CRAMER FISH SCIENCES®
An Employee Owned Consulting Company

APPENDIX C. DATA SOURCES AND INPUT REQUIREMENTS

This appendix supports the Limiting Factors Analysis for Lower Trinity River Chinook salmon (*Oncorhynchus tshawytscha*) prepared for the Trinity River Restoration Program. The Trinity River Chinook salmon Limiting Factors Analysis applies the general method of Hamilton and Murphy (2018), which uses a life-cycle framework to organize potential limiting factors by life stage, identify hypothesized drivers and causes, and evaluate the data needed to parameterize and test those hypotheses. This appendix describes the data requirements to inform parameterization of a quantitative life cycle model (LCM), which is under development for Phase 2 of the Trinity LFA. The information is organized by Chinook salmon life stages and their transitions as shown in the revised conceptual life cycle diagram for Trinity River Chinook developed during Phase 1 (Figure 1). Potential drivers and causes were identified for life stages and transitions in Phase 1, and these are described for each life stage transition along with working hypotheses associated with these potential drivers and causes. Finally, we provide guidelines that were used for the preliminary data requests focused on key datasets and life stage transitions. Additional data requests were made as data were evaluated in coordination with the technical advisory group (TAG) and science advisory board (SAB).

Data Requirements

For each life stage and transition, we describe data requirements to help guide the identification and evaluation of available data. These include both required demographic data and potential drivers and causes that were identified in Phase 1 for each life stage. We first describe the desired data for each life stage transition, which includes both the desired demographic data and potential drivers and causes associated with each life stage transition. Working hypotheses are described for each life stage transition and the suite of potential drivers and causes, and these were vetted and refined in coordination with the TAG/SAB to support data evaluation, hypothesis testing, and model parameterization.

CRAMER FISH SCIENCES®
An Employee Owned Consulting Company

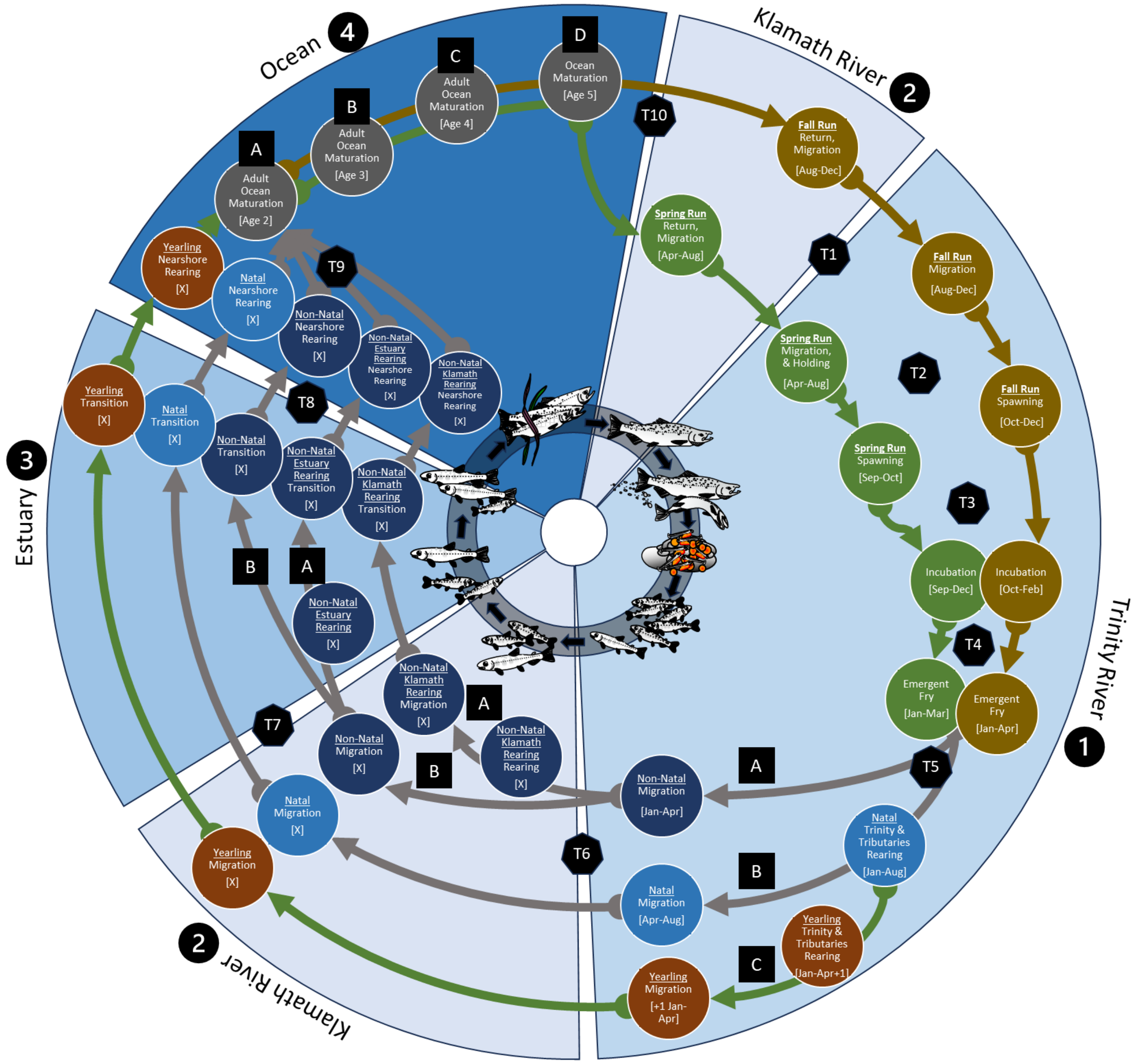

Figure 1. Revised life cycle diagram for Trinity River Chinook salmon that was developed in collaboration with TRRP scientists during Phase 1. This conceptual model shows the spatial structure as fish move through different geographic areas including the Trinity River, Klamath River, Estuary, and Ocean, which are labeled with numbered black circles (1-4). The life stages are shown as colored circles, with the life stage name underlined and the primary behavior indicated with periodicity in brackets. Arrows show transitions from one life stage to another, which may include transition to another geographic area, or different pathways describing variations in life history strategies and population structure that include both run timing (spring- and fall-Run Chinook salmon) and juvenile life history variations (non-natal rearing, natal rearing, and yearling life histories as well as estuary rearing). The transitions are numbered and described in the text, along with the associated drivers and causes that can influence the transition rate and success between each life stage. Life history variations, or alternative strategies, are lettered in black boxes and described further in the text. [X] indicates periodicity is unknown or requires determination.

T1 Adult migration from the Klamath River to Trinity River

Description of Life Stage Transition: Adult Chinook salmon entering the Klamath River and migrating into the Trinity River (Figure 1), including both fall-run and spring-run Chinook salmon.

Demographic Data Requirements for Life Stage Transition: Potentially useful data for this transition include:

1. Weir counts of adult immigration, ideally in the lower Klamath River to represent adult abundance entering the Klamath River
2. Hatchery, natural, and river (stray) origin composition
3. Spring- and fall-run composition
4. Timing (e.g., weekly counts)
5. Snorkel survey estimates of adults in holding areas
6. Survival and/or migration rates for upriver migration through the Klamath River to the Trinity River (e.g., from biotelemetry studies)

Description of Potential Drivers and Causes linked to Life Stage Transition: The Trinity River Science Plan (Pickard et al. 2022) identified two potential limiting factors during adult river life stages, which included water temperatures and fish disease in the lower Klamath River (provided in Table 1 below). Both potential drivers would contribute to pre-spawn mortality, although life history strategy and densities may have a significant effect on mortality rates and responses (Belchik et al. 2004; Fujiwara et al. 2011; Hearsey 2011; Bowerman et al. 2016). Water quantity and quality (e.g., temperature, DO, etc.) can be influenced by flow management as well as water withdrawals, climate variability (e.g., drought), and hypothesized association of climate change and decreases in water quantity with increased temperatures, fish densities, and prevalence of disease and therefore increased pre-spawn mortality. Klamath River water quantity and quality downstream of the Trinity River confluence is influenced by Trinity flow regulation and historically by the upper Klamath River flow regulation prior to dam removal. In addition, numerous tributaries influence water quantity and quality in the lower Klamath River. Spring-run Chinook Salmon would be hypothesized to have greater exposure to stressors related to water quantity, temperatures, and disease in the lower Klamath River due to their earlier run timing that spans summer months (Belchik et al. 2004; Bowerman et al. 2016; Bartholomew et al. 2023). Habitat connectivity would be hypothesized to influence density of and predation on adult salmon and, therefore, overall fish health (e.g., energy conservation and disease) and pre-spawn mortality (Guillen 2003; Hearsey 2011; Bartholomew et al. 2023; Krause 2024). Limited habitat connectivity could reduce the ability for early return adults to find thermal and predatory refugia, which could increase fish abundances in limited space and lead to increased stress, disease transmission, predation, and weakened condition in future life stages (Guillen 2003; Belchik et al. 2004; Hearsey 2011; Bowerman et al. 2016; Bartholomew et al. 2023; Krause 2024). Finally, lower Klamath River basin wildfires could result in alterations to sedimentation, organic inputs, water quality, flow regime, and habitat quality, which could lead to habitat reduction. In response, adult concentrations could increase in the remaining limited space, increasing stress, predation, and fish disease rates, and decreasing spawner survival and success.

Limiting Factor and Potential Driver/Cause Data Requirements for Life Stage Transition: Potentially useful data to evaluate hypotheses and potential limiting factors for this life stage transition include the following:

1. Water temperatures and DO in the lower Klamath River and in holding habitats or other thermal refugia. This could be modeled (e.g., Klamath-Trinity RBM10 Water Temperature Model, NorWeST) and/or empirical data collected (e.g., stream gages or other water quality monitoring stations).
2. Presence or abundance of diseases (specifically *Ichthyopthirius multifilis* (ich) and the bacterial pathogen *Flavobacterium columnare* (columnaris)) in the lower Klamath River, or environmental parameters that represent their potential abundance or infection rates (e.g., water temperature above 69.8°F - see Belchik et al. 2004).
3. Holding habitat area (e.g., quality pool areas), holding habitat capacity, and spatial distribution information for the lower Klamath River.
4. River flow in the lower Klamath River. Modeled data can be useful for simulations and scenario/hypothesis testing, and empirical data from gages are useful for parameterization and calibration.
5. Predator abundances and predation rate data for adult Chinook Salmon in the lower Klamath River.
6. Harvest and fisheries data for Chinook Salmon in the lower Klamath River (e.g., harvest rates, landings, effort, etc., if applicable to Chinook Salmon).
7. Climate change simulations for the lower Klamath River – primarily water temperatures and flows (see models linked above).
8. Wildfire frequency, duration, intensity data, and sedimentation inputs or water quality linked to wildfires in the lower Klamath River.

Table 1. Potential limiting factors identified in Phase 1 associated with life stage transition T1, with working hypotheses for each limiting factor. Asterisks indicate limiting factors identified in the Trinity River Science Plan (Pickard et al. 2022).

Spatial Extent	Life Stage	Limiting Factor	Driver or Cause	Hypothesis
Klamath River	T1 Adult migration from the Klamath River to Trinity River	Habitat connectivity (thermal refugia & tributaries)	Driver	H_{T1a}. Lack of habitat connectivity reduces the ability for early return adults immigrating from the lower Klamath River to find thermal and predatory refugia and access tributaries for holding, resulting in decreased survival.
		Fish health*	Driver	H_{T1b}. Disease and stress in the lower Klamath River reduces survival of adults immigrating to the Trinity River.
		Pre-spawn mortality	Driver	H_{T1c}. Pre-spawn mortality in the lower Klamath River increases the number of non-successful spawners immigrating to the Trinity River.
		Predation* & Predator population	Driver & Cause	H_{T1d}. Predation by marine mammals within their range in the lower Klamath River, and bears and birds of prey on the Klamath and Trinity Rivers, reduce survival of adults immigrating to the Trinity River. These impacts increase as predator populations increase.
		Harvest* & Fisheries management*	Driver & Cause	H_{T1e}. In-river fisheries (direct or incidental take and handling-related mortality by humans) in the lower Klamath River reduce survival of adults immigrating to the Trinity River.
		Water withdrawal*, water quality & quantity*	Driver & Cause	H_{T1f}. Water withdrawal on the lower Klamath River influences flow regimes (water quality and quantity) that affect successful immigration and holding survival of early-run time adults to the Trinity River.
		Abundance	Cause	H_{T1g}. When adult Chinook natural origin and hatchery abundances are high, holding habitat can become limiting for early-run timed adults, and disease exposure can reduce survival of immigrating adults to the Trinity River.
		Climate (change, wet/dry year)*	Cause	H_{T1h}. Climate change causes a change in the frequency of water year types, which affects water quality and quantity, that will influence connectivity and capacity, leading to increased pre-spawn mortality.

Spatial Extent	Life Stage	Limiting Factor	Driver or Cause	Hypothesis
		Wildfire	Cause	H_{T1i}. Wildfire in the lower Klamath River basin results in altered sedimentation and organic inputs, poor water quality, and alterations in shading/temperatures, flow regime, and LWD recruitment, which reduced survival of immigrating adults to the Trinity River.

T2 Adult immigration, holding and spawning in Trinity River

Description of Life Stage Transition: This transition focuses on adults, including spring-run and fall-run Chinook salmon, that have entered the Trinity River and migrate upriver to spawning habitat, which may include holding behavior.

Demographic Data Requirements for Life Stage Transition: Potentially useful data for this transition include:

- Weir counts of adult immigration, ideally in the lower Trinity River and near spawning grounds.
- Hatchery and natural origin composition
- Spring- and fall-run composition
- Sex, age, and size
- Timing (e.g., weekly counts)
- Snorkel survey estimates of adults in holding areas
- Redd survey counts – direct count and aerial imagery
- Carcass surveys
- Carcass assessment of spawning success (e.g., pre-spawn mortality/egg retention)
- River escapement including estimates of adult fish use or final destination by river reach, and tributary
- Hatchery take - total adults.

