habitat conditions and predation risk.

Lehman et al. (2017) addressed how water quality affects swimming performance, which ultimately affects the vulnerability to predation. They established a fixed setting environment in the laboratory and in the river using cages and mobile swim tunnel respirometers to evaluate the swimming performance of hatchery fall-run Chinook salmon when exposed to variable covariates of water temperature, turbidity, dissolved oxygen (DO) and conductivity in the lower San Joaquin River where it enters the Delta. Juveniles that were acclimated to the river when water temperatures were below 18.5°C swam faster than they did when water temperatures were cooler (15-17°C) in the hatchery. They found a negative relationship between the maximum swimming speed and water temperature and turbidity, but these covariates only explained about 48% of the deviance in maximum swimming speeds. Other covariates, such as pH and DO are correlated to temperature, making these variables difficult to measure effectively. Low flow and low turnover rate of water can exacerbate poor water quality conditions in the San Joaquin River, and freshwater turnover in tidal channels may be as important to salmonid health as water temperature. Predators swim more effectively at higher water temperatures when salmonid maximum swimming speeds are reduced, thus increasing their risk of predation.

Habitat

Maslin et al. (1998) assessed the value of intermittent streams as rearing habitat for juvenile Chinook salmon compared to rearing habitat in the mainstem Sacramento River. They found that early spring, juveniles using these tributaries grew faster and were heavier for their respective lengths than those in the mainstem. Tributaries had water temperatures averaging 15°C between February and April, with daily fluctuations of 4°C above and below, whereas the mainstem had diel fluctuations of 2°C. This provided more optimal conditions for growth. Additionally, the tributaries had lower turbidity levels which improved their feeding efficiency. Intermittent flows precluded the establishment of predator populations; therefore, less energy is spent avoiding predators and more energy is spent on feeding and growth.

Sommer et al. (2001) demonstrated that juvenile Chinook salmon rearing seasonally in the Yolo Bypass exhibited substantially higher growth rates than those remaining in the Sacramento River. Mean length increased more rapidly in the floodplain, driven by warmer water temperatures, greater availability of drift invertebrates, higher prey consumption, and improved feeding success, as confirmed by stomach content analysis. Bypass floodplain had higher water temperatures (1998 and 1999), and juvenile salmon ate more prey. Although rearing in warmer water increases metabolic demand, the elevated food resources more than offset these costs. Enhanced survival in the bypass was also attributed to habitat characteristics, including a much larger wetted area compared to the narrow river channel, which reduces competition for food and space and lowers the probability of predator encounters. Together, the findings highlight the importance of productive floodplain habitats in improving growth and survival during early life stages.

Phillis et al. (2018) used otolith analysis to reconstruct juvenile freshwater habitat use by endangered Sacramento River winter-run Chinook salmon that survived to adulthood. They found that 44–65% of returning adults reared in non-natal habitats. Fish that used alternate habitats still achieved similar size at ocean entry as those reared in the mainstem Sacramento River, indicating that non-natal environments provide suitable conditions for growth and survival. These results suggest that winter-run Chinook may rely on a broader range of rearing habitats than previously recognized.

Limm and Marchetti (2009) compared juvenile Chinook salmon growth among main-channel habitats, off-channel ponds, and non-natal seasonal tributaries in the Sacramento River using otolith analysis. They found that juveniles rearing in off-channel and non-natal tributary habitats exhibited larger otolith growth increments than those in the mainstem, reflecting faster growth associated with warmer water temperatures and higher prey densities. These findings indicate that off-channel and intermittent habitats provide particularly productive rearing conditions. Supporting this pattern, isotope analyses have shown that many adult survivors reared in non-natal habitats, suggesting that connectivity to diverse rearing environments contributes to recruitment. Similarly, Maslin et al. documented elevated juvenile growth in intermittent streams, where seasonal drying can reduce piscivorous fish abundance, further highlighting the ecological importance of maintaining access to a mosaic of rearing habitats beyond the mainstem river.

