MEMORANDUM

Date: Draft January 31, 2024, Revised March 25, 2024

To: Trinity River Restoration Program

From: Cramer Fish Sciences

Subject: Final Study Plan – Phase 1

BACKGROUND

The Trinity River Restoration Program (TRRP) has invested in restoring the Trinity River for 20+ years. The long-term goals of the TRRP are to: 1) restore the form and function of the Trinity River; 2) restore and sustain natural production of anadromous fish populations in the Trinity River to pre-dam levels; and 3) facilitate full participation by dependent tribal, commercial, and sport fisheries through enhanced harvest opportunities (Pickard et al. 2023), and restoration actions have focused on achieving these goals.

Restoration actions in the Trinity River over the last 20+ years have been linked to increased Chinook juvenile production (as measured by abundance estimates at rotary screw traps with about 2.63 times increase in abundance), but corresponding increases in adult returns have not been detected (Pinnix et al. 2021). The TRRP devised a strategy to conduct a Limiting Factors Analysis (LFA) with the objective of identifying potential causes for the observed discrepancy between the high number of juvenile fish exiting the system and the lack of corresponding increase in adult returns to the Trinity River. The TRRP is employing a two-phased approach that includes development of LFA Study Plans with options for three levels of effort (Phase 1), and selection and completion of one LFA study plan option (Phase 2). This memo covers the outcomes of Phase 1 (a separate request for proposals (RFP) will be developed for Phase 2). Phase 1 tasks, as described in the SOW for Phase 1 and later clarified by TRRP, included the following:

Task 1 Project management and coordination:

General project management including coordination for meetings and deliverables review, project status updates, invoicing, etc.

Task 2 Data discovery and life cycle diagram:

Conduct a high-level search and review of available Trinity River Watershed information to support preparation of materials to review with the TRRP scientists. This included developing a refined life cycle diagram prior to the kick-off meeting and high-level summaries of available data and information on habitat, population demographics, and previous studies in the Trinity River Watershed.

Task 3 Project kick-off meeting:

Preparation of meeting materials (e.g., refined life cycle diagram information, summaries of available data to discuss with TRRP, primers for discussing approaches to consider for the LFA), hosting and leading one day-long kick-off meeting, and preparation of meeting summaries.

Task 4 Develop draft Limiting Factors Analysis Study Plan:

Develop draft LFA Study Plans that include 3 levels of effort options based on the information obtained during data discovery and the kick-off meeting with the TRRP team. The Plans will provide sufficient detail of each level of effort to inform selection of a preferred approach and put the future study team onto a specific track for how to conduct the LFA but will lack sufficient details needed to complete an LFA, as those details should be developed after the preferred approach is identified as part of the LFA process. The TRRP has specified that each effort level should be described in enough detail to allow for development of an independent government cost estimate by Reclamation. However, direct cost estimates should not be included in the plans. Moreover, each option should clearly define its deliverables and may detail the necessary expertise levels and/or provide estimated time frames (effort levels) needed for the completion of various components within each option.

This memo describes the outcomes of Phase 1 including the project kick-off meeting summary and outcomes (Task 3), data discovery and the revised life cycle diagram (Task 2), and the draft LFA Study Plan options (Task 4) developed in Phase 1.The initial draft was reviewed by the TAG and this is the final version that was revised based on provided comments.

OUTCOMES OF THE PROJECT KICK OFF MEETING

The project kick-off meeting was held on October 19, 2023, in Weaverville, CA with a mix of in-person and remote attendees. The list of attendees and meeting notes were provided in a separate memo (see LFA of Chinook Salmon in the Trinity River – Kick-Off Meeting Summary Memo, Appendix A). The kick-off meeting had 17 TRRP participants (staff, consultants, and Science Advisory Board members), and outcomes included identifying a subcommittee of the TRRP to support Phase 1 (hereafter referred to as the Technical Advisory Group or TAG), articulating the overall goals and objectives of the project, reviewing a conceptual ecological model for the LFA, and developing a revised life cycle diagram (LCD) for Trinity River Chinook. These outcomes are described in more detail below.

Technical Advisory Group

The TAG provided streamlined communication between the TRRP and CFS and was tasked with providing more direct and efficient development and review of Phase 1 deliverables. The following TAG members were identified and confirmed during the kick-off meeting:

- Ken Lindke – California Department of Fish and Wildlife
- Chris Laskodi – TRRP/Yurok Tribe
- Eric Peterson – TRRP/U.S. Bureau of Reclamation
- Bill Pinnix – U.S. Fish and Wildlife Service
- Scott McBain – McBain Associates, consultant to Hoopa Valley Tribe Fisheries Department

TRRP Overarching Goals

As articulated in the Science Plan (Pickard et al, 2023), the overarching long-term goals of the Trinity River Restoration Program (Program) are to

1) restore the form and function of the Trinity River;
2) restore and sustain natural production of anadromous fish populations in the Trinity River to pre-dam levels; and
3) to facilitate full participation by dependent tribal, commercial, and sport fisheries through enhanced harvest opportunities.

In addition, more quantitative fishery goals are referenced in Appendix C of the Science Plan (Pickard et al, 2023). The Science Plan further identifies the Program strategy as restoring "processes that produce a healthy alluvial river through a combination of five management actions mandated by the 2000 Trinity River Record of Decision (ROD)" that include:

1) flow management,
2) habitat rehabilitation,
3) sediment management,
4) watershed rehabilitation, and
5) infrastructure improvements.

These are described in more detail in Appendix B of the Science Plan (Pickard et al, 2023), and are generally intended to be captured by the drivers and causes identified in the revised conceptual life cycle diagram (see Drivers and Causes section and Table 7). The Program goals provide context for the LFA Project objectives that were articulated in coordination with the TRRP and TAG, and described in the following section.

Project Objectives

CFS and TRRP scientists collaborated on outlining the objectives of Phases 1 and 2 during the kickoff meeting to ensure that Phase 1 outcomes align with Phase 2 needs and the TRRP's overall objectives for the LFA. As part of this kick-off meeting discussion, a draft conceptual ecological model for the LFA was discussed and reviewed by the TAG. This conceptual model is described in more detail in the following section and serves as an overall guide for the LFA. The TRRP described their desired outcomes and measures of success for the overall LFA during the kick-off meeting as follows:

Overall desired outcomes of the LFA project:

- ***Provide information to support fishery and production goals:*** The TRRP indicated that their goals are to maintain a robust and sustainable fishery, to protect a way of life as opposed to an endangered species recovery program, restore and sustain natural production of anadromous fishes in the Trinity River. The LFA will ideally provide enough information to understand if available TRRP management actions are sufficient to rebound the fishery, the anticipated timelines and actions required to do so.
- ***Better understanding of what is limiting adult returns of Trinity River Chinook Salmon:*** This high-level objective acknowledges that there are uncertainties about what may be currently or potentially limiting adult returns, and at what life stages and locations these limitations are

occurring. This objective also articulates the need to develop a LFA to provide insights into the drivers and factors that limit population productivity (overall survival from egg to returning adults).

- ***Ability to identify multiple LFs and rank them:*** The LFA should be capable of identifying multiple LFs and supporting ranking them based on their relative influence on population and life stage productivity (e.g., survival from one life stage to another) and the degree to which the TRRP can influence the LF(s).
- ***Identify data gaps and uncertainties:*** This will help the TRRP identify future areas to focus resources and improve our understanding of limiting factors. Furthermore, this supports continued refinement and adaptation of the LFA.
- ***Support identification of restoration or management scenarios to address LFs:*** This assumes that LFs identified in the LFA are linked to potential restoration or management actions within the control of the TRRP. It may also include management actions outside of the TRRP control (e.g., fisheries management), and should consider extrinsic factors within and outside of the Trinity River (e.g., Klamath River or ocean conditions, Trinity River tributaries). Therefore, this objective articulates the desire for the LFA to support the identification or development of restoration and management actions that can address the LFs in a way that anticipated benefits can be evaluated in the context of within and outside of TRRP control. The goal is to support prioritization and development of restoration plans or strategies to be implemented by the TRRP or others.
- ***Support evaluation of current actions, planned, or potential actions to address LFs:*** The TRRP has invested considerable resources and effort into physical restoration (mechanical watershed and mainstem channel restoration and gravel augmentation) on the upper 40 miles, and water temperature and flow management down to the Klamath River confluence (and likely the Klamath River as well). Developing tools to better understand the effectiveness of these actions or how they could be adapted in the future to better address current or emerging LFs was a desired outcome of the LFA. In addition, hatchery infrastructure improvements, channel rehabilitation projects, and other projects that are currently being planned could benefit from the outcomes of the LFA by providing guidance on design or strategies to address identified LFs.
- ***Provide material and tools for public facing outreach materials or tools:*** The TRRP identified a need to efficiently share the outcomes of the LFA in an objective manner to a range of audiences. The LFA should provide tools and materials to support communication of that information to the public.

These desired outcomes were synthesized from the kick-off meeting summary, as well as TAG feedback and used as guiding principles in developing the LFA Study Plan options. In addition to these overall objectives, the TRRP also defined the objectives of Phase 1 specifically during the kick-off meeting that included the following:

Phase 1 objectives:

- ***Develop study plans with 3 levels of effort options for the LFA:*** The study plans developed in Phase 1 should provide sufficient detail to develop budgets, select a study plan option, and develop an RFP to procure a contractor to conduct the selected study plan option. See Task 4 details previously described for more information.