Description of Potential Drivers and Causes linked to Life Stage Transition: Several potential limiting factors were identified in the Trinity River Science Plan (Pickard et al. 2022) and during Phase 1 of the Trinity River LFA. The Science Plan identified two potential limiting factors during the adult migration, holding, and spawning life stage in the Trinity River. These included poor spawning habitat and high water temperatures. Additional potential limiting factors identified for this life stage include increased Trinity River basin water withdrawal, which further influences water quality and quantity. Similarly, flow management can influence habitat connectivity and quantity, which are hypothesized to influence pre-spawn mortality and spawning capacity for the next transition (Sullivan and Hileman 2019; Baldock et al. 2023; Blankenship et al. 2024). Additionally, flow and temperature management on the Trinity River can alter adult migration timing, holding, and spawning success. Climate change is hypothesized to amplify the magnitude of habitat-related alterations with changes in the frequency and duration of flow regimes (wet/dry years) and water quantity and quality. Habitat connectivity can be limited by changes to flow, temperature, and wildfire which can limit fish ability to find thermal and predatory refugia, resulting in overabundance in limited space leading to increased fish disease and predation. Hatchery and fisheries management actions could also potentially influence adult immigration success and survival through direct and incidental take, hatchery fish influence and crowding of natural fish, and disease exposure. Finally, wildfire can impact habitat quantity and quality, which could reduce survival and increase pre-spawn mortality.

Limiting Factor and Potential Driver/Cause Data Requirements for Life Stage Transition:

Potentially useful data to evaluate hypotheses and potential limiting factors for this life stage transition include the following:

1. Holding habitat area (e.g., quality pool areas), holding habitat capacity, and spatial distribution information for the Trinity River.
2. Presence or abundance of diseases (specifically ich and the bacterial pathogen columnaris) in the Trinity River, or environmental parameters that represent their potential abundance or infection rates (e.g., water temperature above 69.8°F - see Belchik et al. 2004).
3. Pre-spawn mortality rates in the Trinity River from carcass surveys.
4. Predator abundances and predation rate data for adult Chinook Salmon in the Trinity River.
5. Harvest and fisheries data for Chinook Salmon in the Trinity River (e.g., harvest rates, landings, effort, etc., if applicable to Chinook Salmon).
6. Water temperatures and DO in the Trinity River, and in holding habitats or other thermal refugia. This could be modeled (e.g., Klamath-Trinity RBM10 Water Temperature Model, NorWeST) and/or empirical data collected (e.g., stream gages or other water quality monitoring stations).
7. River flow in the Trinity River. Modeled data can be useful for simulations and scenario/hypothesis testing, and empirical data from gages are useful for parameterization and calibration.
8. Climate change simulations for the Trinity River – primarily water temperatures and flows (see models linked above).
9. Wildfire frequency, duration, intensity data, and sedimentation inputs or water quality linked to wildfires in the Trinity River.

Table 2. Potential limiting factors identified in Phase 1 associated with life stage transition T2, with working hypotheses for each limiting factor. Asterisks indicate limiting factors identified in the Trinity River Science Plan (Pickard et al. 2022).

Spatial Extent	Life Stage	Limiting Factor	Driver or Cause	Hypothesis
Trinity River	T2 Adult migration and holding in Trinity River to spawning in Trinity River	Habitat connectivity (thermal refugia & tributaries)	Driver	H_{T2a}. Lack of habitat connectivity reduces the ability for early return adults immigrating in the Trinity River to find thermal refugia and access tributaries for holding, resulting in decreased survival.
		Fish health*	Driver	H_{T2b}. Disease and stress in the Trinity River reduce survival of adults immigrating to the Trinity River.
		Pre-spawn mortality	Driver	H_{T2c}. Pre-spawn mortality in the Trinity River increases the number of non-successful spawners immigrating to the Trinity River.
		Predation* & Predator population	Driver & Cause	H_{T2d}. Predation by bears and birds of prey on the Trinity River reduces survival of adults immigrating to the Trinity River. These impacts increase as predator populations increase.
		Harvest & Fisheries Management	Driver & Cause	H_{T2e}. In-river fisheries (direct or incidental take and handling-related mortality by humans) in the Trinity River reduce survival of adults immigrating to, and holding in, the Trinity River.
		Water Withdrawal* & water quality and quantity*	Driver & Cause	H_{T2f}. Water withdrawal on the Trinity River influences flow regimes (water quality and quantity) that affect survival and successful immigration of early-run time adults to the Trinity River.
		Flow management	Cause	H_{T2g}. Flow management agreements and decisions can alter adult migration periods, holding, and spawning success in the Trinity River.
		Temperature management	Cause	H_{T2h}. Temperature management agreements and decisions can alter adult migration periods, holding, and spawning success in the Trinity River.
		Abundance (and hatchery management)*	Cause	H_{T2i}. When adult Chinook Salmon natural origin and hatchery abundances are high, holding habitat can become limiting for early-run timed adults and disease exposure can reduce survival of immigrating and holding adults in the Trinity River.

Spatial Extent	Life Stage	Limiting Factor	Driver or Cause	Hypothesis
		Climate (change, wet/dry year)*	Cause	H_{T2j}. Climate change causes a change in the frequency of water year types, which affects water quality and quantity, that will influence connectivity and capacity, leading to increased pre-spawn mortality.
		Wildfire/ Debris flow	Cause	H_{T2k}. Wildfire in the Trinity River basin results in altered sedimentation and organic inputs, poor water quality, and alterations in shading/temperatures, flow regime, and LWD recruitment, which reduce survival of immigrating adults to the Trinity River.

T3 Adult spawning in Trinity River to incubation

Description of Life Stage Transition: Focused on adult spawning and deposition of eggs in redds, which starts their incubation life stage.

Demographic Data Requirements for Life Stage Transition: Potentially useful data for this transition include:

- Redd surveys - estimate of total river and river reach redd counts or estimated spawning area from HSI or other methods
- Contribution of hatchery and natural origin spawners
- Contribution of spring- and fall-run spawners
- Pre-spawn mortality including stress, disease, predation and angling
- Carcass egg retention - population estimate
- Fecundity by age or size class

Description of Potential Drivers and Causes linked to Life Stage Transition: The same potential limiting factors outlined in the Trinity River Science Plan (Pickard et al. 2022) for stages T1 and T2 apply to T3 but are focused on adult spawning to incubation in the Trinity River (Table 3). Water withdrawals are hypothesized to affect water quantity and quality, which would likely decrease the availability of adequate spawning and incubation habitat (Duffin et al. 2023). Increased temperatures and decreased flows are also hypothesized to increase pre-spawn mortality. Climate change is expected to amplify the magnitude of these effects. Effects of hatchery operations (through abundance of hatchery-origin spawners), predation, and wildfire are all expected to influence the availability of and access to quality habitat, fish disease exposure and rates, and ultimately, spawning success.

Limiting Factor and Potential Driver/Cause Data Requirements for Life Stage Transition:

1. Holding habitat area (e.g., quality pool areas), holding habitat capacity, and spatial distribution information for the Trinity River.
2. Pre-spawn mortality rates in the Trinity River from carcass surveys.
3. Predator abundances and predation rate data for adult Chinook Salmon in the Trinity River.
4. Water temperatures and DO in the Trinity River and in holding habitats or other thermal refugia. This could be modeled (e.g., Klamath-Trinity RBM10 Water Temperature Model, NorWeST) and/or empirical data collected (e.g., stream gages or other water quality monitoring stations).
5. Harvest and fisheries data for Chinook Salmon in the Trinity River (e.g., harvest rates, landings, effort, etc., if applicable to Chinook Salmon).
6. River flow in the Trinity River. Modeled data can be useful for simulations and scenario/hypothesis testing, and empirical data from gages are useful for parameterization and calibration.
7. Climate change simulations for the Trinity River – primarily water temperatures and flows (see models linked above).
8. Wildfire frequency, duration, intensity data, and sedimentation inputs or water quality linked to wildfires in the Trinity River.

Table 3. Potential limiting factors identified in Phase 1 associated with life stage transition T3, with working hypotheses for each limiting factor. Asterisks indicate limiting factors identified in the Trinity River Science Plan (Pickard et al. 2022).

Spatial Extent	Life Stage	Limiting Factor	Driver or Cause	Hypothesis
Trinity River	T3 Adult spawning in Trinity River to incubation	Habitat connectivity (thermal refugia & tributaries)	Driver	H_{T3a}. Lack of habitat connectivity reduces the ability for early return adults immigrating to the Trinity River to find thermal refugia and access tributaries for holding, resulting in decreased spawning success.
		Pre-spawn mortality	Driver	H_{T3b}. Pre-spawn mortality reduces the number of spawners immigrating, holding, and successfully spawning in the Trinity River.
		Predation* & Predator population	Driver & Cause	H_{T3c}. Predation by large mammals and birds of prey on the Trinity River reduces spawning success in the Trinity River. These impacts increase as predator populations increase.

Spatial Extent	Life Stage	Limiting Factor	Driver or Cause	Hypothesis
		Water withdrawal*, water quality & quantity*	Driver & Cause	H_{T3d}. Water withdrawal on the Trinity River influences flow regimes (water quality - such as temperature, dissolved oxygen and suspended sediment - and quantity) that affect spawning success in the Trinity River.
		Abundance (and hatchery management)*	Cause	H_{T3e}. When adult Chinook Salmon natural origin and hatchery abundances are high, limited spawning area and increased redd superimposition reduce spawning success in the Trinity River.
		Temperature management	Cause	H_{T3f}. Alterations to temperature management decisions in the Trinity River due to climate change affect water quantity and quality and alter spawning success in the Trinity River.
		Flow management	Cause	H_{T3g}. Alterations to flow management decisions in the Trinity River due to climate change affect water quantity and alter spawning success in the Trinity River.
		Climate (change, wet/dry year)*	Cause	H_{T3h}. Climate change causes a change in the frequency of water year types, which affects water quality and quantity, that will influence connectivity and capacity, leading to decreased spawning success.
		Wildfire/ Debris flow	Cause	H_{T3i}. Wildfire in the Trinity River basin results in altered sedimentation and organic inputs, poor water quality, and alterations in shading/temperatures, flow regime, and LWD recruitment, which reduce survival of immigrating adults to the Trinity River.

T4 Incubation to emergent fry in Trinity River

Description of Life Stage Transition: Eggs deposited in redds through incubation and emergence to emergent fry.

Demographic Data Requirements for Life Stage Transition: Potentially useful data for this transition include:

- Emergent traps, rotary screw trap (RST) or other calibrated fry traps just below major spawning grounds (McMichael et al. 2005)
- PopGen (tissue taken from post-spawned females and fry) (see Blankenship et al. 2024)

Description of Potential Drivers and Causes linked to Life Stage Transition: Although the Trinity River Science Plan (Pickard et al. 2022) did not explicitly identify potential limiting factors for incubation to emergent fry, factors identified for juveniles and spawning are relevant to this life stage (Table 4). Fluctuations in flow, temperature, and the bed sediment regime would likely affect intergravel velocity, water quality, and emergence, influencing embryo incubation and emergent fry survival. Reduced spawning habitat quantity and quality from wildfire, climate change, flow regulation, and sediment management could decrease spawning success through pre-spawn mortality, spawner overabundance, redd superimposition, and subsequent incubation and emergence failure (David et al. 2018; Chen and Chang 2023). Redd superimposition could also decrease incubation and emergence success through egg dislodgement (Blankenship et al. 2024). Ocean diet alterations are hypothesized to result in thiamine deficiency, which decreases survival to emergent fry (Harder et al. 2018; Mantua et al. 2021; Suffridge et al. 2024).

Limiting Factor and Potential Driver/Cause Data Requirements for Life Stage Transition:

1. Spawning habitat quantity (area) and quality (e.g., substrate matrix), spawning habitat capacity, and spatial distribution information for the Trinity River.
2. Intergravel flow and DO in spawning riffles in the Trinity River.
3. Predator abundances and predation rate data for incubating embryos and alevins and pre-emerging fry in the Trinity River.
4. Spawner abundances and timing data for adult Chinook Salmon in the Trinity River.
5. Redd superimposition rates in the Trinity River either through direct observation or aerial imagery.
6. Rates of thiamine deficiency in returning adults, incubating embryos and alevins, or emergent fry in the Trinity River.
7. Climate change simulations for the Trinity River – primarily water temperatures and flows (see models linked above).
8. Wildfire frequency, duration, intensity data, and sedimentation inputs or water quality linked to wildfires in the Trinity River.
9. Water temperatures and DO in the Trinity River and in spawning/incubation habitats. This could be modeled (e.g., Klamath-Trinity RBM10 Water Temperature Model, NorWeST) and/or empirical data collected (e.g., stream gages or other water quality monitoring stations).
10. River flow in the Trinity River, including peak flows and scour rates. Modeled data can be useful for simulations and scenario/hypothesis testing, and empirical data from gages are useful for parameterization and calibration.
11. Mean gravel size (particularly in spawning areas), gravel augmentation dates and loads, sheer stress data, fine sedimentation infiltration rates, etc., in the Trinity River.

Table 4. Potential limiting factors identified in Phase 1 associated with life stage transition T4, with working hypotheses for each limiting factor. Asterisks indicate limiting factors identified in the Trinity River Science Plan (Pickard et al. 2022).