Michel (2010) examined two hypotheses to assess outmigration survival rates of late fall-run Chinook salmon, looking at reach-specific and total survival, both temporally and spatially. Survival in the San Francisco Estuary ranged from 67% per 10 kilometers (km) (Richmond Bridge to Golden Gate) to 100% per 10 km in the lower Sacramento River (City of Sacramento to Freeport). He found that the total survival throughout the entire migration corridor varied from 3.1% to 6.1% per year with a total survival for all years at 3.9%. He compared the smolt survival in the Sacramento River system to those in Pacific Northwest. He noted that survival of smolts outmigrating from the Snake River to the ocean (910 km) averaged 27.5%, in 2006, survival of smolts in the Faser River to the ocean (up to 395 km) ranged from 2% to 32%, and survival of smolts in the Yakima to the ocean (655 km) had an overall survival of 28%. He showed significant relationships between smolt survival in the river and the percent of riprap along the shoreline, the percent of leveed shoreline, the river sinuosity, the number of diversions per kilometer, and the percent of natural riparian habitat, in decreasing order of significance.

Climate Change

Cordoleani et al. (2021) reviewed strontium isotope ratio data and daily depositional chronology in otoliths to reconstruct juvenile spring-run Chinook salmon migration patterns in the Central Valley. They identified three different migrant patters: 1) early migrants which leave the natal stream after 15 ±14 days at a smaller size and rear for multiple months in non-natal habitat (i.e., Sacramento River and Delta), and enter the ocean at the same size as the intermediate migrants; 2) intermediate migrants which leave after 84 ± 27 days at a slightly larger size and rear for a little less time in non-natal habitat; and 3) late migrants which leave after 194 ± 32 days significantly larger, having reared over the summer. The late migrant phenotype is the least common observed but makes up approximately 60% of the returning adults averaged across years, whereas the intermediate migrants provide 19% of the adults, and early migrants make up about 21% of the adults. Early growth rates were found to be inversely related to emigration timing, that is, faster growers left earlier. By remaining in the natal streams over summer, late migrants may forgo early growth opportunities that the early and intermediate migrants may by feeding in the period when the ocean is more productive. Late migrants have developed a drought-resilient life history tactic of emigrating in the fall when water temperatures in the migratory corridor is lower, however, they must survive the spring and summer heat in headwater habitats for this to be sustainable. Within population phenotypic diversity is important to ensure that at least one portion of the population is successful under varying and extreme environmental conditions.

Buchanan (2021) studied the success of life history strategy related to the climate conditions that fish encounter during juvenile migration. There are implications for population survival with a changing climate. The "Portfolio effect" means that increased species diversity benefits the population. Link to adults: Authors used fish scales from spawning adults & otoliths from adult carcasses to analyze elements (Sr: Strontium; Ca: Calcium; Ba: Barium) and the ratios between them (Sr:Ca, Ba:Ca). This article is a synthesis of Cordoleani et al. (2021). Refer to the synopsis of that paper in this Appendix for more information.

Summary of Survival

Table D1 provides a summary of survival estimates identified in the literature, when provided, for environmental suitability. Not all literature sources provided estimates of survival and those not are not included in the table.

Table D1. Survival Estimates Identified in the Literature Reviewed for Environmental Stressors