- ***Develop transparent tools:*** The outcomes of the LFA options and the tools developed should be transparent and open to the scientific community to review and diagnose, not black-box tools that are not readily understandable, transparent, updateable, or adaptable.
- ***Define success in quantifiable terms:*** This will help guide possible model development for the selected LFA option.
- ***Identify the required components for each LFA option:*** This will help develop the RFP and completion of the selected LFA option, and the three study plan options should describe the appropriate level of effort as well as required data to conduct the selected option.
- ***Recommendations on LFA options:*** Recommendations as to which LFA option(s) to consider, including pros and cons for the study plan options.

Conceptual Ecological Limiting Factors Analysis Model

We developed a conceptual ecological model for the Chinook Salmon LFA in the Trinity River to provide a roadmap for developing and conducting the LFA. A draft of this conceptual model was presented to the TRRP and its partners during the kick-off meeting, and the TAG provided comments and feedback that we incorporated into the revised version (Figure 1). This conceptual model is intended as a guide and provides context for how Phase 1 fits into the larger project and the goals and objectives of the LFA.

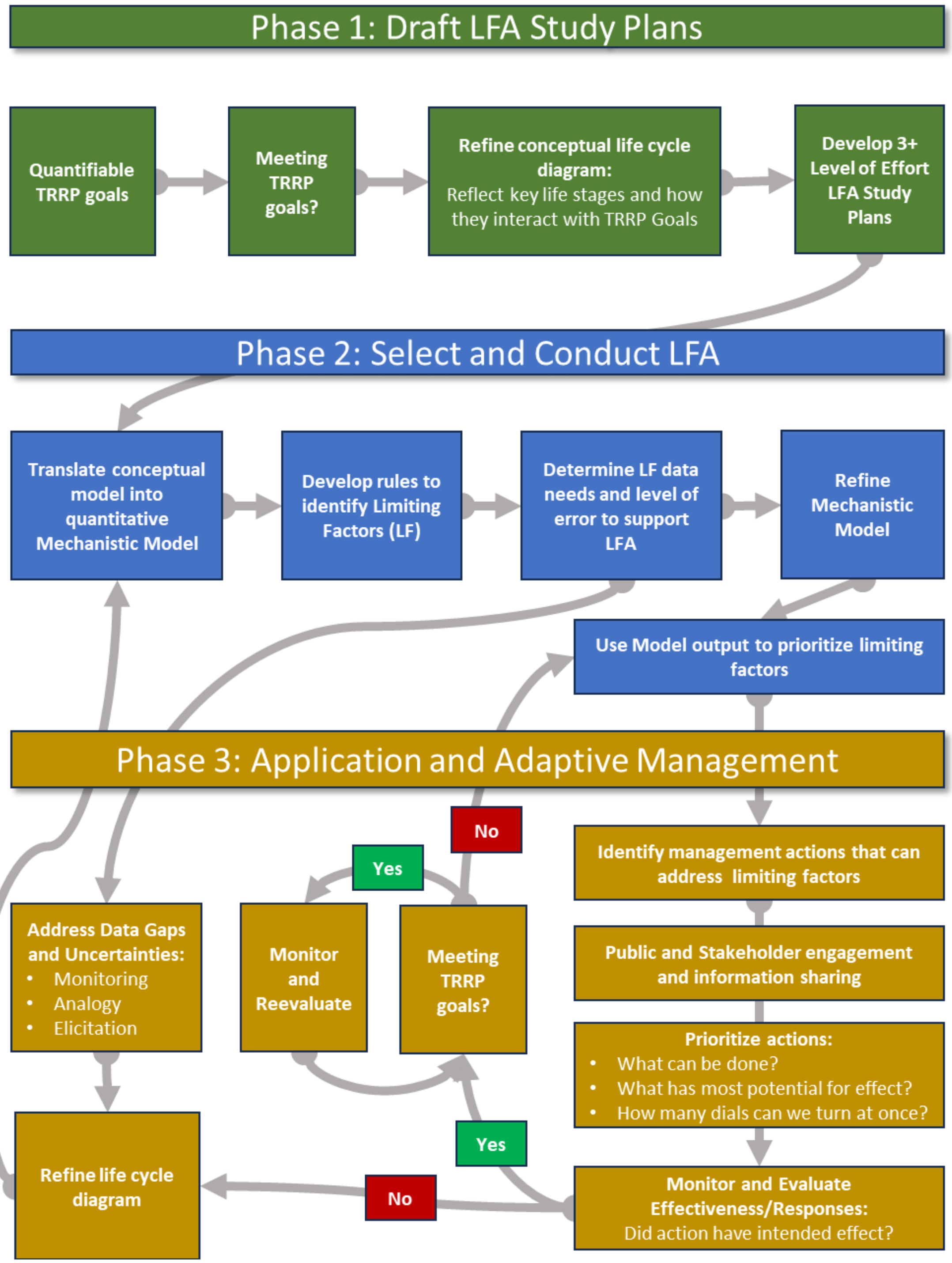

Figure 1. Conceptual Ecological Model for the Trinity River Chinook Salmon Limiting Factors Analysis (LFA) that describes Phase 1 (green) and development of the draft LFA study plans, Phase 2 (blue) and selection and completion of the LFA, and Phase 3 (orange) and application and adaptive management of the LFA and its outcomes.

Conceptual Life Cycle Diagram (LCD)

The LCD is a conceptual model and tool intended to support development and completion of the LFA by identifying key life stages and life stage transitions, and the potential drivers and causes that influence productivity during these life stages. The TRRP provided a draft LCD for review, and we presented recommended revisions at the kick-off meeting. We also summarized our recommendations in a memo for the TAG. The LCD was then revised based on feedback obtained during the kick-off meeting and in collaboration with the TAG (Figure 2). The revised LCD intentionally included increases in complexity so that all pathways considered viable by the team could be described and considered. However, the LFA may use a simplified subset of this conceptual framework, as would be expected in an iterative process (Tear et al. 2005; Williams et al. 2009). Similarly, collection of additional data may support further refinements or addition of detail to the LCD (e.g., addition of lower and upper reaches for the Trinity River and/or Klamath River).

Revisions to the LCD during this phase included the addition of a spatial component, visualized as rings or slices of the life cycle based on location, including the Trinity River, Klamath River, Estuary, and Ocean (Figure 2). In addition, we added a visual representation of the key life stages and life history variations from adult spawners to incubating embryos (eggs), emergent fry, rearing and outmigrating juveniles, and ocean maturation to the inner ring of the LCD to visually orient the reader to the life stage and cycle (Figure 2). To support interpretation of the conceptual LCD and the narratives in the following sections, a generalized study area map showing the spatial context and monitoring components from the Science Plan is provided for reference (Figure 3).

The following sections describe the revised LCD that we developed in coordination with the TRRP and TAG. We include descriptions of the key life stages and transitions, as well as the spatial structure, periodicity, and life history variations shown in the LCD. Periodicity for the life stages will need to be reviewed and refined in Phase 2 as available monitoring data are analyzed. The drivers and causes that potentially influence each life stage and transition rates are described in the Drivers and Causes section and were not included in the LCD to maintain legibility.