Spatial Extent	Life Stage	Limiting Factor	Driver or Cause	Hypothesis
Trinity River	T4 Incubation to emergent fry in Trinity River	Habitat quality (spawning)	Driver	H_{T4a}. Declines in spawning habitat quality, such as increased temperatures and fine sediment, reduce the number of eggs incubating and emerging in the Trinity River.
		Intergravel flow and water quality	Driver	H_{T4b}. Reduced intergravel flow and water quality in the Trinity River decrease rates of incubating eggs surviving to emergent fry in the Trinity River.
		Predation* & Predator population	Driver & Cause	H_{T4c}. Predation on eggs and fry by fish and birds in the Trinity River reduces the rate of incubating eggs surviving to emergent fry in the Trinity River. Increases in redd superimposition led to increases in egg dislodgement and increased predation. These impacts increase as predator populations increase.
		Redd superimposition (habitat quantity, distribution, spawner abundance/timing) & Abundance	Driver & Cause	H_{T4d}. When adult Chinook Salmon natural origin and hatchery abundances are high, limited spawning area and redd superimposition reduce the rate of incubating eggs surviving to emergent fry in the Trinity River.
		Thiamine deficiency & ocean diet	Driver & Cause	H_{T4e}. Alterations in adult Chinook Salmon ocean diet result in thiamine deficiency, decreasing survival of emergent fry in the Trinity River.
		Climate (change, wet/dry year)*	Cause	H_{T4f}. Climate change causes a change in the frequency of water year types, which would alter flows leading to either exposed redds (drought year) or scoured redds (wet year), and changes in water quality, leading to a decreased rate of incubating eggs surviving to emergent fry in the Trinity River.

Spatial Extent	Life Stage	Limiting Factor	Driver or Cause	Hypothesis
		Wildfire/ Debris flow	Cause	H_{T4g}. Wildfire in the Trinity River basin results in altered sedimentation and organic inputs, poor water quality, and alterations in shading/temperatures, and flow regime which reduce the rate of incubating eggs surviving to emergent fry in the Trinity River.
		Flow management	Cause	H_{T4h}. Alterations to flow management decisions in the Trinity River due to climate change affect water quantity and alter egg incubation timing and success in emergence as fry in the Trinity River.
		Temperature management	Cause	H_{T4i}. Alterations to temperature management agreements and decisions in the Trinity River due to climate change affect water quantity and alter egg incubation timing and success in emergence as fry in the Trinity River.
		Sediment management	Cause	H_{T4j}. Sediment management agreements and decisions in the Trinity River can reduce spawning habitat quality which alters egg incubation timing and success in emergence as fry in the Trinity River.

T5 Emergent fry to rearing in Trinity River

Description of Life Stage Transition: Fry that have emerged from redds to initial rearing in the Trinity River, which may vary in duration depending on the life history trajectory.

Demographic Data Requirements for Life Stage Transition: Potentially useful data for this transition include:

- RST calibrated to estimate newly emergent fry as they transition from spawning reaches to peripheral edge habitat where early rearing occurs (Volkhardt et al. 2007)
- Beach seining

Description of Potential Drivers and Causes linked to Life Stage Transition: The Trinity River Science Plan (Pickard et al. 2022) identified two potential limiting factors for rearing juveniles – physical habitat availability and habitat quality (i.e., water temperature and flow) that apply to the T5 transition. For juveniles emerging and rearing in the Trinity River, flow and temperature management changes may lead to alterations in channel form and water quality which may impact habitat quality and connectivity. Specifically, flow and temperature management can impact growth, development, condition and rearing, disease prevalence (Bjork and Bartholomew 2009), and outmigration timing (Zeug et al. 2014). This could limit refugia and tributary access which could reduce access to areas with cooler temperatures, more food, less competition, and protection from predators. The presence of hatchery juveniles (released or progeny of naturally spawning hatchery fish) could increase competition for food and limit the quantity of quality habitat which could lead to increased predation and decreased rearing success and survival (Collis et al. 2007; Naman and Sharpe 2012; Kuruvilla et al. 2024). Factors such as climate change and wildfire influence water quality, flow regimes, and habitat availability (Harder et al. 2018; Chen and Chang 2023; Suffridge et al. 2024).

Limiting Factor and Potential Driver/Cause Data Requirements for Life Stage Transition:

1. Rearing habitat area (e.g., quality off-channel areas), rearing habitat capacity, habitat connectivity, and spatial distribution information for the Trinity River.
2. Water temperatures and DO in the Trinity River, and in spawning/incubation habitats. This could be modeled (e.g., Klamath-Trinity RBM10 Water Temperature Model, NorWeST) and/or empirical data collection (e.g., stream gages or other water quality monitoring stations).
3. Presence or abundance of diseases (specifically *Ceratomyxa shasta* and *Parvicapsula minibicornis;* Voss et al. 2018) in the Trinity River, or environmental parameters that represent their potential abundance or infection rates (e.g., such as water discharge rates - see Bjork and Bartholomew 2009).
4. Macroinvertebrate abundances and productivity indices in the Trinity River.
5. Predator abundances and predation rate data for fry Chinook Salmon in the Trinity River.
6. Abundance and fisheries data for Chinook Salmon in the Trinity River (e.g., hatchery release rates, rearing abundances, etc.).
7. Climate change simulations for the Trinity River – primarily water temperatures and flows (see models linked above).
8. Wildfire frequency, duration, intensity data, and sedimentation inputs or water quality linked to wildfires in the Trinity River.
9. River flow in the Trinity River. Modeled data can be useful for simulations and scenario/hypothesis testing, and empirical data from gages are useful for parameterization and calibration.

Table 5. Potential limiting factors identified in Phase 1 associated with life stage transition T5, with working hypotheses for each limiting factor. Asterisks indicate limiting factors identified in the Trinity River Science Plan (Pickard et al. 2022).

Spatial Extent	Life Stage	Limiting Factor	Driver or Cause	Hypothesis
Trinity River	T5 Emergent fry to rearing in Trinity River	Habitat connectivity (thermal refugia & tributaries)	Driver	H_{T5a}. Lack of habitat connectivity reduces the ability for emergent and rearing fry in the Trinity River to find thermal and predator refugia and access territories for feeding, resulting in decreased survival.
		Water quality*	Driver	H_{T5b}. Poor water quality on the Trinity River reduces survival of emergent and rearing fry in the Trinity River.
		Fish health*	Driver	H_{T5c}. Disease and stress in the Trinity River reduces survival of emergent and rearing fry in the Trinity River.
		Foodscape (drift forage)*	Driver	H_{T5d}. Decreased drift forage reduces survival and growth of emergent and rearing fry in the Trinity River.
		Predation* & Predator population	Driver & Cause	H_{T5e}. Predation by fish and birds in the Trinity River reduces rearing success and survival of rearing fry in the Trinity River. These impacts increase as predator populations increase.
		Habitat quantity & quality (depth, velocity, cover); Channel form	Driver & Cause	H_{T5f}. Decreased habitat quality and quantity, including changes to channel form, in the Trinity River reduce survival of emergent and rearing fry in the Trinity River.
		Temperature (temporal & spatial variability) & Temperature management	Driver & Cause	H_{T5g}. Temperature management agreements and decisions affect spatial and temporal variability in temperature in the Trinity River which can alter life history expression, growth, and survival of fry rearing in the Trinity River.
		Competition, abundance, & hatchery management	Driver & Cause	H_{T5h}. When natural origin and hatchery rearing fry abundances are high, limited territory and increased competition reduce rearing success and survival in the Trinity River.

Spatial Extent	Life Stage	Limiting Factor	Driver or Cause	Hypothesis
		Climate (change, wet/dry year)*	Cause	HT5i. Climate change causes a change in the frequency of water year types, which affects water quality and quantity, that will influence connectivity and capacity, leading to decreased rearing survival.
		Wildfire/ Debris flow	Cause	HT5j. Wildfire in the Trinity River basin results in altered sedimentation and organic inputs, poor water quality, and alterations in shading/temperatures, flow regime, and LWD recruitment which reduces survival of rearing fry in the Trinity River.
		Flow management	Cause	HT5k. Flow management agreements and decisions in the Trinity River can alter the timing, expression, and success of life histories of fry in the Trinity River.

T6 Trinity rearing to emigration from the Trinity River to Klamath River

Description of Life Stage Transition: Juveniles rearing in the Trinity River through their emigration from the Trinity into the Klamath River. This may include multiple life history pathways with varying durations of rearing within the Trinity River (see life history pathways A, B, and C in **Error! Reference source not found.**).

Demographic Data Requirements for Life Stage Transition: Potentially useful data for this transition include:

- RST or smolt traps in the lowest reach calibrated to estimate juveniles leaving the Trinity River (Volkhardt et al. 2007)
- DNA, CWT, otoliths etc. to determine sampling origin (Blakenship et al. 2024; Willmes et al. 2024)
- Subsampling juveniles for PopGen comparison to females off spawning grounds (Blakenship et al. 2024)
- Rearing capacity estimates by river reach

Description of Potential Drivers and Causes linked to Life Stage Transition: The Trinity River Science Plan (Pickard et al. 2022) identified several potentially limiting factors for rearing juveniles – physical habitat availability, habitat quality (water temperature and flow), and high outmigration temperatures (Table 6). Reductions in suitable habitat would be hypothesized to reduce rearing success and increase mortality by limiting access to refugia and food, potentially also increasing competition and predation (Honea et al. 2009). Hatchery management can also potentially influence rearing capacity by oversaturating limited habitat, increasing competition, predation, and altering migration patterns (Collis et al. 2007; Naman and Sharpe 2012; Kuruvilla et al. 2024). Flow and temperature management modifications, as well as water withdrawal, may influence rearing capacity, success, growth, and survival by influencing access to food and refugia, altering growth rates and disease prevalence, and altering timing and expression of life histories (Bjork and Bartholomew 2009; Buxton and Bradley 2022; Cooper-Hertel et al. 2022). Climate change may influence temperature, flow, and wildfire which could limit habitat quantity and quality, water quantity and quality, and ultimately survival to outmigration from the Trinity River (Siegel and Crozier 2018).

Limiting Factor and Potential Driver/Cause Data Requirements for Life Stage Transition:

1. Rearing habitat area (e.g., quality off-channel areas), rearing habitat capacity, and spatial distribution information for the Trinity River; habitat connectivity to the lower Klamath River.
2. Macroinvertebrate abundances and productivity indices in the Trinity River.
3. Presence or abundance of diseases (specifically *Ceratomyxa shasta* and *Parvicapsula minibicornis;* Voss et al. 2018) in the Trinity River, or environmental parameters that represent their potential abundance or infection rates (e.g., such as water discharge rates - see Bjork and Bartholomew 2009).
4. Predator abundances and predation rate data for juvenile Chinook Salmon in the Trinity River.
5. Water temperatures and DO in the Trinity River, and in rearing habitats. This could be modeled (e.g., Klamath-Trinity RBM10 Water Temperature Model, NorWeST) and/or empirical data collection (e.g., stream gages or other water quality monitoring stations).
6. Abundance and fisheries data for Chinook Salmon in the Trinity River (e.g., hatchery release rates, rearing abundances, etc.).
7. River flow in the Trinity River. Modeled data can be useful for simulations and scenario/hypothesis testing, and empirical data from gages are useful for parameterization and calibration.
8. Climate change simulations for the Trinity River – primarily water temperatures and flows (see models linked above).
9. Wildfire frequency, duration, intensity data, and sedimentation inputs or water quality linked to wildfires in the Trinity River.

Table 6. Potential limiting factors identified in Phase 1 associated with life stage transition T6, with working hypotheses for each limiting factor. Asterisks indicate limiting factors identified in the Trinity River Science Plan (Pickard et al. 2022).

Spatial Extent	Life Stage	Limiting Factor	Driver or Cause	Hypothesis
Trinity River	T6 Trinity rearing to emigration from the Trinity River to Klamath River – inclusive of three primary life history variations (A, B, and C)	Habitat connectivity (thermal refugia & tributaries)	Driver	H_{T6a}. Lack of habitat connectivity reduces the ability for rearing fry in the Trinity River to find thermal and predator refugia, find rearing habitat, and access migratory corridors for out-migration to the Klamath River, resulting in decreased survival and rearing capacity, and influence life history expression.
		Foodscape (drift forage)*	Driver	H_{T6b}. Decreased drift forage in the Trinity River influences survival and growth, life history expression, rearing duration, and emigration timing of fry out-migrating to the Klamath River.
		Fish health*	Driver	H_{T6c}. Disease and stress in the Trinity River reduces survival of juveniles rearing in the Trinity River and emigrating to the Klamath River.
		Predation* & Predator population	Driver & Cause	H_{T6d}. Predation by fish and birds in the Trinity River reduces rearing success and survival of fry out-migrating to the Klamath River. These impacts increase as predator populations increase.
		Water withdrawal* & water quality and quantity*	Driver & Cause	H_{T6e}. Water withdrawal on the Trinity River influences flow regimes (water quality and quantity) that affect rearing capacity and success and survival of fry out-migrating to the Klamath River.
		Habitat quantity & quality (depth, velocity, cover); channel form	Driver & Cause	H_{T6f}. Decreased habitat quantity and quality in the Trinity River will decrease rearing capacity and influence the timing and expression of life histories, and survival of juveniles emigrating to the Klamath River.
		Competition, abundance, & hatchery management*	Driver & Cause	H_{T6g}. When natural origin and hatchery rearing fry abundances are high in the Trinity River, limited territory and increased competition reduces rearing capacity and success and survival of fry out-migrating to the Klamath River.
		Temperature (temporal & spatial variability) & Temperature management	Driver & Cause	H_{T6h}. Temperature management decisions affect spatial and temporal variability in temperature in the Trinity River which can alter emigration timing, life history expression, and growth and survival of fry out-migrating to the Klamath River.

Spatial Extent	Life Stage	Limiting Factor	Driver or Cause	Hypothesis
		Flow management	Cause	H_{T6i}. Flow management agreements and decisions in the Trinity River can reduce rearing capacity and success, migration timing, and survival of fry out-migrating to the Klamath River.
		Climate (change, wet/dry year)*	Cause	H_{T6j}. Climate change causes a change in the frequency of water year types, which affect water quality and quantity, that will influence connectivity, capacity, rearing success and survival of fry out-migrating from the Trinity River to the Klamath River.
		Wildfire/ Debris flow	Cause	H_{T6k}. Wildfire in the Trinity River basin results in altered sedimentation and organic inputs, poor water quality, and alterations in shading/temperatures, flow regime, and LWD recruitment which reduces rearing capacity and success and survival of fry out-migrating to the Klamath River.