Author/Reference	Environmental Stressor	Survival Estimates
Cordoleani et al. 2021	Climate Change	Late migrant spring-run = 60% of returning adults (10% of the juveniles)
		Early migrants = 21% of returning adults (64% of the juveniles)
		Intermediate migrants = 19% returning adults (26% of the juveniles)
Michel 2010	Habitat Late fall-run Chinook salmon	Total survival to ocean: total 3.9%, range 3.1% - 6.1%
		Survival in the San Francisco Estuary (Richmond Bridge to Golden Gate): 67% per 10 kilometers
		Survival in the lower Sacramento River (City of Sacramento to Freeport): 100% per 10 kilometers
Michel et al. 2015	Hydrology, 2007-2011 Late fall-run Chinook salmon	Survival through entire migration corridor (516 kilometers): 2.8 - 15.7%
		Survival through the Delta and bays region combined: 15.1% to 23.4% (89.3%–91.7% per 10 kilometers)
		Survival, subyearling fall-run Chinook smolts from Port Chicago to the Golden Gate in 1984-1986: 76% to 84%
		Survival, late fall-run Chinook smolts from Port Chicago to Golden Gate in 2007-2011: 26% to 43%
Michel 2021	Hydrology, 2013-2019 Fall-run, spring-run and winter-run Chinook salmon	Survival when Sacramento River at Wilkins Slough <4,259 cfs: 3%
		Survival when Sacramento River at Wilkins Slough >4,259 and <10,712: 18.9%
		Survival >10,712 cfs <22,872 cfs: 50.8%
		Survival when Sacramento River at Wilkins Slough >22,872 cfs: 35.3%
		Pulse flows increase survival by 55% to 132%
		Survival increased by 79% to 330% with modest increase to water budget

Appendix E

Predation and Ocean Rearing

Appendix E
Predation and Ocean Rearing

Predation

Many of the predators in the CCV are nonnative fish (e.g., striped bass, channel catfish, largemouth bass) that often aggregate in "hotspots" or dense areas of predators (Hayes et al. 2017). While hotspots can be spatiotemporally variable, some areas always have a higher density of predators (e.g., Clifton Court Forebay, the scour hole at the Head of Old River, and Tracy Fish Collection Facility) (Gingras and McGee 1997, Sabal et al. 2016a, Hayes et al. 2017, Karp et al. 2017, Michel et al. 2020). The Head of Old River Barrier (HORB), and other seasonal south Delta agricultural barriers (SDAB), have been identified predatory fish hotspots and modeling from when the HORB was installed suggested a higher density of small juvenile Chinook may lead to increased predation probability (ESA and AECOM 2018). Lindley and Mohr (2003) posit from salmonid population modeling that a population of 1 million striped bass could consume almost 10% of outmigrating winter-run Chinook salmon. Removal of striped bass in the Mokelumne River increased naturally spawned juveniles by 25 to 29%. A reduction of almost 10% of any of the CCV Chinook runs would negatively impact adult abundance. The link between predation and other parameters (like routing) can be found in those sections.

Predation rates are not independent from other stressors like predator presence, salmonid vulnerability, competition, and environmental conditions (Grossman 2016, Michel et al. 2020, McInturf et al. 2022). Even prey density (smolt abundance) impacts predation rates: low density can increase predation while high density can reduce predation due to predator swamping (Perry et al. 2012a). Most of these stressors are spatiotemporally influenced by water operations, and when layered with predation could cause a compounded impact on salmonids. For many CCV aquatic predators, their metabolism and behaviors can be driven by water temperatures – increased water temperature increases predator activity. McInturf et al. (2022) found largemouth bass thermal physiology likely allows these predators to consume more salmonids in increasingly warmer water temperatures.. Michel et al. (2020) found that as water temperature increases, the predation hazard increases. For example, they found that predation hazard ratios when water temperature was 16°C ranged from0.5 to 4.2, but at 19°C, the predation hazard ranged from 1.7 to 14.8 (up to a 77-fold increase).

Michel et al. (2021) hypothesized a faster travel rate as a function of higher flows may decrease predation exposure. But where fish move both upstream and downstream in tidal systems, which increases travel distance, this behavior might increase predator encounter rates (Perry et al. 2012b). Increased predator pressure on outmigrating juveniles in different locations within the CCV system may result in fewer salmonids reaching the Pacific Ocean to mature.

Maslin et al (1998) found that prolonged periods of dry conditions in intermittent streams prevented the establishment of resident piscivorous fish populations. Therefore, juvenile anadromous fish rearing in intermittent streams were protected from predators, which meant that more energy could be spent on feeding and growth.