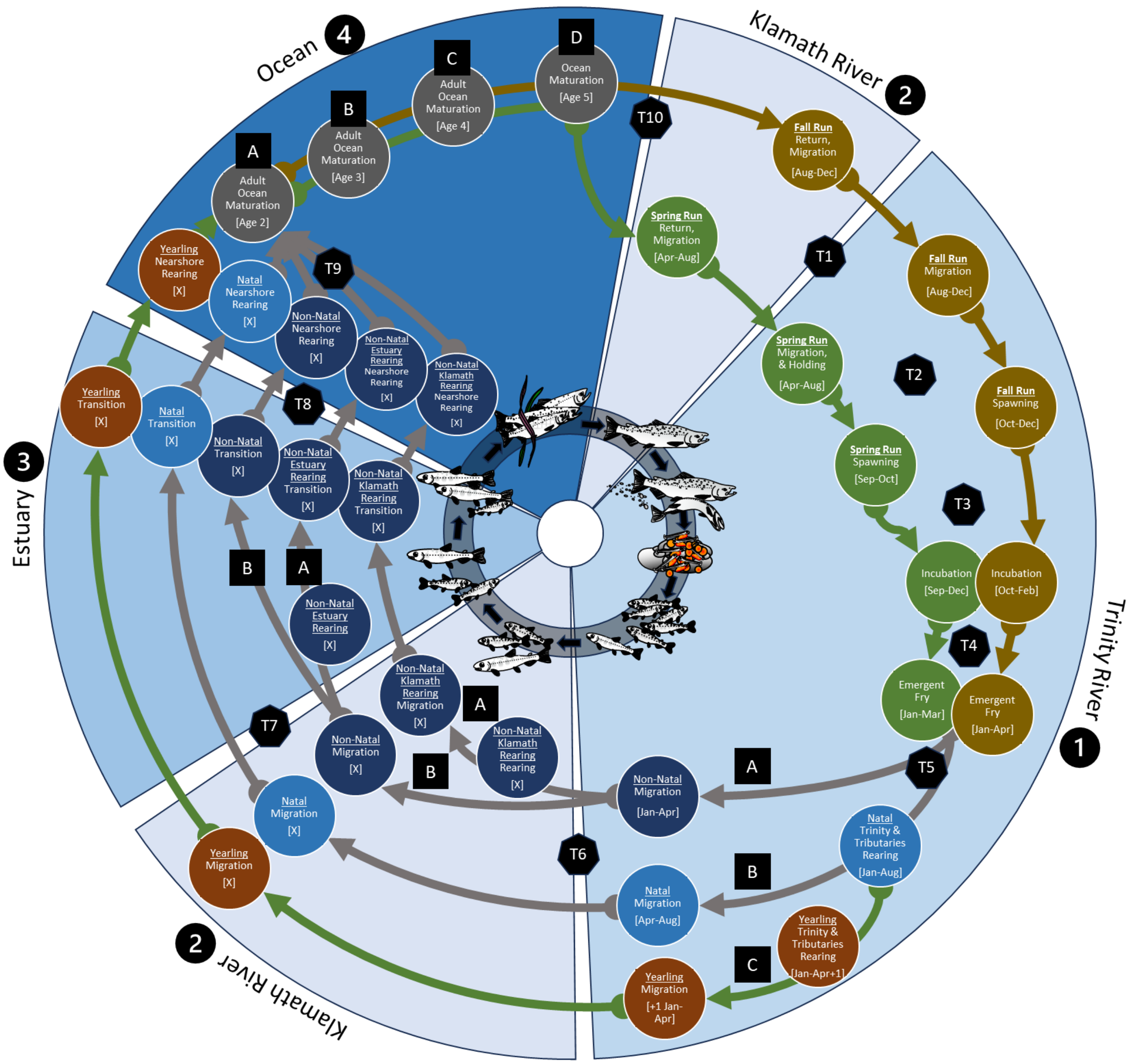

Figure 2. Revised life cycle diagram for Trinity River Chinook that was developed in collaboration with TRRP scientists. This conceptual model shows the spatial structure as fish move through different geographic areas including the Trinity River, Klamath River, Estuary, and the Ocean, which are labeled with numbers in black circles that refer to Figure 3. The life stages are shown as circles, with the name of the life stage 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) 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 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 not known or needs to be determined.

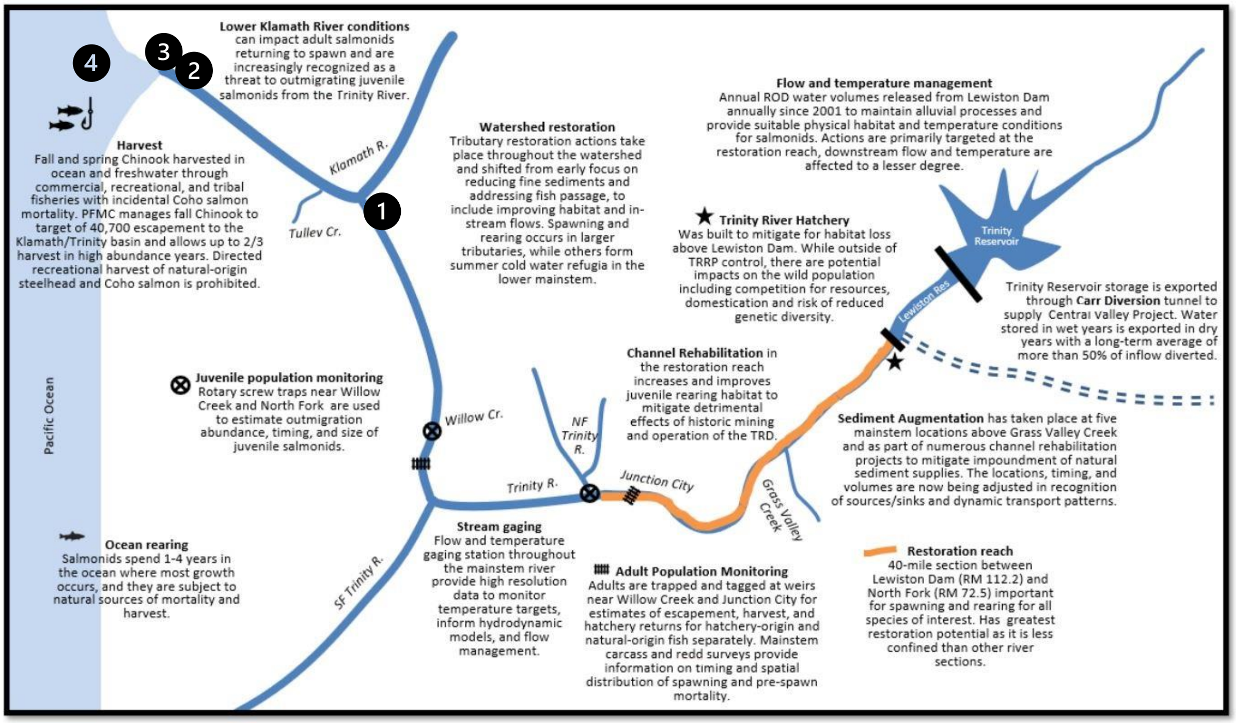

Figure 3. Study area map from the Science Plan (Pickard et al. 2023) that shows the spatial arrangement of the system, as well as Program management actions and monitoring elements. The spatial components shown in the LCD (see Figure 2) are also shown for reference with areas upstream of ❶representing the Trinity River, areas between ❶ and ❷ showing the Klamath River downstream of the Trinity River confluence, ❸ representing the estuary, and ❹ representing the ocean. Note that additional data may be identified during data discovery and Phase 2 that are not represented in this map.

Adult In-River Life Stages

We broke out adult return through spawning life stages to represent both Spring- and Fall-run Chinook, and the pathways for these two populations include a spatial component for the Klamath River and Trinity River portions of their adult in-river life stages (see Figure 2 and Figure 3). The run type pathways and spatial structure of the conceptual model allows the LCD to describe differences in exposure to factors that can influence transition from one life stage to another based on a combination of timing, duration, location, and behavior. In total, three adult in-river life stages with three transitions were identified for both Spring-run and Fall-run Chinook Salmon (Table 1).

Early run timed Chinook (Spring-run) enter the river much earlier (April – June) than late timed (Fall-run) Chinook (August – December), with little upriver migration occurring from July – August (Rupert et al. 2017). Based on TAG feedback, we assume that neither Spring-run nor Fall-run Chinook use the Klamath River for holding. However, Spring-run Chinook Salmon generally enter fresh water in an immature state and require deep holes with appropriate conditions to facilitate maturation while conserving calories (Groot and Margolis 1991; Healy 1991). In contrast, late timed Fall-run adults are typically an "ocean-type" fish that enter fresh water in a mostly mature state and will acquire secondary sexual characteristics relatively quickly. They may still hold in pools for short-term energy conservation while waiting for conditions that facilitate upstream migration and spawning (Groot and Margolis 1991; Healy 1991). Spring- and Fall-run Chinook spawning was temporally and spatially separated prior to dam construction. However, spawning is presently forced to spatially overlap, with some slight differences in spawning timing (Rupert et al. 2017). Spring-run Chinook spawn from September – October whereas Fall-run Chinook spawn from October – December.

In addition, there is a genetic component to run timing for Spring- and Fall-run populations, and modeling has demonstrated that continued selection against the Spring-run phenotype can result in loss of the Spring-run allele (Thompson et al. 2018). Although Spring-run Chinook escapement to the Trinity is generally lower than that of Fall-run, escapement data for the Trinity River indicates that both Spring- and Fall-run Chinook are well represented in escapement to the Trinity River (Gough et al. 2021; Figure 4). From both a population management and resiliency perspective (Ford et al. 2020), preservation of both run types is important and including both pathways in the conceptual model supports hypotheses testing and tracking of these populations in the LFA. Furthermore, differences in timing, duration, and location of exposure to factors that can influence survival rates as adults transition from river entry through spawning life stages supports including both pathways as well as the spatially explicit life stages (Figure 2; Table 1).

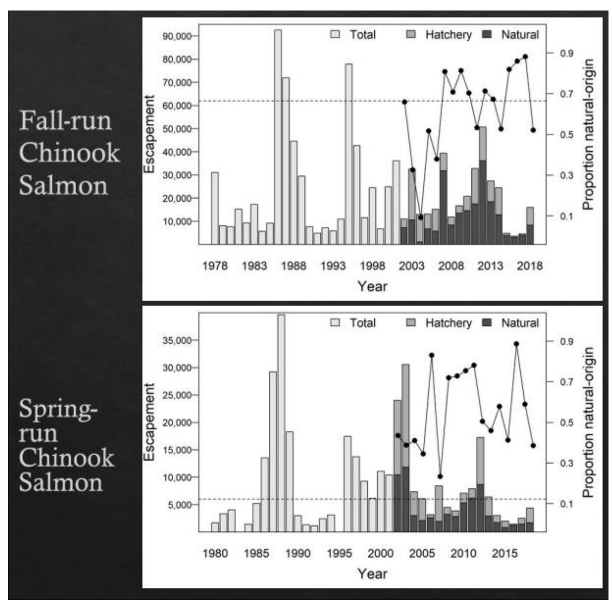

Figure 4. Natural area escapement to Trinity River for Fall-run Chinook (Top) and Spring-run Chinook (Bottom) from Gough et al. (2021).

Table 1. Adult in-river life stages, periodicity, and transitions described in the conceptual life cycle diagram (see Figure 2) that occur in the Klamath River and Trinity River (Figure 3).