T7 Klamath River rearing and emigration to Klamath River estuary

Description of Life Stage Transition: Juvenile Trinity River Chinook salmon that have entered the Klamath River, either for rearing or ocean emigration, through entry into the Klamath River estuary. This transition may include non-natal tributary rearing and is inclusive of all three primary life history pathways (see life history pathways A, B, and C in Figure 1).

Demographic Data Requirements for Life Stage Transition: Potentially useful data for this transition include:

- Calibrated smolt/fry trap as close to estuary as possible
- Calibrated trawl in estuary; use DNA, CWT, otoliths etc. to determine sampling origin (Blakenship et al. 2024; Willmes et al. 2024)
- Systematic beach seine and/or fyke trapping program with DNA, CWT, or otolith sampling to determine origin (Blakenship et al. 2024; Willmes et al. 2024)

Description of Potential Drivers and Causes linked to Life Stage Transition: The Trinity River Science Plan (Pickard et al. 2022) identified some potentially limiting factors for rearing juveniles that could affect life stages T4 and T5, which could also apply to this life stage transition. Additionally, the Science Plan outlines high juvenile outmigration temperatures as a potential limiting factor, similar to life stage T6 (Table 7). Large scale influences such as climate change and wildfire may impact temperature variability (temporal and spatial), periodicity, and decisions surrounding water withdrawal and temperature and flow management which could influence disease prevalence (Bjork and Bartholomew 2009) and habitat quantity, quality, and connectivity. Habitat scale influences are hypothesized to affect changes to the foodscape which would drive alterations to growth and smoltification rates, predator populations, and abundances (Garzke, et al. 2023; Kiffney, et al. 2025). Predator population size and hatchery management could affect competition, growth, and survival of juveniles, and smoltification rates (Collis et al. 2007; Naman and Sharpe 2012; Kuruvilla et al. 2024). We note that it is unclear as to the extent that Trinity River origin Chinook Salmon rear in the lower Klamath River, and S3 modeling results seem to suggest that Trinity River origin Chinook Salmon do not spend much time rearing in the lower Klamath River (Russell Perry 2024, presented at the AFS Annual Meeting in the session titled ‘Dam Removal and Ecological Transformation on the Klamath River’). This could be an artifact of poor rearing conditions and suggest that improved rearing conditions in the lower Klamath River would influence rearing (Sullivan and Hileman 2019). In addition, changes in system dynamics with removal of the Klamath River dams could change rearing and outmigration patterns for Trinity River Chinook Salmon as they emigrate through the lower Klamath River (Pess et al. 2024).

Limiting Factor and Potential Driver/Cause Data Requirements for Life Stage Transition:

1. Rearing habitat area (e.g., quality off-channel areas), rearing habitat capacity, habitat connectivity, and spatial distribution information for the lower Klamath River.
2. Macroinvertebrate abundances and productivity indices in the lower Klamath River.
3. Presence or abundance of diseases (specifically *Ceratomyxa shasta* and *Parvicapsula minibicornis;* Voss et al. 2018) in the Klamath River and Klamath River estuary, or environmental parameters that represent their potential abundance or infection rates (e.g., such as water discharge rates - see Bjork and Bartholomew 2009).
4. Smoltification rates (trap and catch data, etc.) of juveniles emigrating to the Klamath River estuary.
5. Water temperatures and DO in the lower Klamath River, in rearing habitats, and in emigration throughways. This could be modeled (e.g., Klamath-Trinity RBM10 Water Temperature Model, NorWeST) and/or empirical data collection (e.g., stream gages or other water quality monitoring stations).
6. Abundance and fisheries data for Chinook Salmon in the lower Klamath River (e.g., hatchery release rates, rearing abundances, etc.).
7. Predator abundances and predation rate data for juvenile Chinook Salmon in the lower Klamath River.
8. River flow in the lower Klamath River. Modeled data can be useful for simulations and scenario/hypothesis testing, and empirical data from gages are useful for parameterization and calibration.
9. Climate change simulations for the lower Klamath River – primarily water temperatures and flows (see models linked above).

10. Wildfire frequency, duration, intensity data and sedimentation inputs or water quality linked to wildfires in the lower Klamath River.

Table 7. Potential limiting factors identified in Phase 1 associated with life stage transition T7, with working hypotheses for each limiting factor. Asterisks indicate limiting factors identified in the Trinity River Science Plan (Pickard et al. 2022).

Spatial Extent	Life Stage	Limiting Factor	Driver or Cause	Hypothesis
Klamath River	T7 Klamath River rearing and emigration to Klamath River estuary. Inclusive of three primary life history variations (A, B, and C).	Habitat connectivity (thermal refugia & tributaries)	Driver	H_{T7a}. Lack of habitat connectivity reduces the ability for rearing fry in the Klamath River to find thermal and predator refugia, reduces rearing capacity, and limits access to migratory corridors for out-migration to the Klamath River estuary, resulting in decreased survival.
		Habitat quantity & quality (depth, velocity, cover)	Driver	H_{T7b}. Decreased habitat quantity and quality in the Klamath River will influence the timing and expression of life histories, rearing capacity, and survival of juveniles emigrating to the Klamath River estuary.
		Foodscape	Driver	H_{T7c}. Decreases in foodscape in the Klamath River reduce growth rates and rearing success and survival of fry emigrating to the Klamath River estuary.
		Fish heath*	Driver	H_{T7d}. Disease and stress in the Klamath River reduces survival of juveniles rearing in the Klamath River and emigrating to the Klamath River estuary.
		Temperature (temporal & spatial variability)	Driver	H_{T7e}. Increased variability in temporal and spatial temperature regimes in the Klamath River results in reduced survival of fry rearing in the Klamath River and emigrating to the Klamath River estuary.
		Smoltification	Driver	H_{T7f}. Habitat quality and quantity, and water quantity and quality influence smoltification rates and success, which influences survival and transition to the marine life stages.
		Water withdrawal*, water quality & quantity*	Driver & Cause	H_{T7g}. Water withdrawal on the Klamath River and its tributaries influences flow regimes (water quality and quantity) that affect rearing success and survival of fry emigrating to the Klamath River estuary.

Spatial Extent	Life Stage	Limiting Factor	Driver or Cause	Hypothesis
		Abundance, & hatchery management*	Driver & Cause	H_{T7h}. When wild origin and hatchery rearing and emigrating fry abundances are high in the Klamath River, limited territory and increased competition reduces rearing capacity and success and survival of fry emigrating to the Klamath River estuary.
		Temperature management	Cause	H_{T7i}. Temperature management decisions prior to dam removal in the Klamath River may have reduced rearing success and survival of fry emigrating to the Klamath River estuary. These effects should be considered null for periods following dam removal.
		Predator population	Cause	H_{T7j}. Predation by fish and birds in the Klamath River reduces rearing success and survival of fry emigrating to the Klamath River estuary. These impacts increase as predator populations increase.
		Flow management	Cause	H_{T7k}. Flow management decisions in the Klamath and Trinity Rivers can reduce rearing capacity and success and survival of fry emigrating to the Klamath River estuary.
		Climate (change, wet/dry year)*	Cause	H_{T7l}. Climate change causes a change in the frequency of water year types, which affect water quality and quantity, that will influence connectivity, capacity, rearing success, and survival of fry emigrating to the Klamath River estuary.
		Wildfire/ Debris flow	Cause	H_{T7m}. Wildfire in the Klamath River basin results in altered sedimentation and organic inputs, poor water quality, and alterations in shading/temperatures, flow regime, and LWD recruitment which reduces rearing success and survival of fry emigrating to the Klamath River estuary.
		Periodicity	Cause	H_{T7n}. The timing of entry into the Klamath River and timing of outmigration to the Klamath River estuary can be affected by climate change, alterations in flow regimes, and ocean and in-stream temperatures. These changes in periodicity can influence rearing and outmigration success.

T8 Klamath River estuary rearing and emigration to nearshore

Description of Life Stage Transition: Entry into the Klamath River estuary and emigration to nearshore habitats, which may include extended rearing in estuary and transitional habitats or primarily emigrating through the estuary with little to no rearing in the estuary.

Demographic Data Requirements for Life Stage Transition: Potentially useful data for this transition include:

- Use methods from Dan Bottom manuscript on Coos Bay Salmon River; NOAA Sci Center trawl surveys might also work (Bottom et al. 2005)
- Paired with DNA, CWT, and otolith to determine origin (Blakenship et al. 2024; Willmes et al. 2024)

Description of Potential Drivers and Causes linked to Life Stage Transition: The Trinity River Science Plan (Pickard et al. 2022) identified potential limiting factors for juveniles in T4 - T7 that apply to this life stage transition as well. Climate change, flow regulation, water withdrawals, and water quantity, which are interrelated, have the potential to drive changes in habitat connectivity by way of lagoon formation, and limiting access to thermal and predatory refugia, as well as saltwater acclimation (Wallace and Collins 1997). It also has the potential for driving alterations in temperature variability (temporal and spatial) that may influence disease prevalence, rearing duration, timing, and survival, as well as smoltification rates and success (Bjork and Bartholomew 2009; Buxton and Bradley 2022; Cooper-Hertel et al. 2022; Smith et al. 2024). This could influence survival and transition to marine life stages (T9 and T10). Hatchery management practices may increase abundances in limited spaces and alterations to the foodscape may lead to increases in competition. Predation by marine mammals, birds, and fish may increase as refuge habitat decreases; these effects may be amplified as predator populations increase or with hatchery release strategies altering the behavior of predators and natural salmon (Lawrence et al. 2011; Crozier et al. 2021; Beamer et al. 2024).

Limiting Factor and Potential Driver/Cause Data Requirements for Life Stage Transition:

1. Rearing habitat area (e.g., quality off-channel areas), rearing habitat capacity, habitat connectivity (including lagoon formation), and spatial distribution information for the Klamath River estuary.
2. Water temperatures and DO in the lower Klamath River estuary, in rearing habitats, and in emigration throughways. This could be modeled (e.g., Klamath-Trinity RBM10 Water Temperature Model, NorWeST) and/or empirical data collection (e.g., stream gages or other water quality monitoring stations).
3. Macroinvertebrate abundances and productivity indices in the Klamath River estuary.
4. Presence or abundance of diseases (specifically *Ceratomyxa shasta* and *Parvicapsula minibicornis;* Voss et al. 2018) in the Klamath River and Klamath River estuary, or environmental parameters that represent their potential abundance or infection rates (e.g., such as water discharge rates - see Bjork and Bartholomew 2009).
5. Smoltification rates (trap and catch data, etc.).
6. Predator abundances and predation rate data for juvenile Chinook Salmon in the Klamath River estuary.

7. Abundance and fisheries data for Chinook Salmon in the Klamath River estuary (e.g., hatchery release rates, rearing abundances, etc.).
8. Climate change simulations for the Klamath River estuary – primarily water temperatures and flows (see models linked above).

Table 8. Potential limiting factors identified in Phase 1 associated with life stage transition T8, with working hypotheses for each limiting factor. Asterisks indicate limiting factors identified in the Trinity River Science Plan (Pickard et al. 2022).

Spatial Extent	Life Stage	Limiting Factor	Driver or Cause	Hypothesis
Trinity River	T8 Klamath River estuary rearing and emigration to nearshore. Inclusive of three primary life history variations (A, B, and C).	Habitat connectivity (lagoon formation, thermal refugia/barriers)	Driver	H_{T8a}. Lack of habitat connectivity, such as lagoon formation or limited access to tidal floodplain and tidal channel habitats, reduces the ability for rearing juveniles in the Klamath River estuary to find thermal refugia, avoid thermal barriers, and emigrate to nearshore, influencing rearing capacity and survival.
		Temperature (temporal & spatial variability)	Driver	H_{T8b}. Increased variability in temporal and spatial temperature regimes in the Klamath River estuary results in reduced rearing duration, rearing timing, and survival of juveniles in the estuary emigrating to nearshore habitat.
		Foodscape	Driver	H_{T8c}. Decreases in foodscape in the Klamath River estuary reduce growth rates and survival of juveniles emigrating to nearshore habitat.
		Fish health*	Driver	H_{T8d}. Disease and stress in the Klamath River reduces survival of juveniles rearing in the Klamath River and emigrating to the Klamath River estuary.
		Smoltification & saltwater	Driver	H_{T8e}. Habitat quality and quantity, and water quantity and quality influence smoltification rates and success, which influences survival and transition to the marine life stages.
		Predation* & Predator population	Driver & Cause	H_{T8f}. Predation by marine mammals, birds, and fish in the lower Klamath River estuary increases as refuge habitat becomes limited and reduces survival of juveniles rearing in the estuary and emigrating to nearshore habitat. These impacts increase as predator populations increase.

Spatial Extent	Life Stage	Limiting Factor	Driver or Cause	Hypothesis
		Competition, abundance, & hatchery management*	Driver & Cause	H_{T8g}. When natural origin and hatchery rearing juveniles' abundances are high in the Klamath River estuary, limited territory and increased competition reduces rearing capacity and survival of juveniles emigrating to nearshore habitats.
		Climate (change, wet/dry year)*	Cause	H_{T8h}. Climate change causes a change in the frequency of water year types, which affect water quality and quantity, that will influence connectivity, capacity, rearing success, and survival of juveniles rearing in the Klamath River estuary and emigrating to nearshore habitat.

T9 Nearshore rearing to ocean rearing and maturation

Description of Life Stage Transition: Juveniles that have left the estuary and entered nearshore habitats to ocean rearing and maturation, which may include transition from shallow nearshore to deeper offshore habitats and extensive ocean migrations.

Demographic Data Requirements for Life Stage Transition: Potentially useful data for this transition include:

- Ocean harvest surveys; see Pacific States methods – primarily relies on CWT recoveries
- Abundance in ocean at age, which may require DNA or CWT recoveries in fisheries to estimate.