Ocean Rearing

Juveniles should arrive when their prey base is abundant to optimize survival probabilities. Fiechter et al. (2015) reported CCV hatchery Chinook that entered the Gulf of the Farallones coinciding with increased prey (krill concentrations driven by early season upwelling) typically had higher growth rates during their first 90 days at sea. Satterthwaite et al (2014) found that ocean survival was highest when CCV Chinook salmon were released within 70 to 115 days of the upwelling transition date. There are data that suggest timing of hatchery releases be planned to match marine conditions to maximize survival (Brosnan et al. 2014) and that larger smolts could be released closer to the ocean to avoid high in-river mortality (Sabal et al. 2016b). CCV hatchery fall-run Chinook salmon release-timing played a role in smolt-to-adult return (SAR) rates: fish released earlier in the season were more likely to return to the hatchery than those released later (Adase et al. 2026). However, all authors acknowledge that hatchery fish may not behave or respond like wild-origin fish. For example, tagged wild and hatchery Chinook in the Columbia River Basin exhibited different timing and arrival patterns: hatchery fish displayed a temporally clumped arrival while wild fish displayed an earlier arrival-time with wider temporally spread probability distribution (Chasco et al. 2021).

Further north in the California Current, the hydrology of the Columbia River plume differs from the San Francisco Bay plume and the interaction salmonids have with environmental conditions is not the same. Studies of the Columbia River plume suggest that increased plume survival is related to a decreased plume residence time (Brosnan et al. 2014). This could be a function of both larger- and smaller-scale forcings like sea surface temperature and localized groups of predators. Crozier et al. (2021) reported from a climate change projection exercise that an increase in sea surface temperature led to modeled Snake River Chinook populations declines regardless of freshwater-focused actions to increase outmigrating juveniles travel time or survival. However, the "carry over" conditions fish experience during the freshwater component of their life cycle should not be discounted.

Summary of Survival

Table E1 provides a summary of estimated survival identified in the literature, when provided, for environmental suitability. Not all literature sources provided estimates of survival and those not are not included in the table.

Table E1. Survival or Loss Estimates Identified in the Literature Reviewed for Predation and Ocean Rearing Stressors

Author/Reference	Environmental Stressor	Literature Summary
Hayes et al. 2017	Predation Chinook salmon	Chapter 3: Survival of entire lower San Joaquin and Delta: 0.23
		Chapter 3: Survival of entire lower San Joaquin and Delta IF predators removed: 0.36
Karp et al. 2017	Predation, 2013 Chinook salmon and steelhead	24.6% mortality of Chinook lost to predators
		8.2% of steelhead lost to predators
Lindley and Mohr 2003	Predation Winter-run Chinook salmon	A population of 700,000 striped bass would increase the probability of quasi-extinction from 28% to 30%
		Eliminating striped bass population would decrease quasi-extinction risk to 23%
Sabal et al. 2016a	Predation, Mokelumne River, 2013 Fall-run Chinook salmon	Survival increased by 10.2% with the removal of 0.92% per capita striped bass
		Naturally spawned juvenile Chinook increased by 25-29% after predator removal
Sabal et al. 2016b	Ocean Rearing, 1999-2012 Fall-run Chinook salmon	Survival to age 3: 0.0058 - 0.0563

Appendix F

Selected Information from Literature Reporting Smolt-to-Adult Return Rates

Appendix F
Selected Information from Literature Reporting Smolt-to-Adult Return Rates

Table F1 provides a summary of four articles focused on smolt-to-adult (SAR) return rates.