Population	Life Stage	Spatial Location	Periodicity	Transition From Previous Life Stage	Transition To Next Life Stage
Fall-run	Adult return and migration	Klamath River	Aug-Dec	T10	T1
	Adult migration	Trinity River	Aug-Dec	T1	T2
	Adult spawning	Trinity River	Oct-Dec	T2	T3
Spring-run	Adult return and migration	Klamath River	Apr-Aug	T10	T1
	Adult migration and holding	Trinity River	Apr-Aug	T1	T2
	Adult spawning	Trinity River	Sep-Oct	T2	T3

Incubation Life Stage

The incubation life stage represents the period in which fertilized eggs deposited by successful spawners in the Trinity River incubate until they emerge as fry (Figure 2 and Figure 3). Given the differences in spawn timing for Spring- and Fall-run, and the potential genetic differences in their progeny (Thompson et al. 2018), we separated life stages for the incubation of Spring- and Fall-run eggs (Figure 2; Table 2). These life stages are shown as overlapping in the conceptual LCD to represent the mixing that occurs because of temporal and spatial overlap during spawning as well as variance in juvenile development and growth of the two populations related to complexity of habitat and water temperatures (Figure 2). Eggs deposited in spawning reaches of the Trinity River represent a mix of both populations, and parentage can only be determined through genetic analyses of their progeny. Furthermore, redd superimposition is a concern given that Fall-run adults may spawn over redds previously constructed by Spring-run adults given the spatial overlap in spawning ranges (Gaeuman et al. 2023). Redd scour from high flows is also another potential factor influencing survival to emergence for incubating eggs and embryos. It is hypothesized that the impact of superimposition on survival to emergence is less than that of redd scour, but this does not appear to have been tested or quantified (Gaeuman et al. 2023). The duration of incubation depends on the individual timing of spawning, temperature, and other factors, and we generally describe periodicity for incubation as occurring between September – December for Spring-run progeny and October – February for Fall-run progeny (Figure 2; Table 2). Variations in temperature and overlaps in spawn timing can also lead to variance in growth rates that can result in overlap of sizes during rearing and emigration (e.g., Merz et al. 2014).

Table 2. Incubation life stages, periodicity, and transitions for Chinook Salmon in the Trinity River, as described in the conceptual life cycle diagram (see Figure 2 and Figure 3).

Population	Life Stage	Spatial Location	Periodicity	Transition From Previous Life Stage	Transition To Next Life Stage
Fall-run	Incubation	Trinity River	Sep-Dec	T3	T4
Spring-run	Incubation	Trinity River	Oct-Feb	T3	T4

Trinity River Juvenile Life Stages

The emergent fry life stage represents juveniles that survived incubation and substrate emergence to form the brood year that can express several different life histories (Figure 2). The emergent fry life stages that occur in the Trinity River are shown as two different but overlapping life stages in the conceptual LCD (Figure 3) to represent the mixing of Spring-run and Fall-run progeny during spawning and the potential for genetic-based expression of the Spring-run and Fall-run timing (Figure 2). From the emergent fry life stage, the conceptual LCD shows three primary life history pathways (or strategies) expressed by juvenile Chinook that represent a gradation of increasing time rearing in their natal habitats before migration. They therefore display an increasing size and development at migration and timing of emigration from the Trinity River. These are shown as two subyearling migrant and a yearling migrant life history in the conceptual LCD (Figure 2; Table 3). Miller et al. (2010) described most naturally spawned Fall-run Chinook juveniles emigrating in two pulses: small juveniles (referred to as fry), typically ≤55 mm fork length (FL), emigrating from natal streams in February–March, whereas larger juveniles (smolts), typically > 75 mm FL, emigrate in mid-April–May. As noted previously, variations in temperatures and temporal overlap in spawning can result in overlaps and differences in emergence timing and growth rates that can result in overlapping sizes among life histories and progeny of Fall-run and Spring-run juveniles (see Merz et al. 2014).

Apgar et al. (2020) further articulated two predominant subyearling migrant Chinook Salmon life histories considered in the conceptual LCD, which include natal rearing migrants (natal) and non-natal rearing migrants (non-natal). Natal migrants, as described by Apgar et al. (2020), spend extended time (e.g., 1-6 months, or more for yearling migrants) rearing in natal streams where they feed and attain a larger body size before migrating downstream. In contrast, non-natal migrants spend only a few days to weeks in their natal streams and therefore emigrate earlier and at a smaller size compared to natal emigrants (Apgar et al. 2020). The TAG indicated that they would like to review the concepts of non-natal and natal rearing life histories as they apply to the Trinity River, and this is something that should be considered in Phase 2. Traditionally, non-natal rearing migrants were considered surplus production that cannot be supported by their natal stream's carrying capacity, have poorer survival to adult return due to size selective mortality, and contribute little to adult returns. However, differences in timing of emigration and location of rearing combined with variations in relative production can spread risk over space and time (Greene et al. 2010; Apgar et al. 2020). This is generally referred to as a portfolio effect whereby variation in the timing of occupancy or migrations can spread risk, or exposure to factors that influence survival over spatial (e.g., Trinity River vs Klamath River) and temporal scales (e.g., earlier emigrations vs later emigrations). In general, studies have shown that smaller emigrants have a lower survival rate due to size selective morality (e.g., Beamer et al. 2005), but higher total abundance of earlier and smaller timed individuals can compensate for reduced survival rates. In addition, studies have shown that non-natal survival rates can approach natal survival rates in some years and populations (e.g., Satterthwaite and Carlson 2015; Sturrock et al. 2015; Sturrock et al. 2019); therefore, both natal and non-natal rearing can contribute to population resilience and are included in the Trinity River conceptual LCD (Figure 2).

In addition, analysis of long-term monitoring data in the Trinity River has demonstrated changes in the abundance and size at emigration relative to implementation of the Record of Decision (ROD) after 2004 (Pinnix et al. 2022) and these results are supported in the literature (Zeug et al. 2014). This potential linkage between management actions and life history expression, and its subsequent potential effects on survivorship further highlight the benefit of including both natal and non-natal rearing migrants in the conceptual LCD. In fact, this is a central question that should be addressed in the LFA. For the purposes of the Trinity River conceptual LCD, we assume that non-natal emigrants leave their natal stream (the Trinity River or natal tributaries to the Trinity) soon after emergence from January – April (see (A) in Trinity River in Figure 2). In contrast, natal rearing emigrants rear in their natal stream or tributaries before emigration from April – July (see (B) in Trinity River in Figure 2).

In addition to these subyearling life histories, the conceptual LCD includes yearling migrants that may remain in their natal river and overwinter in the Trinity River or its tributaries before migrating downstream and leaving the Trinity River in January – April in the year after emergence (see (C) in Trinity River in Figure 2). There is potential for both Spring-run and Fall-run Chinook to produce yearling life histories, as well as the subyearling life histories shown in the conceptual LCD (Healy 1991), but we assume yearlings are primarily produced by Spring-run Chinook. These assumptions are shown in the conceptual LCD with gray arrows for both the natal and non-natal rearing migrants, representing a mix of Spring-run and Fall-run progeny, while yearling migrants are shown with a green arrow, representing primarily Spring-run progeny (Figure 2). The TAG provided comments that suggested the yearling life history pathway is not common but may be important to consider, especially for Spring-run Trinity River Chinook. However, rotary screw trap (RST) monitoring can be ineffective at capturing yearlings due to low abundance, low trap capture efficiency, lack of calibrations specific to yearling size classes, or deployments that do not span the emigration timing for yearlings (e.g., see Lisi et al. 2022). Because there is uncertainty regarding the expression of yearling life histories for Trinity River Chinook Salmon, we retained the yearling pathway in the conceptual LCD to account for the possible expression of this life history in the population and to support identification of data gaps and uncertainties in the LFA.

The TAG also noted that the Trinity River is relatively large and there may be some rationale for breaking up the spatial structure and life history pathways to represent rearing in the upper and lower reaches of the Trinity River as well as its tributaries, but current monitoring data may not be sufficient to tease apart pathway dynamics. Two Trinity River RSTs provide some spatial resolution (see Pickard et al. 2022 and Pinnix et al. 2022), but both traps are located in the mid to upper reaches (Willow Creek and Pear Tree RSTs). Without monitoring in the lower reaches of the Trinity, there will be uncertainty as to whether juveniles captured at the lower RST (Willow Creek) represent outmigrants from the Trinity and if they will rear in the lower reaches of the Trinity (or its tributaries) before moving downstream into the Klamath River.

Table 3. Trinity River juvenile life stages, periodicity, and transitions described in the conceptual life cycle diagram (see Figure 2 and Figure 3).

Population	Life Stage	Spatial Location	Periodicity	Transition From Previous Life Stage	Transition To Next Life Stage
Spring- and Fall-run	Emergent Fry	Trinity River	Jan-Aug	T4	T5
	Non-Natal Migration (A)	Trinity River	Jan-Apr	T5	T6

	Natal Trinity and Tributary Rearing (B)	Trinity River	Jan-Aug	T5	T6
	Natal Migration (B)	Trinity River	Apr-Aug	T5	T6
Spring-run	Yearling Trinity and Tributary Rearing (C)	Trinity River	Jan – Apr+1	T5	T6

Klamath River Juvenile Rearing and Outmigrant Life Stages

Trinity River emigrants, whether non-natal rearing (A), natal rearing (B), or yearling (C), entering the Klamath River represent a transition into different life stages in the LCD (Figure 2; Figure 3). We assume five primary life stages in the Klamath River (Figure 2; Table 4), with two representing alternative rearing strategies. However, there is no RST monitoring in the Klamath River below the Trinity confluence (based on TAG feedback); therefore, our representation of life history pathways is based on general known juvenile Chinook life history expression (e.g., Healy 1991; Apgar et al. 2020). Without RST monitoring in the Klamath River, information on the periodicity of juvenile lifestages that originated in the Trinty and their utilization of the Klamath River is lacking. Therefore, periodicity is presently denoted with an [X] in the conceptual LCD (Figure 2) until this information can be obtained and validated by the TAG and TRRP scientists. Furthermore, juveniles produced by Klamath River Chinook populations would mix with Trinity River production and this may further complicate our ability to determine Trinity River-specific patterns from available data.