Description of Potential Drivers and Causes linked to Life Stage Transition: The Trinity River Science Plan (Pickard et al. 2022) identified potential limiting factors for juveniles in T4-T8 that also apply to this life stage transition, though slightly different given the ocean habitat (Table 9). Climate change and ocean chemistry changes could impact marine water quality and productivity (Lindke 2014). Alteration of ocean chemistry and the frequency of marine heat waves, will affect ocean productivity and marine water quality, further influencing juvenile maturation rates and survival (Crozier et al. 2021; Smith et al. 2024). Ocean fisheries reduce rearing success, maturation rates, and survival through direct and incidental take of sub-adults, including size selectivity, and handling related mortality. Shifts in predator populations as well as changes in available prey diversity may also disproportionately increase predation rates on this life stage.

Limiting Factor and Potential Driver/Cause Data Requirements for Life Stage Transition:

1. Water temperature and DO in nearshore rearing habitats and in emigration throughways. This could be modeled and/or empirical data collection (e.g., water quality monitoring stations).

2. Harvest and fisheries data for Chinook Salmon in nearshore rearing habitats (e.g., harvest rates, landings, effort, etc. if applicable to Chinook Salmon).
3. Harvest and fisheries data for Chinook Salmon prey items in nearshore rearing habitats (e.g., harvest rates, landings, effort, etc.); primary productivity indices.
4. Water temperature and changes in ocean chemistry in ocean habitats and in emigration throughways. This could be modeled and/or empirical data (e.g., water quality monitoring stations).
5. Predator abundances and predation rate data for juvenile Chinook Salmon in nearshore rearing habitats.
6. Climate change simulations for nearshore rearing habitats – primarily water temperatures and flows (see models linked above).

Table 9. Potential limiting factors identified in Phase 1 associated with life stage transition T9, with working hypotheses for each limiting factor. Asterisks indicate limiting factors identified in the Trinity River Science Plan (Pickard et al. 2022).

Spatial Extent	Life Stage	Limiting Factor	Driver or Cause	Hypothesis
Trinity River	T9 Nearshore rearing to ocean rearing and maturation	Temperature	Driver	HT1j. Increased variability in temporal and spatial temperature regimes in nearshore and ocean habitats due to changes in climate and ocean productivity result in reduced rearing capacity and success, maturation rates, and survival of juveniles.
		Harvest & Fisheries management	Driver & Cause	H_{T1b}. Ocean fisheries (direct or incidental take, size selectivity, and handling related mortality by humans) reduce rearing success, maturation rates, and survival of juveniles in nearshore and ocean habitats.
		Foodscape (drift forage) & Bottom-up dynamics	Driver & Cause	HT2f. Decreases in foodscape in nearshore and ocean habitats due to changes in climate and ocean productivity reduce rearing capacity and success, maturation rates, and survival of juveniles.

Spatial Extent	Life Stage	Limiting Factor	Driver or Cause	Hypothesis
		Marine water quality (temperature & chemistry)* & Ocean productivity indices* & Bottom-up dynamics	Driver & Cause	H_{T2e}. Poor marine water quality due to changes in climate and ocean productivity indices reduce rearing success, maturation rates, and survival of juveniles in nearshore and ocean habitats.
		Predation* & Predator population	Driver & Cause	H_{T2a}. Predation by marine mammals, birds, and fish in the nearshore and ocean habitats reduces rearing success, maturation rates, and survival in nearshore habitat and ocean habitats. These impacts increase as predator populations increase.
		Ocean chemistry*	Cause	H_{T2e}. Fluctuations in ocean chemistry due to changes in climate, ocean productivity, pH, and carbonate chemistry, and foodscape reduce rearing success, maturation rates, and survival of juveniles in nearshore and ocean habitats.
		Climate (change, marine heat waves, ocean productivity)*	Cause	HT2j. Climate change causes a change in the frequency of marine heat waves, which affect ocean productivity, that will influence connectivity, capacity, rearing success, maturation rates, and survival of juveniles in nearshore and ocean habitats.

T10 Ocean rearing and maturation to river entry into Klamath River

Description of Life Stage Transition: Adults that have matured in the ocean to their river entry into the Klamath River (via the Klamath River estuary), thus beginning their upriver immigration.

Demographic Data Requirements for Life Stage Transition: Potentially useful data for this transition include:

- Escapement surveys, either by weir or other passage count (video, manual, etc.), ideally with monitoring points near the estuary and near mouth of the Trinity River.

Description of Potential Drivers and Causes linked to Life Stage Transition: The Trinity River Science Plan (Pickard et al. 2022) outlines one potential limiting factor affecting this life stage - high water temperatures for adults (Table 10). Marine water quality (temperature and chemistry) could be influenced by climate change through heat waves, which may affect ocean productivity and the timing of adults returning to the Klamath River (Crozier et al. 2021). Additionally, increased variability in temporal and spatial temperature regimes in nearshore and ocean habitats has the possibility of reducing rearing success, maturation rates, and adult survival (Buxton and Bradley 2022; Cooper-Hertel et al. 2022). All these landscape- and habitat-level alterations have the potential to influence ocean foodscapes which limit prey availability and diversity, leading to thiamine deficiency, reduced rearing success, maturation rates, and survival of returning ocean adults (Harder et al. 2018; Mantua et al. 2021; Suffridge et al. 2024). Finally, ocean fisheries and predation may influence rearing success, maturation rates, and survival as described for T9.

Limiting Factor and Potential Driver/Cause Data Requirements for Life Stage Transition:

1. Water temperature and changes in ocean chemistry in ocean rearing habitats and in immigration throughways. This could be modeled and/or empirical data (e.g., water quality monitoring stations).
2. Harvest and fisheries data for Chinook prey items in ocean rearing habitats (e.g., harvest rates, landings, effort, etc.); primary productivity indices.
3. Harvest and fisheries data for Chinook Salmon in ocean rearing habitats (e.g., harvest rates, landings, effort, etc. if applicable to Chinook Salmon).
4. Predator abundances and predation rate data for juvenile Chinook Salmon in ocean rearing habitats
5. Climate change simulations for ocean rearing habitats – primarily water temperatures and sea levels

Table 10. Potential limiting factors identified in Phase 1 associated with life stage transition T10, with working hypotheses for each limiting factor. Asterisks indicate limiting factors identified in the Trinity River Science Plan (Pickard et al. 2022).

Spatial Extent	Life Stage	Limiting Factor	Driver or Cause	Hypothesis
Trinity River	T10 Ocean rearing and maturation to river entry into Klamath River.	Temperature	Driver	HT1j. Increased variability in temporal and spatial temperature regimes in nearshore and ocean habitats due to changes in climate and ocean productivity result in reduced rearing success, maturation rates, and survival of adults to river entry to the Klamath River.
		Marine water quality (temperature & chemistry)* & Ocean productivity indices* & Bottom-up dynamics	Driver & Cause	H_{T2e}. Poor marine water quality due to changes in climate and ocean productivity indices reduce rearing success, maturation rates, and survival of adults to river entry to the Klamath River.

Spatial Extent	Life Stage	Limiting Factor	Driver or Cause	Hypothesis
		Foodscape & Bottom-up dynamics	Driver & Cause	HT2f. Decreases in foodscape in ocean habitats limits food diversity which leads to thiamine deficiency, and reduces ocean rearing success, maturation rates, and survival of adults to river entry to the Klamath River.
		Harvest & Fisheries management	Driver & Cause	H_{T1b}. Ocean fisheries (direct or incidental take, size selectivity, and handling related mortality by humans) reduce ocean rearing success, maturation rates, and survival of adults to river entry to the Klamath River.
		Predation* & Predator population	Driver & Cause	H_{T2a}. Predation by marine mammals and fishes reduces ocean rearing success, maturation rates, and survival of adults to river entry to the Klamath River. These impacts increase as predator populations increase.
		Ocean chemistry*	Cause	H_{T2e}. Fluctuations in ocean chemistry due to changes in climate, ocean productivity, pH, and carbonate chemistry, and foodscape reduce rearing success, maturation rates, and survival of adults to entry to the Klamath River.
		Climate (change, marine heat waves, ocean productivity)*	Cause	H_{T2j}. Climate change causes a change in the frequency of marine heat waves, which affect ocean productivity, that will influence connectivity, capacity, ocean rearing success, maturation rates, and survival of adults to river entry to the Klamath River.

Preliminary Data Requests

To support initial development of the LCM framework, evaluation of available data, and hypothesis testing, the following sections describe the data needed to parameterize the LCM for key life stages and were used to coordinate data discovery and evaluation with the TAG and SAB. This information will inform continued discussion of available data, dataset assumptions and limitations, initial data requests for key life stages, and identification of data gaps and information needs. These sections also support future efforts to address data gaps, which will be important for continued LCM refinement.

Key Data Sets and Information to Inform Parameterization of the LCM

Juvenile salmon abundance can be used as a measurement of salmonid production and survival attributable to flow and non-flow restoration actions within natal streams. When normalized for the number of adult females that escape to natal stream, relative changes in numbers of juvenile salmon produced should serve as a primary indicator of habitat conditions in the stream being assessed. It has been hypothesized that the focus on juvenile salmon avoids the need to account for many variables not related to in-river actions, including ocean conditions, ocean sport and commercial harvest, habitat conditions and water quality outside of natal streams, in-river sport harvest, and predation and water project operations outside the natal stream.

The conceptual approach is to combine juvenile outmigrant monitoring for a watershed with estimates of effects of each in-river restoration action (both flow and non-flow) on juvenile production and condition to assess the relative effectiveness of action categories in restoring anadromous fish populations (Merz et al. 2013). Rotary screw traps are the primary means to evaluate trends in juvenile salmon abundance in California. However, only recently have adequate datasets and implementation strategies facilitated evaluation of the effectiveness of monitoring programs or strategies to successfully use the system to measure specific success of life-history segments or specific management actions (e.g., Zeug et al.2014; Ogston et al. 2015; Sturrock et al. 2020).

Freshwater sampling methods relevant to Chinook salmon life history include adult salmon carcass surveys, redd surveys, seining programs, and RSTs to estimate juvenile production and outmigration for specific drainages. The more life stage-specific data available to a management program, the better the fine-scale assessment of watershed stressors and management actions.

1. Cohort reconstruction data

Describing survival during ocean rearing and maturation is key to life cycle modeling for anadromous populations like Trinity River spring- and fall-run Chinook salmon. We met with a TAG/SAB subgroup on October 18, 2024, to discuss outputs from an ongoing cohort reconstruction analysis that can support LCM parameterization. These outputs will provide key information for the T10 life stage transition. Although the cohort reconstruction model and analyses are still being developed, current outputs can generate ocean abundance estimates by age class (2–5-year-olds) that account for maturation and survival rates. The analysis also provides annual harvest and survival estimates with fixed maturation rates. These estimates are not currently related to ocean conditions, and maturation rates may have changed over time, but they provide important initial data for LCM parameterization. We assume data are not available to differentiate Trinity and Klamath populations, or spring- and fall-run types, and that the combined stock can be used as a proxy until such data are available. Because cohort reconstruction is ongoing, inputs should be updated if new information becomes available during Phase 2 of the Trinity LFA.

2. Adult escapement data

Accurate escapement estimates are essential for effective management and conservation of salmonids (Busby et al. 1996; McElhany et al. 2000). In California, a variety of methods are used to estimate adult escapement including hatchery returns and direct counts at fish ladders and weir facilities (Williams 2006; Anderson et al. 2015). However, the most consistently used method to generate escapement estimates involves mark–recapture techniques applied to carcasses (Williams 2001). Since 1976, the California Department of Fish and Wildlife has used a modified Schaefer method but recently has reported estimates based on the Jolly–Seber method (e.g., Snider and Reavis 1996). In the Central Valley they have developed procedures for calculating adult escapement estimates using a superpopulation modification to the Cormack–Jolly–Seber model. This effort has been expanded, and significant work has been performed to compare and contrast various escapement estimates on specific systems including video, infrared imaging, DIDSON, carcass, and hatchery escapement estimates (Merz and Merz 2004; Workman 2004; Holmes et al. 2005).

At present, we are not aware of any available data to directly estimate adult escapement to the Trinity River. While hatchery escapement and carcass counts could be used, they would not account for mortality during river entry or along the holding and migration reaches below the spawning grounds. The TAG/SAB indicated there are discrepancies between mark-recapture at the Willow Creek adult weir and returns to the hatchery. In addition, redd-based expansions to estimate escapement are potentially problematic given that the two-adults per redd assumption has not been validated and redd surveys do not cover all spawning habitat within the Trinity River basin (e.g., tributaries and forks). In addition, the TAG/SAB indicated that fractional marking may impact the accuracy of percent hatchery origin estimates for escapement estimates in the Trinity River.

While the adult weir data are perhaps the most efficient method presently available to estimate counts by species, race, size, origin, and sex for the Trinity River, side-scanning sonar (e.g., Adaptive resolution imaging sonar or ARIS) coupled with snorkeling or other subsamples to verify species, etc., could benefit these data needs in the short term. Furthermore, the locations of existing adult weirs do not provide the ability to differentiate adults that may spawn in forks or tributaries, and the lower ~25 miles are not covered.

3. Spawning survey data

As noted above, redd counts are commonly used to index adult escapement and assess population trends (Beland 1996; Rieman and Myers 1997; Isaak et al. 2003; Gallagher and Gallagher 2005). As the product of reproductive females, redd counts provide an index of effective population size (Meffe 1986). The use of redd counts for population monitoring may be complicated if females produce false or "test" redds, which are abandoned before eggs are deposited or make more than one redd (Reingold 1965; Crisp and Carling 1989). Sources of counting errors involved in redd counts must be identified and reduced before they can be useful for long-term monitoring (Maxell 1999; Dunham et al. 2001). Redd surveys must also span the geographic range of spawning within a system to provide an accurate accounting of abundance, although index-based survey designs are often used to evaluate relative trends over time.

Chinook Salmon redds are typically monitored by two methods: direct count observations by wading and boat on smaller streams (Merz and Setka 2004) and aerial photographs on larger streams where water quality is clear enough to identify disturbed substrate, (Williams 2001). Redd survey data are also potentially problematic as species association often requires observation of redd construction (Sellheim et al. 2022; Gallagher and Gallagher 2005), and association of redds to run type is not feasible from redd surveys.