Table F1. Smolt-to-Adult Return Rates Literature Summary

Category	Wilson et al. 2021	Bosch et al. 2023	James et al. 2023	Adase et al. 2025
Location	USA Washington State Columbia River Basin Wind River	USA Washington State Columbia River Basin Yakima River	Canada British Columbia Multiple basins Multiple rivers	USA California Sac/SJR Basin Sacramento River & Delta
Species / Run	Summer-run steelhead	Spring Chinook	Chinook salmon Coho salmon	Fall-run Chinook salmon
Life Stage	Smolts	Smolts	• Chinook: fry, sub-yearling smolts, yearling smolts • Coho: fry, yearling smolts	Smolts
Number of Fish (approx.)	22,116	344,000 +	• Chinook 1,597 release groups • coho 1,006 release groups	Millions (annual release numbers ranging from 142,043 to 3,128,375)
Hatchery / Wild	Wild	Hatchery	• 21 Chinook hatcheries • 16 coho hatcheries	Hatchery
Tagging Method	PIT tags	PIT	CWT	CWT
Study Period	Fish tagged / released 2003 – 2014 SAR estimates through 12/31/2017	• Fish tagged / released 2002 – 2014 (BYs) • Juvenile migration 2004 – 2016 • Spawning / return 2004 - 2019	• Fish tagged / released 1971 – 2015 • Juvenile-to-adult estimates through 2017	• Fish tagged with standard strategy 2001 – 2020 • Fish tagged with both early (March) and standard (April) strategies 2016, 2017, 2019, 2020
Metric	Smolt-To-Adult Return Rates (SAR)	Juvenile survival, SAR	Juvenile-to-adult survival (Note: not entirely 1:1 proxy for SAR given additional life stages)	Smolt-To-Adult Return Rates (SAR)
"Route"	Smolts released upper Wind River; Adults returned to Bonneville Dam	Released at 3 "acclimation sites" to Bonneville Dam	None documented in specifics; 37 hatcheries and 40+ years of data used	Juveniles released Battle Creek; Adults returned to Coleman National Fish Hatchery
Modeling	Multi-level Bayesian regression models (covariates e.g., fish morphometrics, annual and sub-annual environmental conditions)	Traditional statistics: mixed-effects linear regression, ANOVA, mark-recapture CJS	Multi-level multi-hatchery hierarchical Bayesian models (covariates e.g., fish morphometrics, SST and PDO environmental conditions, HS abundance on young and KW abundance on adults as predation)	State-space mixed-effects logistic regression model (covariates e.g., fish morphometrics, air temperature, PDO, upwelling)

Category	Wilson et al. 2021	Bosch et al. 2023	James et al. 2023	Adase et al. 2025

Results (Quantitative & Qualitative)	• SAR rates ranged from 1.8% to 7.6% (averaged 4%; 850 adults returned from 22,116 smolts released)
	• Survival positively associated with size. Survival negatively associated with annual biological transition date.
	• Survival was strongly size- and timing-dependent: larger fish had higher survival, survival was higher when the biological spring transition occurred earlier in the year and before fish outmigrated.
		• Generally low (20 – 25%) survival of juveniles released at all 3 locations to Bonneville Dam. Highest average survival at one site (25.10 +/- 1.66%)
		• Observed SAR fluctuated by BY: BY 2002 – 2005 (~0.5%), BY 2006 (over 1.5%), BY 2007 – 2014 (between 0.5% and 1.0%)
		• Predicted SAR increasing from ~0.3% to 1.7% for early migrating fish from CFJ and from 0.3% to 0.6% for late migrating fish. Predicted SAR decreasing for smaller smolts 0.75 to 0.4% and for larger smolts 1.0 to 0.4%.
		• Larger smolts and particularly early outmigrants display increased predicted SAR. Outmigrants leaving later in the season display decreased predicted SAR.
			Chinook Salmon:
			• Higher survival rates associated with earlier releases and increasing weight at release
			• "Optimizing releases" could increase Chinook 6% - 245% (based on median posterior estimates)
			• Mean posterior Chinook sub-yearling smolt survival 1972 – 2015 declined from 2.3% to 0.2%
			Coho Salmon:
			• Higher survival rates associated with later releases and increasing weight at release
			• "Optimizing releases" could increase coho 5% - 160%
			• Mean posterior coho yearling smolt survival 1973 – 2017 declined from 9.8% to 0.8%
			• Survival can be optimized by aiming for release weight and timing.
				In most but not all years
				• Timing: odds of SAR decreased mean 30.6% for every 10 days later the fish are hatchery released
				• Size: odds of SAR increasing mean 5.9% for each 1mm increase in FL
				• Best fit model = only 65.7% explanation of variation in SARs, used model to estimate SARs and compared with observed – and they were close
				• Flows at Wilkins Slough had significant effects on SAR (e.g., increase in flow from 5,000 to 10,000 cfs increased SAR by 147%)
				4 years (2016, 2017, 2019, 2020):
				• Early fish (March release)
				  • SAR Estimates means: 0.07% to 0.19%
				  • SAR Observed: 0.09% to 0.22%
				• Standard fish (April release)
				  • SAR Estimates means: 0.04% to 0.18%
				  • SAR Observed: 0.03% to 0.18% [and observed 0.03% to 0.26% for full 2001 – 2020]