For Trinity River emigrants, we assume non-natal rearing juveniles enter the Klamath River the earliest and at a smaller size than natal rearing and yearling rearing life histories, based on RST monitoring data from the Trinity (see Pickard et al. 2022 and Pinnix et al. 2022) and assumptions from Apgar et al. (2020). Once in the Klamath River, we assume that these non-natal rearing migrants may either rear in the Klamath River or its tributaries or continue to migrate downstream to the estuary and spend little time rearing in the Klamath River (Murray and Rosenau 1989, Limm and Marchetti 2009). These two pathways are shown as (A) and (B) in the conceptual LCD (Figure 2; Table 4). Similar to natal rearing migrants that reared in the Trinity, the non-natal Trinity migrants that rear in the Klamath River are assumed to represent an alternate rearing strategy (that would presumably spread risk over space and time with respect to rearing, e.g., Greene et al. 2010), whereby they attain a similar size as natal Trinity rearing juveniles but with the rearing occurring in the non-natal Klamath River (see Beamer et al. 2005a and 2005b for analogous patterns in Skagit River Chinook).

The natal Trinity and Trinity tributary rearing migrants are assumed to spend little time rearing in the Klamath River and use it primarily as a migration corridor as they migrate to the estuary and ocean (Figure 2; Table 4). Similarly, yearling migrants produced by the Trinity River are assumed to primarily migrate downstream through the Klamath River and spend little time rearing in the Klamath River (Figure 2; Table 4). In addition, the conceptual LCD assumes that non-natal migrants that rear in the Klamath River and natal Trinity rearing migrants do not overwinter in the Klamath River to produce an alternative yearling rearing life history strategy.

Table 4. Klamath River juvenile life stages, periodicity, and transitions described in the conceptual life cycle diagram (see Figure 2 and Figure 3). Note that [X] indicates periodicity is not known or needs to be determined.

Population	Life Stage	Spatial Location	Periodicity	Transition From Previous Life Stage	Transition To Next Life Stage
Spring- and Fall-run	Non-natal Migration (B)	Klamath River	[X]	T6	T7
	Non-natal Klamath River rearing (A)	Klamath River	[X]	T6	T7
	Non-natal Klamath River Rearing Migration (A)	Klamath River	[X]	T6	T7
	Natal Migration	Klamath River	[X]	T6	T7
Spring-run	Yearling Migration	Klamath River	[X]	T6	T7

Estuary Juvenile Rearing and Transition Life Stages

A total of six life history variations are identified for the estuary rearing and transition life stages for juvenile Chinook Salmon produced in the Trinity River (Figure 2 and Figure 3). All but one of these are assumed to spend little to no time rearing in the estuary and primarily use the estuary as transitional habitat to support physiological adaptation to marine life. The non-natal rearing migrants produced by the Trinity River that do rear in the Klamath River are assumed to either rear for weeks to months in the estuary (A) or continue through the estuary with little to no rearing (B) (see Beamer et al. 2005a and 2005b for analogous patterns in Skagit River Chinook). It is generally assumed that the juveniles rearing in the estuary would attain a size similar to natal Trinity juveniles that rear in the Trinity or Klamath River at the time of transition to marine life stages with this alternative rearing strategy. In contrast, non-natal outmigrants that do not rear in the Trinity, Klamath River, or estuary before transitioning to marine life stages would be assumed to enter the ocean earliest and at the smallest size. Survival to adult return can generally follow a size selective pattern with increasing body size at emigration generally increasing survivorship, although variations in the timing of emigration and spatial location of rearing can spread risk over space and time and survival rates can vary from year to year and among life histories (Ruff et al. 2017; Apar et al. 2020). However, similar to the Klamath River life stages, monitoring information for the estuary is limited and analyses of these data or future monitoring may be needed to determine how Trinity River Chinook utilize the estuary, including periodicity, which is currently denoted as [X]. The TAG indicated that some estuary monitoring has occurred, but these data will need to be evaluated as part of Phase 2. In addition, potential for lagoon formation as well as mixing of progeny from Klamath River Chinook populations may further complicate the ability to determine patterns specific to Trinity River Chinook.

Table 5. Estuary juvenile life stages, periodicity, and transitions described in the conceptual life cycle diagram (see Figure 2 and Figure 3). Note that [X] indicates periodicity is not known or needs to be determined.

Population	Life Stage	Spatial Location	Periodicity	Transition From Previous Life Stage	Transition To Next Life Stage
Spring- and Fall-run	Non-natal Klamath Rearing Transition	Estuary	[X]	T7	T8
	Non-natal Estuary Rearing (A)	Estuary	[X]	T7	T8
	Non-natal Estuary Rearing Transition (A)	Estuary	[X]	T7	T8
	Non-natal Transition (B)	Estuary	[X]	T7	T8
	Natal Transition	Estuary	[X]	T7	T8
Spring-run	Yearling Transition	Estuary	[X]	T7	T8

Nearshore and Marine Life Stages

A total of five life stages are identified for nearshore juveniles, which represent the outputs for estuary transition life stages as juvenile move into nearshore marine habitats (Figure 2 and Figure 3). Similar to Klamath River and estuary life stages, we have little information to inform life history pathways and periodicity for these life stages. It is assumed that life histories with larger sizes at migration to the nearshore would utilize deeper and more offshore habitats. In contrast, life history pathways with smaller sizes at outmigration would presumably utilize shallower and more nearshore habitats for the initial stages of rearing (e.g., Beamer et al. 2005b). As these juveniles mature, they transition into adult maturation life stages and the conceptual LCD shows these alternative life history pathways as converging into the adult ocean maturation life stages where they may remain for one to four years before returning. These are shown as (A), (B), (C), and (D) representing age-2, age-3, age-4, and age-5 adults in the ocean, respectively, with the connecting arrows indicating that individuals in each age class may return to the river. Note that transition rates from marine age classes represent a combination of marine survival as well as maturation rate. A cohort reconstruction that is currently underway will inform these life stages and transition (maturation) rates (see Lindke 2021 for summary). Age-5 adults appear to make up a very small portion of the returns, with ages 3-4 making up most returns in most years (Lindke 2021). Age-2 adults vary among years but represent a substantial proportion of the returns in some years (Lindke 2021).

Table 6. Nearshore and marine life stages, periodicity, and transitions described in the conceptual life cycle diagram (see Figure 2 and Figure 3). Note that [X] indicates periodicity is not known or needs to be determined.

Population	Life Stage	Spatial Location	Periodicity	Transition From Previous Life Stage	Transition To Next Life Stage
Spring- and Fall-run	Non-natal Klamath River Rearing Nearshore Rearing	Nearshore	[X]	T8	T9
	Non-natal Estuary Rearing Nearshore Rearing	Nearshore	[X]	T8	T9
	Non-natal Nearshore Rearing	Nearshore	[X]	T8	T9
	Natal Nearshore Rearing	Nearshore	[X]	T8	T9
Spring-run	Yearling Nearshore Rearing	Nearshore	[X]	T8	T9
Spring- and Fall-run	Adult Ocean Maturation (A)	Ocean	Age 2	T9	T10
	Adult Ocean Maturation (B)	Ocean	Age 3	T9	T10
	Adult Ocean Maturation (C)	Ocean	Age 4	T9	T10
	Adult Ocean Maturation (D)	Ocean	Age 5	T9	T10

Drivers and Causes

The TRRP provided an initial list of drivers and causes along with the preliminary LCD that was reviewed as part of Phase 1. Based on information reported in the Science Plan (Pickard et al. 2022), TAG review and recommendations, and other materials compiled by the TRRP (TRRP 2023), we developed a revised list of drivers and causes (Table 7). These drivers and causes are organized by life stage and life history pathway, as shown in the conceptual LCD (see Figure 2).

The revised list of drivers and causes listed Table 7 represent factors that should be considered in the LFA or are hypothesized to potentially influence productivity or capacity at various life stages. However, inclusion of a driver or cause in the revised table does not imply that it is a limiting factor as that will be evaluated in Phase 2. To that end, the list was intentionally inclusive of a larger suite of factors to consider, and it will be one of the LFA goals to determine which among these are in fact limiting population production at various life stages (e.g., juvenile production, adult production). Where applicable, drivers and causes that are linked to TRRP management actions are identified because these represent "dials" that the TRRP can potentially control or influence through their management actions. This will also help support prioritization and ranking of limiting factors during the LFA (Phase 2). Similarly, drivers and causes potentially linked to other management actions outside of TRRP control are also identified given that these are potential "dials" that could be influenced by changes in management actions from outside agencies (e.g., hatcheries or harvest).

Table 7. Drivers and causes linked to life stages and transitions identified in the conceptual life cycle diagram (Figure 2). Life histories represent pathways shown in the conceptual life history diagram, and life stages are shown in Figure 2. Note that this table focuses on the transitions and those may apply to multiple life history pathways. The spatial extent indicates which geographic area the life stage is occupying, and the transition represents the transition from the life stage indicated to the next life stage (see Figure 2). †Indicates a cause is linked to TRRP management actions. ‡Indicates a cause is potentially linked to TRRP management actions but indirectly. *Indicates there is a potential link to management that is outside of TRRP control.