Egg retention, identified in post-spawn females, is often used as an indicator of spawning success and has been correlated with stream temperature in other systems (Quinn et al. 2007), but these data require carcass surveys as described in the next section.

4. Carcass surveys

As noted above, carcass survey estimates of egg retention in post-spawn females is often used as an indicator of spawning success and has been correlated with stream temperature in other systems (Quinn et al 2007). Carcass surveys can also provide another means by which to estimate age, size, sex, and origin structure in the population (e.g., length frequencies, sex organ classification, scale collection etc.), as well as an opportunity to collect tissue, otolith, or other samples to support many other estimates (e.g., genetic mark recapture, otolith aging and microchemistry, etc.).

5. Incubation and Emergence

According to Williams (2006), there are no regular programs for monitoring incubation conditions or egg and alevin survival in the Central Valley (CV), but this has been done in various short-term CV studies (e.g., Vyverberg et al. 1997; Merz et al. 2013). The TAG/SAB indicated that the Forest Service conducted some redd cap studies in the Trinity River, but they did not work well. Modeling exercises have been suggested for assessing/predicting embryo survival as a function of sediment deposition (e.g., (Tappel and Bjornn 1983). Wu (2000) presented a framework that integrates three quantitative relationships modeling the variations of substrate permeability with sediment deposition, apparent velocity with substrate permeability, and embryo survival rate with apparent velocity. The model allows evaluation of the impacts of sediment deposition on embryo survival. In addition, the S3 model provides some potential inputs and functions that can inform parameterization of the LCM (e.g., Perry et al. 2018) along with modeling of temperatures and flow from the Klamath-Trinity RBM10 Water Temperature Model and NorWeST data.

The main technical tool the Biological Opinion and Operations, Criteria and Plan (OCAP) used for assessing the effects of projected water temperature changes from the proposed Project on the Trinity River, Sacramento River below Keswick/Shasta dams, and in tributaries was the

Reclamation's Salmon Mortality Model developed in 1991(USBR 1991). The Salmon Mortality Model is used to determine impacts of temperature on individual eggs and early fry, and inference is made to population impacts based on this individual-survival model. The model is based on laboratory studies of temperature and survival of Chinook Salmon embryos and early fry. The model cumulatively calculates mortality rates under different water types (wet, dry, critical) by relating temperature level, duration of exposure (function of spawning timing and rate of development), and distribution information to output from the water temperature model to estimate instantaneous mortality at various temperatures. The advantage of the model is that it allows quantitative comparisons of projected egg/early fry mortality losses under different project/temperature scenarios. The population-level impact is then estimated by assuming a direct relationship: i.e., the change in the number of eggs and early fry due to temperature effects is directly equivalent to an equal change in the number of juvenile outmigrants (additive mortality).

Given the lack of direct emergence studies or data for the Trinity River, our preliminary data requests to support parameterization of the incubation and emergence life stages is focused on fecundity estimates. Redd abundance data along with age structure, size structure, and fecundity data provide estimates of total egg deposition resulting from spawning. The TAG/SAB indicated that fecundity data are available from hatchery returns, but no data are collected for natural origin adults. Therefore, fecundity data from hatchery origin adults are used to estimate natural origin fecundity.

6. Rearing

Various traps, including incline plane and RST, have been used throughout the Pacific Northwest to estimate juvenile salmon rearing characteristics, such as: Emigration abundance (Tsumura and Hume 1986; Baranski 1989; Orciari et al. 1994; Thedinga et al. 1994; Letcher et al. 2002; Johnson et al. 2005); Outmigration timing (Wagner et al. 1963; Hartman et al. 1982); Outmigrant body size (Orciari et al. 1994; Olsson et al. 2001; Workman 2003, 2004a); Survival (Schoeneman et al. 1961; Wagner et al. 1963; Tsumura and Hume 1986; Thedinga et al. 1994; Olsson et al. 2001; Letcher et al. 2002); and Behavior (Brown and Hartman 1988; Roper and Scarnecchia 1996). Juvenile salmon are also assessed with beach seines (e.g., Brandes and McClain 2001) and snorkel surveys (Gard and Gallagher 2024). Juvenile abundance monitoring during each life stage (e.g., fry, parr, smolt) enables mortality to be partitioned between freshwater (emergence-to-migration) and marine (smolt-to-adult) life stages (Volkhardt et al. 2007).

However, we are unaware of any ongoing or long-term direct monitoring or quantification of rearing abundances within the Trinity River reaches aside from what can be estimated from RST monitoring at two locations. Furthermore, while spawning is generally assumed to occur in the mainstem and in the restoration reach specifically, spawning occurs within tributaries and forks of the Trinity River that are not monitored directly for juvenile production or rearing.

Therefore, preliminary modeling of rearing will likely rely on estimates of rearing habitat quantity and quality from habitat and water quantity/quality data (modeled or empirical) along with data from RST monitoring (see description and requests below). Furthermore, we note that information from the S3 model may also be used to support parameterization and modeling of rearing in the Trinity River (e.g., Perry et al. 2018).

7. Emigration

There are several checkpoints of emigration that are of interest for modeling the life cycle of Trinity River Chinook Salmon. The first is emigration from natal streams to the Klamath River, and two RSTs are used to monitor emigration abundance, size, and timing within the Trinity River. The first RST is located near the North Fork Trinity River confluence downstream of the restoration reach, and the second is located near Willow Creek downstream of the South Fork Trinity River confluence. The upper RST is well positioned to estimate juvenile emigration off the spawning grounds with abundance, timing, and size information. However, the lower RST is located ~25 river miles upstream of the Trinity River confluence with the Klamath and may not provide the best estimates of emigration from the Trinity River to the Klamath River. While the RSTs provide good information on the abundance, timing, and size structure of juveniles captured, fractional marking practices and lack of genetic sampling may limit our ability to tease apart aspects of origin (natural vs hatchery, and progeny of spring- vs fall-run type).

Furthermore, we are not aware of any active or ongoing RST monitoring in the Klamath River downstream of the Trinity River confluence, which could be used to estimate emigration survival from the Trinity River into the Klamath River. The TAG/SAB indicated that a survival study was previously conducted that could provide some data on survival from the hatchery to the estuary, which could provide some information on the second check point of interest – emigration from the Klamath River through the estuary. Additionally, the TAG/SAB indicated that a relatively new study has been collecting fish assemblage information in the estuary (see Schuitman et al. 2024, Presented as a poster at the AFS Annual Meeting, "Co-produced data describes the fish community of the Lower Klamath River estuary before and after dam removal").

It is unlikely that these data will provide abundance estimates that can be used to inform emigration success or rates, but the time series could provide important information on timing – although genetic sampling, otolith sampling, CWT recoveries, or other biotelemetry/mark recapture strategies would be needed to differentiate populations (e.g., Klamath vs Trinity, and run type).

The final emigration check point of interest is from the estuary to nearshore. We are unaware of any previous or ongoing monitoring (other than the potential information from the cohort reconstruction) that can directly provide an estimate of survival from estuary to nearshore for Trinity River populations, but there are many such efforts underway in the CV and other systems that may offer methods for this program. For instance, emigrant survival estimates from natal streams to the Pacific Ocean can be developed for various populations by tagging juveniles captured in migrant traps and estimating the escapement and fishery impacts on the tagged population. According to Baker and Morhardt (2001), since 1978, as part of the Interagency Ecological Program (IEP), the USFWS has monitored the relative abundance of Chinook Salmon smolts emigrating from the CV with mid-water trawl surveys at Chipps Island. The sampling effort varies over the course of the season, but during peak emigration season there are a maximum of 10, 20-minute trawls per day, 7 days per week. Smolts with adipose fin clips are killed and their CWTs are read. The number of smolts captured is expanded to account for time spent sampling and the ratio of the net width to channel width to form an estimate of absolute abundance. For CWT-bearing smolts, the expanded recovery for each tag group is divided by the number of smolts originally released and reported as a smolt survival index (SSI). Population genetics may also be used (Teel et al. 2014).

The Chipps Island trawls are of special importance for investigating questions of Delta Smolt survival, because this trawl location can be loosely regarded as marking the transition from delta to bay environments, and because data have been gathered quite consistently at this location for two decades (Baker and Morhardt 2001). In the spring of 1997, as part of the Vernalis Adaptive Management Plan, a new USFWS trawl survey location was added at Jersey Point on the San Joaquin River, to supplement the Chipps Island data with data more specific to San Joaquin salmon populations.

Since 1989, DFG has conducted similar monitoring in the San Joaquin River near Mossdale Landing County Park, just upstream of the head of Old River. Ten 10-minute trawls are conducted during a five-hour "index" period each day, typically for 5 days each week during the peak of the emigration season (Baker and Morhardt 2001). The number of smolts captured is expanded by an efficiency index obtained by experiments in which smolts marked with subcutaneously-injected paint are released a short distance upstream of the trawl location. However, we are unaware of any ongoing or long-term direct monitoring or quantification of emigrants from the Trinity River.

Within the last two decades, radio and acoustic telemetry studies have expanded exponentially in the CV to estimate the probability of emigrants utilizing various migration routes and the probability of surviving through each route (Perry et al. 2010). With the present technology available, such projects typically require juvenile salmon large enough to carry the transmitter which is typically a tag burden of no more than ~5% (e.g., 75-80 mm FL; Zeug et al. 2020). We are also unaware of Chinook Salmon telemetry studies to assess emigrant survival from the Trinity River.

Preliminary Data Requests

The following table provides a summary of the key data requested to begin data evaluation, preliminarily parameterize the LCM, and perform initial hypotheses testing. Additional and refined data requests are anticipated as we evaluate data and parametrize the model. To be useful in LCM parameterization, all desired and requested data should meet some core requirements including the following:

1. Specificity to Trinity River Chinook Salmon populations and run type where possible;
2. Specificity to life stages, life stage transitions, life histories and their spatial and temporal extents associated with what is expected in the Trinity River;
3. Data errors less than the life stage transition rate (survival rate) or response to specific driver being described; and
4. Sufficient time series are available to characterize patterns across multiple cohorts that span a range of expected conditions.

Where data that meet these requirements are not available, we will consider simplifying assumptions or the modeling framework or use information from available literature or expert elicitation to address data gaps. These determinations will be made in coordination with the Project Team and the TAG.

Table 11. Preliminary data requests for initial data evaluation and parametrization of key life stages for the Trinity River LCM.

Data Type and Transition	Desired Data/Information	Description of Applications and Caveats
Adult escapement to the Trinity River (T1, T2)	1. Annual time series of abundance broken out by origin (hatchery and natural), run type (spring- and fall-run), sex, and age or size class. 2. Timing or periodicity within years (e.g., weekly abundance for each year), with demographic information as above.	Provides abundance and demographic information to describe the number of adults, periodicity, and composition of adults that make it to, and hold in, the Trinity River. Time series need to be sufficiently long enough to cover a range of environmental conditions, and abundance estimates sufficiently accurate to support evaluation of potential drivers and causes.
Successful adult spawners (T3)	3. Annual time series of redd counts, ideally with relative contributions of redd construction by origin and run type. 4. Timing or periodicity within years (e.g., weekly redd counts). 5. Annual time series of pre-spawn mortality. 6. Timing or periodicity of pre-spawn mortality (e.g., weekly pre-spawn mortality estimates within each year). 7. Egg retention rates. 8. Annual time series of redd superimposition rates. 9. Location information on redds, ideally individual points.	Provides an estimate of the abundance of successful adults spawning in Trinity River, and the location of spawning activity. Data likely from a combination of redd surveys and carcass surveys. Pre-spawn mortality may vary temporally within a year, and therefore within year estimates provide information that can inform driver/cause evaluation.
Incubation and emergence (T4)	10. Annual time series of fecundity estimates by origin and age/size class. 11. Annual time series of emergent fry abundance. 12. Timing and periodicity of emergence (e.g., weekly emergence abundance).	Fecundity is used along with redd counts to estimate the total number of incubating eggs, which forms the basis for estimating emergent fry abundance from egg to fry survival rates.
Emigration from spawning grounds (T5)	13. Abundance of fry emigrating from spawning ground. 14. Timing and periodicity (e.g., weekly or daily abundance estimates), with origin and size information (e.g., FL).	Likely from upstream RST located below restoration reach, provides an estimate of total production and timing of emergent fry emigration from the spawning grounds and life history expression.

Data Type and Transition	Desired Data/Information	Description of Applications and Caveats
Emigration from the Trinity River (T6)	15. Abundance of fry, parr, and yearlings emigrating from the Trinity River to the Klamath River. 16. Timing and periodicity (e.g., weekly or daily abundance estimates), with origin and size information (e.g., FL).	Likely from the downstream RST but does not include the lower ~25 miles of the Trinity. Provides an estimate of total juvenile production, timing, and life history expression from Trinity River.
Emigration from the Klamath River (T7)	17. Abundance of Trinity River origin juveniles emigrating from the Klamath River. 18. Timing and periodicity (e.g., weekly or daily abundance estimates), with origin, size (e.g., FL), and smoltification rate information	Provides abundance of juveniles that survive to emigration from the Klamath River to the estuary.
Emigration from the estuary (T8)	19. Abundance of Trinity River origin juveniles' emigration from the estuary. 20. Timing and periodicity (e.g., weekly or daily abundance estimates), with origin, size (e.g., FL), and smoltification rate information	Provides abundance of juveniles that survive to emigration from the estuary to nearshore.
Emigration from nearshore (T9)	21. Abundance of Trinity River origin juveniles' emigration from the nearshore. 22. Timing and periodicity (e.g., weekly or daily abundance estimates), with origin and size information (e.g., FL).	Provides abundance of juveniles that survive to emigrate from the nearshore to ocean rearing and maturation. Likely from cohort reconstruction model.
Adult escapement to the Klamath River (T10)	23. Annual time series of abundance at river entry by age class, origin, run type, life history (subyearling and yearling), and sex. 24. Annual time series of life history specific harvest, survival, and maturation rates.	Provides abundance at river entry and estimates of harvest, maturation, and survival rates. Likely from cohort reconstruction model and does not currently differentiate populations or run type. Reconstructions are based on CWT recoveries and assumed to represent naturally produced adults.
Habitat connectivity, quantity, and quality in Trinity River (T2, T3, T5, T6), Klamath River (T1, T7), Klamath estuary (T8)	25. Holding habitat area (e.g., quality pool areas), holding habitat capacity, and spatial distribution information for the Trinity and lower Klamath Rivers. 26. Rearing habitat area (e.g., quality off-channel areas), rearing habitat capacity, habitat connectivity (including lagoon formation), and spatial distribution information for the Klamath River estuary.	Provides potential to calculate capacity values for holding and rearing which may be valuable for modeling if real-count data are not available for some reaches. Habitat connectivity data would allow for testing of potential driver/cause that loss of connectivity at certain times limits emigration, immigration and spawning potential.