Sources:

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Key:
ANOVA = analysis of variance
BY = brood year
CJS = Cormack Jolly Seber
CWT = coded wire tag
FL = fork length
HS = harbor seal
KW = killer whale
PDO = Pacific Decadal Oscillation
PIT = passive integrated transponder
SAR = smolt-adult return ratio
SST = Sea surface temperature

Appendix G

IOS

Appendix G
IOS

The Interactive Object-Oriented Simulation Models (IOS) is a life cycle model (LCM) developed specifically for Central Valley winter-run Chinook salmon. IOS predicts adult abundance by incorporating environmental factors and habitat estimates.

Tables G1 and G2 show significant drivers for modeled escapement by age class (Table G1) and the influence of simulated changes in environmental variables on modeled escapement (Table G2).

Table G1. Fish Returning to Spawning Grounds by Age-Class, Significant Input Parameters Driving Variability in Escapement by Age Class from Sobol' Index Sensitivity Analyses

Age Class	Account for Percent of Total	Significant Drivers of Variability in Age – "X" Escapement	Significant Drivers of Variability in Age – "X" Escapement, Accounting for Interactions
2-year-old	8%	Water year type, Delta survival, smolt-to-age-2 survival	Water year type, river migration survival, smolt-to-age-2 survival
3-year-old	88%	Water year type, egg mortality, Delta survival, ocean productivity, age 3 harvest	Delta survival
4-year-old	4%	Egg mortality, fry-to-smolt survival, Delta survival, smolt-to-age-2 survival ocean productivity, age 3 harvest, age 4 harvest	None

Source: Zeug et al. 2012.

Note:

Parameters reported as both an independent, main parameter and as part of a total accounting for interactions with other parameters.

Drivers of variability in fish returning to spawning grounds (for each age class) were assessed independently and accounting for interactions with other drivers using Sobol' sensitivity indices (1,000 MC iterations). While modeling supports Water Year type (WY) is a significant driver of variability in age-2 escapement (accounting for interactions with other drivers), age-2 only accounts for 8% of the total. WY is not a significant driver in age-3 escapement (accounting for interactions with other drivers) and age 3 accounts for 88% of the total. Therefore, we might conclude WY drives variability and has an impact forming adult WR population but not as large an impact as Delta survival.

Table G2. Influence of Simulations of an Increase and Decrease of Environmental Parameters on Escapement Model Output

Factor	Affected by ±10%	10% +	10% -
Temperature	Significant	95.7% reduction in escapement	11% increase in escapement
Flow	Not Significant	6.2% increase in escapement	4.7% decrease in escapement
Exports	Not Significant	Not reported in text, plotted in Figure 4	Not reported in text, plotted in Figure 4
Ocean Conditions	Not Significant	Not reported in text, plotted in Figure 4	Not reported in text, plotted in Figure 4

Source: Zeug et al. 2012.

Note: Environmental variables influence on escapement were assessed using 3 sets of 100 MC simulations. Only temperature of 4 environmental variables significantly affected escapement compared to baseline when both a 10% increase and decrease were applied. And, of the applied increase and decrease, the increase in temperature had a much greater effect than a decrease in temperature: 10% increase led to 95.7% reduction in escapement and 10% decrease led to 11% increase in escapement. This indicates that of the 4 stressors, temperature (and particularly an increase in temperature) will impact adult populations the most. This may be because the temperatures are already close to upper limits of Chinook tolerance.