Previous Life Stage(s) & Life History(s)	Spatial Extent	Transition to Next Life Stage	Drivers	Causes
Spring-Run & Fall-Run Chinook: Adult return, migration.	Klamath River	T1	• Predation • Harvest • Disease • Pre-spawn mortality • Water quality and quantity (temperature, flow) • Habitat connectivity (thermal refugia & tributaries)	• Water quality‡ • Abundance • Fisheries management* • Predator population • Climate (change, wet/dry water year) • Water withdrawal* • Wildfire
Spring-Run Chinook: Migration & holding.	Trinity River	T2	• Predation • Harvest • Disease • Pre-spawn mortality • Habitat quantity and quality (holding) • Water quality and quantity (temperature, flow) • Habitat connectivity (thermal refugia & tributaries)	• Flow management† • Water quality† • Temperature management† • Abundance (and Hatchery management*) • Fisheries management* • Predator population • Climate (change, wet/dry water year) • Water withdrawal* • Wildfire

Previous Life Stage(s) & Life History(s)	Spatial Extent	Transition to Next Life Stage	Drivers	Causes
Fall-Run Chinook: Adult migration.	Trinity River	T2	• Predation • Harvest • Disease • Pre-spawn mortality • Water quality and quantity (temperature, flow) • Habitat connectivity (thermal refugia & tributaries)	• Flow management† • Water quality† • Temperature management† • Abundance • Fisheries management* • Predator population • Climate (change, wet/dry water year) • Water withdrawal* • Wildfire
Spring-Run & Fall-Run Chinook: Spawning.	Trinity River	T3	• Pre-spawn mortality • Habitat quantity and quality (spawning) • Water quality and quantity (temperature, flow) • Habitat connectivity	• Flow management† • Water quality† • Temperature management† • Abundance (and Hatchery management*) • Predator population • Climate (change, wet/dry water year) • Water withdrawal* • Wildfire
Spring-Run & Fall-Run Chinook: Incubation.	Trinity River	T4	• Habitat quality (spawning) • Redd superimposition (habitat quantity, distribution, spawner abundance/timing) • Thiamine deficiency • Predation (egg) • Temperature	• Flow management† • Temperature management† • Sediment management† • Ocean diet • Predator population • Abundance • Climate (change, wet/dry water year) • Wildfire

Previous Life Stage(s) & Life History(s)	Spatial Extent	Transition to Next Life Stage	Drivers	Causes
Spring-Run & Fall-Run Chinook: Emergent Fry.	Trinity River	T5	• Physical habitat (depth, velocity, cover) • Temperature (temporal & spatial variability) • Foodscape (drift forage) • Competition • Predation • Habitat connectivity (thermal refugia & tributaries)	• Flow management† • Temperature management† • Hatchery management* • Channel form‡ • Predator population • Abundance • Climate (change, wet/dry water year) • Wildfire
Non-natal Rearing Migration (A): Juveniles that do not rear in Trinity or its tributaries after emergence.	Trinity River	T6	• Habitat quantity & quality (depth, velocity, cover) • Habitat connectivity (thermal refugia & tributaries) • Temperature (temporal & spatial variability) • Foodscape (drift forage) • Competition • Predation	• Flow management† • Temperature management† • Hatchery management* • Channel form‡ • Predator population • Abundance • Climate (change, wet/dry water year) • Wildfire
Natal Rearing & Outmigration (B): Juveniles that rear in Trinity or its tributaries before migration, but do not overwinter.	Trinity River	T6	• Habitat quantity & quality (depth, velocity, cover) • Habitat connectivity (thermal refugia & tributaries) • Temperature (temporal & spatial variability) • Foodscape (drift forage) • Competition • Predation	• Flow management† • Temperature management† • Hatchery management* • Channel form‡ • Predator population • Abundance • Climate (change, wet/dry water year) • Wildfire

Previous Life Stage(s) & Life History(s)	Spatial Extent	Transition to Next Life Stage	Drivers	Causes
Yearling Rearing & Migration (C): Juveniles that rear and overwinter in the Trinity and its tributaries before outmigration.	Trinity River	T6	• Habitat quantity & quality (depth, velocity, cover) • Habitat connectivity (thermal refugia & tributaries) • Temperature (temporal & spatial variability) • Foodscape (drift forage) • Competition • Predation	• Flow management† • Temperature management† • Hatchery management* • Channel form‡ • Predator population • Abundance • Climate (change, wet/dry water year) • Wildfire • Water withdrawal*
Non-natal Migration (B): Juveniles that left the Trinity as non-natal migrants and do not rear in the Klamath **River** before outmigration from the Klamath River.	Klamath River	T7	• Lower Klamath River disease (*C. shasta*) • Habitat connectivity (thermal refugia & tributaries) • Temperature (temporal & spatial variability) • Foodscape • Habitat quantity & quality (depth, velocity, cover) • Predation • Smoltification	• Flow management (altered hydraulic function, TRD/Klamath River Proj)‡ • Temperature management‡ • Hatchery management* • Poor lower Klamath River habitat • Climate (change, wet/dry water year) • Predator population • Abundance • Wildfire • Water withdrawal* • Periodicity‡

Previous Life Stage(s) & Life History(s)	Spatial Extent	Transition to Next Life Stage	Drivers	Causes
Non-natal Klamath River Rearing & Migration (A): Juveniles that left the Trinity as non-natal migrants and rear in the Klamath River before outmigration from the Klamath River.	Klamath River	T7	• Lower Klamath River disease (*C. shasta*) • Habitat connectivity (thermal refugia & tributaries) • Temperature (temporal & spatial variability) • Foodscape • Habitat quantity & quality (depth, velocity, cover) • Predation • Smoltification	• Flow management (altered hydraulic function, TRD/Klamath River Proj)‡ • Temperature management‡ • Hatchery management* • Poor lower Klamath River habitat • Climate (change, wet/dry water year) • Predator population • Abundance • Wildfire • Water withdrawal* • Periodicity‡
Natal Migration: Juveniles that left the Trinity as natal migrants that do not rear in the Klamath River.	Klamath River	T7	• Lower Klamath River disease (*C. shasta*) • Habitat connectivity (thermal refugia & tributaries) • Temperature (temporal & spatial variability) • Foodscape • Habitat quantity & quality (depth, velocity, cover) • Predation • Smoltification	• Flow management (altered hydraulic function, TRD/Klamath River Proj)‡ • Temperature management‡ • Hatchery management* • Poor lower Klamath River habitat • Climate (change, wet/dry water year) • Predator population • Abundance • Wildfire • Water withdrawal* • Periodicity‡

Previous Life Stage(s) & Life History(s)	Spatial Extent	Transition to Next Life Stage	Drivers	Causes
Yearling Migration: Juveniles that left the Trinity as yearlings and do not rear in the Klamath River.	Klamath River	T7	• Lower Klamath River disease (*C. shasta*) • Habitat connectivity (thermal refugia & tributaries) • Temperature (temporal & spatial variability) • Foodscape • Habitat quantity & quality (depth, velocity, cover) • Predation • Smoltification	• Flow management (altered hydraulic function, TRD/Klamath River Proj)‡ • Temperature management‡ • Hatchery management* • Poor lower Klamath River habitat • Climate (change, wet/dry water year) • Predator population • Abundance • Wildfire • Water withdrawal* • Periodicity‡
Non-natal Estuary Rearing and Transition (A): Juveniles that left the Trinity and Klamath River as non-natal migrants that rear in the estuary.	Estuary	T8	• Habitat connectivity (lagoon formation, thermal refugia/barriers) • Water quantity & quality (depth, velocity, temp, salinity) • Smoltification & saltwater transition • Predation • Competition • Foodscape • Habitat quantity & quality (depth, velocity, cover)	• Flow management‡ • Water quality & temp management‡ • Hatchery management* • Abundance • Predator population • Climate (change, wet/dry water year, marine heat waves)

Previous Life Stage(s) & Life History(s)	Spatial Extent	Transition to Next Life Stage	Drivers	Causes
Non-natal Estuary Transition (B): Juveniles that left the Trinity and Klamath River as non-natal migrants that do not rear in the estuary.	Estuary	T8	• Habitat connectivity (lagoon formation, thermal refugia/barriers) • Water quantity & quality (depth, velocity, temp, salinity) • Smoltification & saltwater transition • Predation • Competition • Foodscape • Habitat quantity & quality (depth, velocity, cover)	• Flow management‡ • Water quality & temp management‡ • Hatchery management* • Abundance • Predator population • Climate (change, wet/dry water year, marine heat waves)
Non-natal Klamath River Rearing Estuary Transition: Juveniles that left the Trinity as non-natal migrants that reared in Klamath River but do not rear in the estuary.	Estuary	T8	• Habitat connectivity (lagoon formation, thermal refugia/barriers) • Water quantity & quality (depth, velocity, temp, salinity) • Smoltification & saltwater transition • Predation • Competition • Foodscape • Habitat quantity & quality (depth, velocity, cover)	• Flow management‡ • Water quality & temp management‡ • Hatchery management* • Abundance • Predator population • Climate (change, wet/dry water year, marine heat waves)