Data Type and Transition	Desired Data/Information	Description of Applications and Caveats
	27. Rearing habitat area (e.g., quality off-channel areas), rearing habitat capacity, habitat connectivity, and spatial distribution information for the Trinity and lower Klamath Rivers; habitat connectivity from Trinity River to lower Klamath River .	
Spawning habitat (T4)	28. Spawning habitat area (e.g., quality riffle areas), spawning habitat capacity, and spatial distribution information for the Trinity River.	Provides potential to calculate capacity values for holding and rearing which may be valuable for modeling if real-count data are not available for some reaches. Provides insight into potential for redd superimposition if abundance exceeds capacity.
Adult fish health (T1, T2)	29. Presence or abundance of diseases (specifically *Ichthyopthirius multifilis* (ich) and the bacterial pathogen *Flavobacter columnare* (columnaris)) in the Trinity and lower Klamath Rivers. 30. Time series water temperature data that corresponds with disease prevalence.	Provides insight into pre-spawn mortality causes and allows for more accurate calculation of population that spawned successfully. Increased water temperatures have been associated with greater disease burden so could model disease prevalence based on temperatures.
Juvenile fish health (T5 - T8)	31. Presence or abundance of diseases (specifically *Ceratomyxa shasta* and *Parvicapsula minibicornis)* in the Trinity River, Klamath River and Klamath River estuary. 32. Time series flow data that corresponds with disease prevalence.	Provides insight into juvenile mortality causes and allows for more accurate calculation of population that reared and emigrated successfully. Decreased water flows have been associated with greater disease burden so could model disease prevalence based on flows.
Predation & predator populations (T1 – T10)	33. Predator population sizes and predation rates in the Trinity River (adults, juveniles, eggs), Klamath River (adults, juveniles), Klamath River estuary (juveniles), and nearshore (juveniles) and ocean habitats (adults and juveniles).	Provides insight into mortality causes at various life stage transitions. Could model predation rates based on predator population size.
Harvest & fisheries management (T1, T2, T9, T10)	34. Harvest and fisheries data for Chinook Salmon in lower Klamath River and ocean (e.g., harvest rates, landings, effort, etc. if applicable to Chinook Salmon).	Provides insight into mortality causes during adult life stage transitions. Could be used to help model expected adult return rates.

Data Type and Transition	Desired Data/Information	Description of Applications and Caveats
Water withdrawal & water quantity (T1 – T3, T6, T7)	35. River flow in the Trinity & Klamath Rivers.	Modeled data can be useful for simulations and scenario/hypothesis testing, and empirical data from gages are useful for parameterization and calibration.
Water quality (T1 – T7, T9, T10) & Temperature management (T2 - T8)	36. Water temperature and dissolved oxygen in the Trinity and Klamath Rivers, Klamath River estuary, and nearshore and ocean habitats and in emigration throughways.	Modeled data can be useful for simulations and scenario/hypothesis testing, and empirical data from gages are useful for parameterization and calibration.
Intergravel flow (T4)	37. Intergravel flow and dissolved oxygen in spawning riffles in the Trinity River.	Provides potential to model spawning ground quality and thus, incubation success.
Flow management (T2 - T7)	38. River flow management decisions/ change orders in the Trinity and Klamath Rivers.	Can be used to model potential flow change orders based on various flow regimes.
Climate change (T1 – T10)	39. Climate change simulations for Trinity and Klamath Rivers – primarily water temperatures and flows. 40. Climate change simulations for ocean rearing habitats – primarily water temperatures and sea levels.	Makes flow and temperature models more robust by including higher level factors/drivers.
Wildfire (T1 - T7)	41. Wildfire frequency, duration, intensity data, and sedimentation inputs or water quality linked to wildfires in Trinity and Klamath Rivers.	When paired with precipitation data, debris flows and water quality impacts may be able to be modeled.
Hatchery management (T2 – T8)	42. Return data including dates, counts, sizes/ages, run of hatchery origin adults. 43. Release data including dates, counts, sizes/ages, run of hatchery released juveniles.	Provides insight into potential competition for redd territory (redd superimposition) for adults and competition for food and rearing habitat for juveniles. Also feeds into potential for higher disease transmission risk and alteration of life history expression, growth and survival of wild origin fish.
Sediment management (T4)	44. Mean gravel size (particularly in spawning areas), gravel augmentation dates and loads, sheer stress data, and sedimentation rates in Trinity River (mix of empirical and modeled data).	Provides potential to model spawning ground quality and thus, incubation success, over time.
Foodscape (T5 – T10)	45. Chinook Salmon prey (macroinvertebrates and other fish) abundances in Trinity River,	Provides potential to model rearing habitat quality via productivity over time.

Data Type and Transition	Desired Data/Information	Description of Applications and Caveats
	Klamath River, Klamath River estuary, and nearshore habitats. 46. Harvest and fisheries data for Chinook Salmon prey items in ocean rearing habitats (e.g., harvest rates, landings, effort, etc.); primary productivity indices. 47. Rates of thiamine deficiency in returning adults, incubating eggs, or emergent fry in Trinity River.	
Ocean chemistry (T9 - T10)	48. Changes in ocean chemistry in ocean rearing habitats and in immigration throughways.	Modeled data can be useful for simulations and scenario/hypothesis testing, and empirical data from gages are useful for parameterization and calibration.
Ocean productivity (T9 - T10)	49. Changes in ocean productivity indices in ocean rearing habitats and in immigration throughways.	Modeled data can be useful for simulations and scenario/hypothesis testing, and empirical data from gages are useful for parameterization and calibration.

Literature Cited

Anderson, J. T., J. E. Merz, C. B. Watry, and M. K. Saiki. 2015. Comparison of selected population characteristics of adult Chinook salmon during upstream passage through a resistance board weir and during carcass surveys. California Fish and Game 101(1):24-39.

Baker, P.F. and J.E. Morhardt. 2001. Survival of Chinook salmon smolts in the Sacramento–San Joaquin Delta and Pacific Ocean. Pages 163-182 in R. L. Brown, editor. Contributions to the biology of Central Valley salmonids, volume 2. Fish Bulletin 179. California Department of Fish and Game.

Baldock, J. R., R. Al-Chokhachy, T. E. Walsworth, and A. Walters. 2023. Redd superimposition mediates the accuracy, precision, and significance of redd counts for cutthroat trout. Canadian Journal of Fisheries and Aquatic Sciences 80(5):825–839.

Baranski, C. 1989. Coho smolt production in ten Puget Sound streams. Olympia (WA): Washington Department of Fisheries. Technical Report 99.

Bartholomew, J. L., J. D. Alexander, J. Alvarez, S. D. Atkinson, M. Belchik, S. J. Bjork, J. S. Foott, A. Gonyaw, M. E. Hereford, R. A. Holt, and B. McCovey Jr. 2023. Deconstructing dams and disease: predictions for salmon disease risk following Klamath River dam removals. Frontiers in Ecology and Evolution 11:1245967.

Beamer, E., C. Rice, J. Chamberlin, R. Henderson, D. Lomax, and C. Greene. 2024. Differential use of tidal delta, shoreline, and neritic habitats by natural- and hatchery-origin juvenile Chinook Salmon. Transactions of the American Fisheries Society 153:10.1002/tafs.10488.

Beland, K. F. 1996. The relation between redd counts and Atlantic salmon (*Salmo salar)* parr populations in the Dennys River, Maine. Canadian Journal of Fisheries and Aquatic Sciences 53:513–519.

Belchik, M., D. Hillemeier, and R. M. Pierce. 2004. The Klamath River fish kill of 2002: analysis of contributing factors. Yurok Tribal Fisheries Program 2(3):4.

Bjork, S. and J. Bartholomew. 2009. Effects of *Ceratomyxa shasta* dose on a susceptible strain of rainbow trout and comparatively resistant Chinook and coho salmon. Diseases of Aquatic Organisms 86:29-37.

Blankenship, S. M., A. Scherer, C. Dean, K. Sellheim, J. Sweeney, and J. Merz. 2024. Applying parentage methods to detect gravel augmentation effects on juvenile Chinook Salmon recruitment rates. River Research and Applications 40(5):791–808.

Bottom, D. L., K. K. Jones, T. J. Cornwell, A. Gray, and C. A. Simenstad 2005. Patterns of Chinook salmon migration and residency in the Salmon River estuary (Oregon). Estuarine, Coastal and Shelf Science 64(1):79-93.

Bowerman, T., M. L. Keefer, and C. C. Caudill. 2016. Pacific salmon prespawn mortality: patterns, methods, and study design considerations. Fisheries 41(12):738–749.

Brandes, P. L. and J. S. McLain. 2001. Juvenile Chinook Salmon abundance, distribution, and survival in the Sacramento-San Joaquin Estuary. Pages 39–138 in R. L. Brown, editor. Contributions to the biology of Central Valley salmonids, volume 2. Fish Bulletin 179. California Department of Fish and Game.

Brown, T. G. and G. F. Hartman. 1988. Contributions of seasonally flooded lands and minor tributaries to the production of coho salmon in Carnation Creek, British Columbia. Transactions of the American Fisheries Society 117:546–551.

Busby, P. J., T. C. Wainwright, G. J. Bryant, L. J. Lierheimer, R. S. Waples, F. W. Waknitz, and I. V. Lagomarsino. 1996. Status review of West Coast steelhead from Washington, Idaho, Oregon, and California. NOAA technical memorandum NMFS.

Buxton, T. H. and D. N. Bradley. 2022. Evolution of tributary junctions and their capacity for rearing juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) on a regulated river. Ecohydrology 15(8):e2463.

Chen, J. and H. Chang. 2023. A review of wildfire impacts on stream temperature and turbidity across scales. Progress in Physical Geography: Earth and Environment 47(3):369–394. https://doi.org/10.1177/03091333221118363.

Collis, K., S. K. Anderson, D. D. Roby, D. E. Lyons, and K. Collis. 2007. Relationship of Caspian Tern foraging ecology to nesting success in the Columbia River estuary, Oregon, USA. Estuarine, Coastal, and Shelf Science 73:447–456.

Cooper-Hertel, E. J., K. T. Lindke, T. Daley, K. DeJuilio, and K. Hopkins. 2022. Assessing temperature regimes and juvenile Chinook Salmon growth in Trinity River off-channel and mainstem habitats.

Crisp, D. T. and P. A. Carling. 1989. Observations on siting, dimensions, and structure of salmonid redds. Journal of Fish Biology 34:119–134.

Crozier, L. G., B. J. Burke, B. E. Chasco, D. L. Widener, and R. W. Zabel. 2021. Climate change threatens Chinook Salmon throughout their life cycle. Communications Biology 4(1):222.

David, A. T., J. E. Asarian, and F. K. Lake. 2018. Wildfire smoke cools summer river and stream water temperatures. Water Resources Research 54(10):7273–7290.

Duffin, J., E. M. Yager, J. M. Buffington, R. Benjankar, C. Borden, and D. Tonina. 2023. Impact of flow regulation on stream morphology and habitat quality distribution. Science of the Total Environment 878:163016.

Dunham, J. B., B. E. Rieman, and K. Davis. 2001. Sources and magnitude of sampling error in redd counts of bull trout. North American Journal of Fisheries Management 21:343–352.

Fujiwara, M., M. S. Mohr, A. Greenberg, J. S. Foott, and J. L. Bartholomew. 2011. Effects of ceratomyxosis on population dynamics of Klamath fall-run Chinook Salmon. Transactions of the American Fisheries Society 140(5):1380–1391.

Gallagher, S. P. and B. M. Gallagher. 2005. Discrimination of Chinook salmon, coho salmon, and steelhead redds and evaluation of the use of redd data for estimating escapement in several unregulated streams in northern California. North American Journal of Fisheries Management 25:284–300.

Gard, M. and S. Gallagher. 2024. Effects of cover and mesohabitat type on the abundance or young-of-the-year Chinook salmon. California Fish and Wildlife Journal 110(3).

Garzke, J., I. Forster, C. Graham, D. Costalago, and B. Hunt. 2023. Future climate change-related decreases in food quality may affect juvenile Chinook Salmon growth and survival. Marine Environmental Research 191:106171. https://doi.org/10.1016/j.marenvres.2023.106171.

Guillen, G. 2003. Klamath River fish die-off, September 2002: Causative factors of mortality. U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office.

Harder, A. M., W. R. Ardren, A. N. Evans, M. H. Futia, C. E. Kraft, J. E. Marsden, C. A. Richter, J. Rinchard, D. E. Tillitt, and M. R. Christie. 2018. Thiamine deficiency in fishes: causes, consequences, and potential solutions. Reviews in Fish Biology and Fisheries 28:865–886.

Hartman, G. F., B. C. Anderson, and J. C. Scrivener. 1982. Seaward movement of coho salmon (*Oncorhynchus kisutch*) fry in Carnation Creek, an unstable coastal stream in British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 39:588–597.

Hamilton, S. A. and D. D. Murphy. 2018. Analysis of limiting factors across the life cycle of Delta Smelt (*Hypomesus transpacificus*). Environmental Management 62:365–382.

Hearsey, J. 2011. Run timing, fat content and maturity of spring- and fall-run Klamath River Chinook salmon (Oncorhynchus tshawytscha). Master's thesis. Humboldt State University, Arcata, California.