Previous Life Stage(s) & Life History(s)	Spatial Extent	Transition to Next Life Stage	Drivers	Causes
Natal Estuary Transition: Juveniles that left the Trinity as natal migrants, migrated through Klamath River without rearing, and do not rear in estuary.	Estuary	T8	• Habitat connectivity (lagoon formation, thermal refugia/barriers) • Water quantity & quality (depth, velocity, temp, salinity) • Smoltification & saltwater transition • Predation • Competition • Foodscape • Habitat quantity & quality (depth, velocity, cover)	• Flow management‡ • Water quality & temp management‡ • Hatchery management* • Abundance • Predator population • Climate (change, wet/dry water year, marine heat waves)
Yearling Transition: Juveniles that left the Trinity as yearlings and do not rear in the Klamath River or estuary.	Estuary	T8	• Habitat connectivity (lagoon formation, thermal refugia/barriers) • Water quantity & quality (depth, velocity, temp, salinity) • Smoltification & saltwater transition • Predation • Competition • Foodscape • Habitat quantity & quality (depth, velocity, cover)	• Flow management‡ • Water quality & temp management‡ • Hatchery management* • Abundance • Predator population • Climate (change, wet/dry water year, marine heat waves)

Previous Life Stage(s) & Life History(s)	Spatial Extent	Transition to Next Life Stage	Drivers	Causes
Subyearling Rearing: All juveniles that transition from the estuary as subyearlings.	Ocean - Nearshore	T9	• Foodscape • Harvest • Predation • Temperature • Marine water quality (temperature & chemistry) and Ocean productivity indices	• Climate (change, marine heat waves, ocean productivity) • Ocean chemistry • Bottom-up dynamics • Predator population
Yearling Rearing: Juveniles that left the Trinity as yearling migrants.	Ocean - Nearshore	T9	• Foodscape • Harvest • Predation • Temperature • Marine water quality (temperature & chemistry) and Ocean productivity indices	• Climate (change, marine heat waves, ocean productivity) • Ocean chemistry • Bottom-up dynamics • Predator population

DRAFT STUDY PLANS FOR THE TRINITY RIVER CHINOOK LFA

Overview of LFA Study Plan approaches and recommendations

The LFA Study Plans developed as part of Phase 1 considered the guidelines in the Phase 1 RFP and SOW (see *Background* and *Project Objectives* sections), and the general recommendations from the Science Plan (Pickard et al. 2022). The Science Plan stated, "a new limiting factor analysis would have to be carefully designed to be effective at identifying factors which are truly limiting, and to be useful enough to inform adjustments in management actions if warranted." The LFA must also consider the complexity of the Chinook Salmon life cycle (Figure 2), available data from ongoing population monitoring efforts (see Figure 3 for examples; Pickard et al. 2022; TRRP 2023), and the multitude of potential management actions, drivers, and causes under consideration for the Trinity River Chinook LFA (Table 7). In addition, the TRRP is faced with the challenge of considering multiple potential management strategies to achieve Program goals, how to evaluate the potential effectiveness of alternative strategies and implemented actions, how to adaptively manage actions as they are implemented, and newly identified or emerging issues.

To develop tools that address these needs, the LFA Study Plan options described here were framed around a life cycle modeling (LCM) approach (see *Rationale for an LCM-based approach to the LFA*) with increasing levels of effort that build on each other. In this way, each level of effort provides the foundation needed to complete the next level of effort, which will provide the TRRP with a road map for continued development of the LFA if a lower level of effort option is initially selected. Given that an LCM-based approach is central to the overall LFA strategy described by the Study Plans, supporting information is provided in the sections that follow the Study Plans, including:

- *Rationale for an LCM-based approach to the LFA*
- *Considerations for selecting the appropriate model complexity*
- *General LCM approach and structure*
- *Considerations for required data and data quality*
- *Hypotheses and Limiting Factors Analysis approach with a Life Cycle Model*

The overall tasks and sequencing for each option are shown in Table 8. Table 9 provides a summary of estimated timelines, data requirements, experience required, key deliverables, and pros/cons for each option. In this overview section, we provide high-level summaries of the options, with supporting information provided in the sections that follow. Please refer to the *LFA Study Plans* section that follows for more information on these LFA Study Plan Options.

Option 1: The first option represents the lowest level of effort and takes a "big picture" approach focused on four key life stages (adult return, migration, and spawning; incubation and emergence; rearing and emigration; and ocean maturation). This option collapses TRRP priorities into four broad management action categories: improved Chinook production; improved rearing and emigration; harvest adjustment; and improved immigration. We assume that improvements in any one of the four categories reduces the need for improvements in the other three. Therefore, a prudent approach for the first level of effort involves assisting the TRRP in determining the extent to which each category can and should contribute to the overall solution. The first steps of this approach include determining population goals and the number of fish needed at key life stages to achieve Program goals. Next, it involves determining the quantity and quality of habitat needed to reach these goals. Finally, it entails comparing these modeled targets with existing monitoring data to pinpoint any discrepancies. The outcomes of the initial steps could then guide a decision-making process, which would continue with two further steps: establishing improvement goals for each category and identifying specific strategies to achieve each goal. The main benefits of this option include its minimal effort requirement, simplicity in adapting to data, and lower sensitivity to data gaps compared to other options. Additionally, it offers a high-level focus that can guide management decisions and the completion of the higher level of effort options. If this option is selected, the final product will be a spreadsheet-style LCM that can support the TRRP in the development of a more complex LCM and associated management actions under an adaptive management framework.

Option 2: This approach expands upon Option 1 by developing a comprehensive Life Cycle Model (LCM) that includes the entire life cycle complexity (refer to Figure 2) and incorporates a graphical user interface (GUI) to facilitate the model's use. The underlying LCM framework will be developed in open-source platforms such as R (R Core Team 2019) with an RShiny GUI (Chang et al. 2019) that will allow model transparency, a low barrier to users (e.g., would not require a user to know how to program or use R), and portability (ease of sharing within or outside of the Program). The initial step involves formulating hypotheses for specific life stages identified in Option 1, followed by identifying the data required to evaluate these hypotheses. An LCM framework will subsequently be developed for the entire lifecycle to test hypotheses and provide outputs that help identify and prioritize limiting factors. Based on the data available, information from reference systems or assumptions may be employed to fill in data gaps, though this approach may lessen the certainty of the outcomes. Nonetheless, the findings from this LFA Study Plan option can serve to identify and prioritize data gaps for future monitoring efforts. The LCM should also be designed to incorporate new data as it becomes available. Further, this will support adaptive management by allowing the model to integrate monitoring data on actions as they are implemented (supporting adaptive management and evaluation of action effectiveness). The LCM supports the LFA by providing a framework to assess how various drivers and causes explain variance in life stage transition rates. Together with identifying bottlenecks through the LCM, this can help identify and prioritize potential limiting factors that also considers the ability of management actions to influence the bottlenecks. While this approach requires significantly more effort and expertise compared to Option 1, it yields a quantitative and transparent tool based on the LCM. This tool supports the LFA in establishing improvement goals, formulating specific tactics and strategies to address limiting factors, assessing the success of these strategies, and adjusting to new information and emerging issues.

Option 3: This approach builds on Option 2 by developing scenarios that can better inform management actions, adaptive management, and action effectiveness evaluation. Scenarios will be built into the GUI and use the underlying LCM framework to allow the TRRP to run “what-if” scenarios. These scenarios could include management actions or suites of management actions, non-management or extrinsic factors (e.g., climate change, ocean productivity), or management actions outside of TRRP control (e.g., hatchery strategies, harvest and fisheries management, Klamath River dam removals). By building scenarios into the GUI, the TRRP can evaluate the effectiveness of previous, current, or future actions in the context of the full life cycle and other drivers and causes acting on the population and set improvement goals that consider more dynamic factors or scenarios. For example, if goals are set under current conditions but underlying conditions shift (e.g., ocean conditions, water year type, climate change, or harvest), previously identified actions may not be sufficient to address the limiting factors and attain Program goals. By considering extrinsic or "what-if" scenarios, the TRRP can potentially develop more robust strategies that will have a greater chance of attaining Program goals. This option represents the "end game" for the LFA Study Plans, with both Options 1 and 2 leading to the outcomes of Option 3. Although this option comes with the highest amount of effort, longest timelines, and highest data needs, it produces the most useful tools to support the TRRP and LFA goals and objectives.

Recommendations: Option 2 provides a good balance of complexity, level of effort, and ability to support TRRP goals and LFA Project objectives. Therefore, we recommend considering LFA Study Plan Option 2 for Phase 2 (unless budgets and timelines are restrictive), and then expanding to Option 3 in the future.

Table 8. General tasks within the LFA Study Plan Options, showing the sequential nature of the study plans with effort increasing from Option 1 – 3 and the options building on each other. *Key life stages include adult return, migration, and spawning; incubation and emergence; rearing and emigration; and ocean maturation; but this may be scalable to the effort level selected so that the initial step includes a finer resolution of life stages (see Figure 2).