Holmes, J. A., G. M. Cronkite, H. J. Enzenhofer, T. J. Mulligan. 2005. Accuracy and precision of fish-count data from a “dual-frequency identification sonar” (DIDSON) imaging system. ICES Journal of Marine Science 63:543–555.

Honea, J. M., J. C. Jorgensen, M. M. McClure, T. D. Cooney, K. Engie, D. M. Holzer, and R. Hilborn. 2009. Evaluating habitat effects on population status: influence of habitat restoration on spring-run Chinook salmon. Freshwater Biology 54(7):1581–1598.

Isaak D. J., R. K. Thurow, B. E. Rieman, and J. B. Dunham. 2003. Temporal variation in synchrony among Chinook salmon (*Oncorhynchus tshawytscha*) redd counts from a wilderness area in central Idaho. Canadian Journal of Fisheries and Aquatic Sciences 60:840–848.

Johnson, S. L., J. D. Rodgers, M. F. Solazzi, and T. E. Nickelson. 2005. Effects of an increase in large wood on abundance and survival of juvenile salmonids (*Oncorhynchus spp*.) in an Oregon coastal stream. Canadian Journal of Fisheries and Aquatic Sciences 62:412–424

Kiffney, P. M., Sanderson, B. L., Veggerby, K. B., Lamb, J. J., & Axel, G. A. (2025). Water Temperature, Prey Concentration and Salmonid Density Influence Daily Growth of Wild Juvenile Salmonids in Tributaries of the Upper Salmon River, Idaho (USA). Freshwater Biology, 70(1), 101–117.

Krause, H. A. 2024. Distribution and abundance of seven salmonid pathogens in the Upper Klamath Basin: pathogen risks to returning anadromous salmonid populations. Master's thesis. Oregon State University, Corvallis, Oregon.

Kuruvilla, M. 2024. Impacts of environmental and social factors on fish movement and behavior over three timescales. Doctoral dissertation. University of Washington, Seattle.

Lawrence, D. J., B. Stewart-Koster, J. D. Olden, A. S. Rogers, E. Fleishman, C. R. Poulsen, and C. E. Mahlum. 2011. The virtues and shortcomings of a national park system for conserving freshwater fish diversity. Biological Conservation 144(11):2636–2646.

Letcher, B. H., G. Gries, and F. Juanes. 2002. Survival of stream dwelling Atlantic salmon: effects of lifehistory variation, season, and age. Transactions of the American Fisheries Society 131:885–844.

Lindke, K. T. 2014. An evaluation of Chinook salmon (Oncorhynchus tshawytscha) survival from Klamath-Trinity river hatcheries in their first year at sea reveals unique response to local oceanographic conditions. Master's thesis. California State Polytechnic University, Humboldt, Arcata, California.

Maxell, B. A. 1999. A power analysis on the monitoring of bull trout stocks using redd counts. North American Journal of Fisheries Management 19:860–866.

McElhany, P., M. H. Rucklelshaus, M. J. Ford, T. C. Wainwright, and E. P. Bjorkstedt. 2000. Viable salmonid populations and the recovery of evolutionary significant units. NOAA technical memorandum NMFS.

McMichael, G. A., C. L. Rakowski, B. B. James, and J. A. Lukas. 2005. Estimated fall Chinook salmon survival to emergence in dewatered redds in a shallow side channel of the Columbia River. North American Journal of Fisheries Management 25(3):876-884.

Meffe, G. K. 1986. Conservation genetics and the management of endangered fishes. Fisheries 11:14–23.

Merz, J. E. and W. R. Merz. 2004. Morphological features used to identify chinook salmon sex during fish passage. The Southwestern Naturalist 49:197–202

Merz J. E. and J. D. Setka. 2004. Evaluation of a spawning habitat enhancement site for Chinook salmon in a regulated California river. North American Journal of Fisheries Management 24:397–407.

Merz, J., M. Workman, D. Threloff, and B. Cavallo. 2013. Salmon life cycle considerations to guide stream management: examples from California's Central Valley. San Francisco Estuary and Watershed Science 11(2).

Naman, S. W., and C. S. Sharpe. 2012. Predation by hatchery yearling salmonids on wild subyearling salmonids in the freshwater environment: a review of studies, two case histories, and implications for management. Environmental Biology of Fishes 94(1):21–28.

Ogston, L., S. Gidora, M. Foy, and J. Rosenfeld. 2015. Watershed-scale effectiveness of floodplain habitat restoration for juvenile coho salmon in the Chilliwack River, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 72(4):479-490.

Olsson, I. C., L. A. Greenberg, and A. G. Eklov. 2001. Effect of an artificial pond on migrating brown trout smolts. North American Journal of Fisheries Management 21:498–506.

Orciari, R. D., G. H. Leonard, D. J. Mysling, and E. C. Schluntz. 1994. Survival, growth, and smolt production of Atlantic salmon stocked as fry in a southern New England stream. North American Journal of Fisheries Management 14:588–606.

Perry, R. W. 2024. Presentation in the symposium *Dam Removal and Ecological Transformation on the Klamath River*. American Fisheries Society Annual Meeting, Honolulu, Hawaii.

Perry, R. W., J. R. Skalski, P. L. Brandes, P. T. Sandstrom, A. P. Klimley, A. Ammann, B. MacFarlane. 2010. Estimating survival and migration route probabilities of juvenile Chinook salmon in the Sacramento–San Joaquin River Delta. North American Journal of Fisheries Management 30(1):142–156.

Perry, R. W., E. C. Jones, J. M. Plumb, N. A. Som, N. J. Hetrick, T. B. Hardy, J. C. Polos, A. C. Martin, J. S. Alvarez, and K. P. De Juilio. 2018. Application of the Stream Salmonid Simulator (S3) to the restoration reach of the Trinity River, California—Parameterization and calibration. U.S. Geological Survey.

Pess G., M. McHenry, K. Denton, J. Anderson, M. Liermann, R. Peters, J. McMillan, S. Brenkman, T. Bennett, J. Duda, and K. Hanson. 2024. Initial responses of Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*Oncorhynchus mykiss*) to removal of two dams on the Elwha River, Washington State, U.S.A. Frontiers in Ecology and Evolution 12:1241028. https://doi.org/10.3389/fevo.2024.1241028.

Pickard, D., J. Alvarez, K. De Julio, L. Gogan, J. Lee, K. Lindke, S. Naman, C. Smith, N. Som, and P. Zedonis. 2022. Trinity River Restoration Program: Science Plan. Weaverville, California.

Quinn T. P., D. M. Eggers, J. H. Clark, and H. B. Rich. 2007. Density, climate, and the processes of prespawning mortality and egg retention in Pacific salmon (*Oncorhynchus spp*.). Canadian Journal of Fisheries and Aquatic Sciences 64:574–582.

Reingold, M. 1965. A steelhead spawning study. Idaho Wildlife Review, Jan.-Feb., 1965. Idaho Fish and Game Commission 17:8-10.

Rieman, B. E. and D. L. Myers. 1997. Use of redd counts to detect trends in bull trout (*Salvelinus confluentus*) populations. Conservation Biology 11:1015–1018.

Roper B. and D. L. Scarnecchia. 1996. A comparison of trap efficiencies for wild and hatchery age-0 Chinook salmon. North American Journal of Fisheries Management 16:214–217

Schoeneman, D. E., R. T. Pressey, and C.O. Junge. 1961. Mortalities of downstream migrant salmon at McNary Dam. Transactions of the American Fisheries Society 90:58–72.

Schuiteman, M., J. Marin Jarrin, and the Pulikla Tribe of Yurok People. 2024. Co-produced data describes the fish community of the Lower Klamath River estuary before and after dam removal. Poster presented at the 154th Annual Meeting of the American Fisheries Society, Honolulu, Hawaii.

Sellheim, K., J. Sweeney, and J. Merz. 2022. Increasing objectivity associated with anadromous fish redd identification using a discriminant function analysis. Frontiers in Environmental Science 10:p.1085941.

Siegel, J. and L. Crozier. 2018. Impacts of climate change on salmon of the Pacific Northwest. A review of the scientific literature published in 2018. National Marine Fisheries Service.

Smith, J. M. B. J. Burke, D. Jackson, B. Wells, B. Beckman, W. Duguid, T. Quinn, and D. Huff. 2024. Marine biophysical conditions influence the vertical and horizontal distribution of sub-adult Chinook salmon in the nearshore marine waters of Washington State. Marine Ecology Progress Series 744:10.3354/meps14672.

Snider, W. M. and B. Reavis. 1996. Lower American River chinook salmon escapement survey, October 1995–January 1996. Sacramento (CA): California Department of Fish and Game. 17 p + appendices.

Sturrock, A. M., S. M. Carlson, J. D. Wikert, T. Heyne, S. Nusslé, J. E. Merz, and R. C. Johnson. 2020. Unnatural selection of salmon life histories in a modified landscape. Global Change Biology 26(3):1235–1247.

Suffridge, C. P., K. C. Shannon, H. Matthews, R. C. Johnson, C. Jeffres, N. Mantua, A. E. Ward, E. Holmes, J. Kindopp, M. Aidoo, and F. S. Colwell. 2024. Connecting thiamine availability to the microbial community composition in Chinook salmon spawning habitats of the Sacramento River basin. Applied and Environmental Microbiology 90(1):e01760-23.

Sullivan, R. M. and J. P. Hileman. 2019. Effects of managed flows on Chinook Salmon (*Oncorhynchus tshawytscha*) in relation to run-timing, fertility, and fluctuations in water temperature and flow. California Fish and Game 105(3):132-176.

Tappel, P. D., and T. C. Bjornn. 1983. A new method of relating size of spawning gravel to salmonid embryo survival. North American Journal of Fisheries Management 3(2):123–135.

Teel, D. J., D. L. Bottom, S. A. Hinton, D. R. Kuligowski, G. T. McCabe, R. McNatt, G. C. Roegner, L. A. Stamatiou, and C. A. Simenstad. 2014. Genetic identification of Chinook Salmon in the Columbia River estuary: stock-specific distributions of juveniles in shallow tidal freshwater habitats. North American Journal of Fisheries Management 34(3):621-641.

Thedinga, J. F., M. L. Murphy, S. W. Johnson, J. M. Lorenz, K. V. Koski. 1994. Determination of salmonid smolt yield with rotary-screw traps in the Situk River, Alaska, to predict effects of glacial flooding. North American Journal of Fisheries Management 14:837–851.

Tsumura, K. and J. M. B. Hume. 1986. Two variations of a salmonid smolt trap for small rivers. North American Journal of Fisheries Management 6:272–276.

USBR (U.S. Bureau of Reclamation). 1991. Appendixes to Shasta outflow temperature control, planning report/environmental statement, Appendix A: U.S. Bureau of Reclamation, Mid-Pacific Region. 176 p. Originally issued in November 1990, revised May 1991.

Volkhardt, G. C., S. L. Johnson, B. A. Miller, T. E. Nickelson, D. E. Seiler. 2007. Rotary screw traps and inclined plane screen traps. Pages 235-266 *in* D. H. Johnson, et al., editors. Salmonid field protocols handbook: techniques for assessing status and trends in salmon and trout populations. American Fisheries Society.

Voss, A., K. True, and J. Foott. 2018. Myxosporean parasite (*Ceratonova shasta* and *Parvicapsula minibicornis*) prevalence of infection in Klamath River basin juvenile Chinook Salmon, March - August 2018. U.S. Fish & Wildlife Service California – Nevada Fish Health Center. http://www.fws.gov/canvfhc/reports.html.

Vyverberg K., B. Snider, R. B. Titus. 1997. Lower American River chinook spawning habitat evaluation, October 1994. Sacramento (CA): California Department of Fish and Game.

Wagner, H. H., R. L. Wallace, H. J. Campbell. 1963. The seaward migration and return of hatchery-reared steelhead trout, *Salmo gairdneri* Richardson, in the Alsea River, Oregon. Transactions of the American Fisheries Society 92:202–210.

Wallace, M. and B. W. Collins. 1997. Variation in use of the Klamath River estuary by juvenile chinook salmon. California Fish and Game 83:132-143.

Williams, J. G. 2001. Chinook salmon in the lower American River, California's largest urban stream. Pages 1-38 in R. L. Brown, editor. Contributions to the biology of Central Valley salmonids, volume 2. Fish Bulletin 179. California Department of Fish and Game.

Williams, J. G. 2006. Central Valley salmon: a perspective on Chinook and steelhead in the Central Valley of California. San Francisco Estuary and Watershed Science 4(3).

Willmes, M., F. Cordoleani, A. M. Sturrock, A. M. FitzGerald, B. Cavallo, K. True, and R. C. Johnson. 2024. Integrating otolith and genetic tools to reveal intraspecific biodiversity in a highly impacted salmon population. Journal of Fish Biology 106(2):522–536.

Workman, M. 2003. Downstream migration monitoring at Woodbridge Dam on the lower Mokelumne River, California, December 2002 through July 2003. EBMUD unpublished report. Lodi Fisheries and Wildlife Division.

Workman, M. 2004. Lower Mokelumne River upstream fish migration monitoring conducted at Woodbridge Irrigation District Dam and the lower Mokelumne River ,August 2003 through July 2004. EBMUD unpublished report. Lodi Fisheries and Wildlife Division.

Wu, F. C. 2000. Modeling embryo survival affected by sediment deposition into salmonid spawning gravels: application to flushing flow prescriptions. Water Resources Research 36:1595–1603

Zeug, S. C., K. Sellheim, J. Melgo, and J. E. Merz. 2020. Spatial variation of juvenile Chinook Salmon (Oncorhynchus tshawytscha) survival in a modified California river. Environmental Biology of Fishes 103(5):465-479.

Zeug, S. C., K. Sellheim, C. Watry, J. D. Wikert, and J. Merz. 2014. Response of juvenile Chinook Salmon to managed flow: Lessons learned from a population at the southern extent of their range in North America. Fisheries Management and Ecology 21(2):155-168.