Options			**Task**	**Description**
1	2	3		
			1	Project kickoff meeting, introduce Project teams, articulate Project objectives and timelines, establish Technical Advisory Group(s)
			2	Determine population goals and the number of fish needed at key life stages* to meet Program goals (Biological Targets)
			3	Determine the amount and quality of habitat needed (Physical Targets) to meet the Biological Targets for key life stages*
			4	Determine the data needed to compare modeled Biological and Physical Targets, compile data, and identify data gaps
			5	Compare modeled targets to monitoring data to identify discrepancies and key life stages* limiting Program goals
			6	Set improvement goals for key life stages* and determine specific tactics/actions to attain goals and monitoring needed to address data gaps and support evaluation
			7	Formulate hypotheses about which life stages limit the population, determine the data required to test these hypotheses, and identify missing data.
			8	Build out full life cycle model (LCM) for multiple sub-stages within the key life stages
			9	Parameterize model with available data, evaluate data gaps and determine where reference data can be used
			10	Evaluate data and model, tune and calibrate model, and refine parameterization (data) and model as needed, including increasing spatial or temporal resolution
			11	Evaluate hypotheses and how drivers and causes explain variance in transition rates, identify and prioritize limiting factors, and identify and prioritize data gaps
			12	Build out graphical user interface (GUI) to support model use, including limiting factors analysis outputs and updating the model with new data
			13	Set improvement goals for limiting life stages and determine specific tactics/actions to attain goals and monitoring needed to address data gaps and support evaluation
			14	Determine suite of management actions or other scenarios to inform management actions, adaptive management, and effectiveness evaluations
			15	Build out scenarios in GUI to inform management actions, adaptive management of the LCM and limiting factors analysis, and effectiveness evaluations
			16	Analyze scenarios and develop strategies and specific tactics/actions or suites of actions to attain goals; and develop adaptive management plans with scenarios

Table 9. Summary of effort levels for LFA Study Plan Options. Pros and cons are described relative to other options. See *LFA Study Plans* Section below for more details.

	Option 1	Option 2	Option 3
Estimated Timelines	***Lowest:*** 6-9 months	***High:*** 12-18 months	***Highest:*** 18-24 months
Data Requirements	***Lowest:*** • Population goals • Demographics for key life stages • Habitat estimates at key life stages	***High:*** • Same as Option 1+ • Demographics for all life stages • Metrics describing drivers and causes	***Highest:*** • Same as Option 2+ • Additional data for scenarios
Experience Required	***Lowest:*** Primarily junior biologists and biometricians; Support from Senior Scientists and Biometricians	***High:*** Will require Senior level Biometricians and Scientist/Principal; Support from junior level staff	***High:*** Will require Senior level Biometricians and Scientist/Principal; Support from junior level staff
Key Deliverables	• Spreadsheet style LCM model • Technical memo • High-level improvement goals and strategies to address these	• Full LCM with GUI • Technical memo • Identified and prioritized limiting factors • Evaluation of strategies to address limiting factors • LCM and GUI User Guides	• Full LCM with GUI and scenarios • Technical memo • Identified and prioritized limiting factors • Scenario-based evaluations of strategies • LCM and GUI User Guides
Pros	• Lowest level of effort • Shortest timelines • Less experience required • Easiest to fit data • Less sensitive to data gaps • Provides initial information to inform more complex modeling and monitoring later • Can be used to set goals and identify strategies to address goals	• Provides LCM to support a more complete LFA • GUI to support model use, portability, and updates • Ability to drill down to life cycle complexity and identify factors • Can be used to identify and prioritize limiting factors • Can be used to identify and prioritize data gaps • LCM can be updated with new data and identify new limiting factors	• Same as Option 2+ • Ability to evaluate scenarios and adaptive management plans
Cons	• Does not directly identify limiting factors • Limited resolution on life stages • Would require LCM development in future to drill down to life stages and identify limiting factors	• Higher level of effort • Longer timelines • Higher staffing levels • Higher data requirements • Increased complexity and sensitivity to data gaps or uncertainties	• Same as Option 2+ • Longer timeline to develop scenarios • More data requirements to support scenarios

The following sections provide more detail on the LFA Study Plan options, including the following:

- *Overview of approach and objectives*
- *Key tasks and deliverables*
- *Data requirements*
- *Timelines and required level of expertise,*
- *Pros and cons compared to other LFA Study Plan options*

This more detailed information should be considered with the supporting information provided in the sections that follow the *LFA Study Plans* section, as noted previously.

LFA Study Plans

Option 1

Overview of approach and objectives

The first option represents the lowest level of effort and takes a big picture approach focused on four key life stages (adult return, migration, and spawning; incubation and emergence; rearing and emigration; and ocean maturation). This option collapses TRRP priorities into four broad Chinook Salmon management action categories: improved production; improved rearing and emigration; reduced harvest; and improved immigration. We assume that improvements in any one of the four categories will reduce the need for improvements in the other three. Therefore, a prudent approach for the first level of effort involves assisting the TRRP in determining the extent to which each category can and should contribute to the overall solution. To that end, the first steps of this option include determining population goals and the number of fish needed at key life stages to meet Program goals, determine the amount and quality of habitat needed to meet those targets, and then compare modeled targets to available monitoring data to identify discrepancies. The model should be designed to guide managers on the required number of fish to be produced at each life stage, while biological monitoring data provides the actual numbers present. Similarly, the model will estimate the necessary habitat for each life stage, and physical monitoring will reveal the actual habitat available. By comparing these modeled needs with observed conditions, deficits can be identified, pinpointing where they occur. This comparison lays the groundwork for a basic-level LFA effort. The findings from this effort can then guide a two-step decision-making process: establishing improvement objectives for each category and determining specific strategies to achieve these goals. The main advantages of this approach are its minimal effort requirement, ease of fitting data and reduced sensitivity to data gaps, and a high-level focus that can inform management actions. Choosing this low-effort option results in a spreadsheet-style LCM as the final output, supporting the TRRP with the long-term aim of creating a more sophisticated LCM and related management strategies.

Key tasks and deliverables

The key tasks for Option 1 are identified in Table 8, with more information provided here to support evaluation of each option.

1. ***Project kick-off meeting:*** Introductions of team members and establish roles and communication plans; articulate project objectives, tasks, and timelines; establish technical advisory group(s) to guide and focus development and review of technical components, interpretation of findings, and deliverables.

   Deliverables: Kick-off meeting, meeting summary with articulated project objectives, TAG members and roles.

2. ***Develop population goals:*** In coordination with the TAG and considering available data and Program goals, develop population goals and the number of fish needed at key life stages to meet Program goals (Biological Targets).

   Deliverables: Clearly articulated Program goals and quantified population goals (Biological Targets).

3. ***Determine amount and quality of habitat needed to meet goals:*** In coordination with the TAG and considering available data, determine the amount and quality of habitat needed to meet the Biological Targets for each life stage.

   Deliverables: Clearly articulated physical habitat requirements (Physical Targets) to meet the Biological Targets.

4. ***Determine the data needed to evaluate modeled targets:*** In coordination with the TAG, determine the required data and data quality to compare modeled targets to observed abundance or survival rates and physical habitat extent or quality. This would also include evaluating and identifying sensitivities when assessing potential data. This task will also identify data gaps and potential monitoring needs, as well as where reference data can or should be used to address data gaps.

   Deliverables: Data inventory and assessment of data and quality needed; identification of data gaps; reference data to be used to address data gaps.

5. ***Compare modeled targets to monitoring data:*** Compare information from Tasks 2-4 to identify discrepancies between modeled targets and current conditions to identify potentially limiting life stages and conditions. This can be done with the development of a simple spreadsheet-based LCM if Option 1 is selected, or within a more complex framework if this task is completed as part of progress towards another option. Note this is different than using empirical data to calibrate and tune models as described in the LCM development tasks for Options 2-3.

   Deliverables: Comparisons of modeled targets and current conditions, identification of limiting life stages, and a simple spreadsheet-based LCM that can be used to support subsequent tasks and creating a more sophisticated LCM. The spreadsheet-based LCM should also include appropriate documentation and/or user guide to clearly describe the inputs, rules, and assumptions relevant to the data sources, calculations, and outputs.

6. ***Set improvement goals and determine strategies:*** Using the outcomes of Task 5, develop improvement goals and determine specific tactics or strategies to attain goals in coordination with the TAG. In addition, this Task should also identify and prioritize data gaps that can be addressed by future monitoring efforts.

   Deliverables: Technical memo describing the methods and outcomes of the previous tasks, including a summary of the improvement goals and specific tactics and strategies recommended to attain goals based on this level of effort. Note this may not be applicable if Options 2 or 3 are selected, but some form of documentation (interim memo could be developed at this stage). Timelines should include sufficient time for the TAG to review draft memos and memo revisions based on the review.

Data requirements

This option requires the lowest resolution of data of the three options, which is both a pro and a con of this approach. This option will require establishing population goals for key life stages and habitat requirements to meet those targets, and data to compare modeled targets to current conditions. This should also include refining the periodicity information for these key life stages, but finer scale resolution may not be needed if this option is selected. See general discussion in the *Considerations for required data and data quality* section, although most of those considerations will be more applicable to the higher effort options and parameterization of a full LCM.

Timelines and required level of expertise

This LFA Study Plan option requires the least amount of time to accomplish, owing to the simplification of the life cycle into key stages and the LCM approach itself, when compared to other LFA Study Plan options. (see Table 9). In addition, most of the work can be completed primarily by junior level biologists and biometricians with support from senior level scientists and biometricians. The Project team should also include support and oversight from a principal and/or senior scientist.

The timeline and budget should also include sufficient time for a kickoff meeting, 3-5 TAG meetings or workshops to support Tasks 2-6, and time to review and revise draft deliverables for Tasks 1-6. This approach will likely require at least 6-9 months to complete, which also could fit into the planned timelines for Phase 2 discussed during the Phase 1 kickoff meeting.

Pros and cons compared to other LFA Study Plan options

Pros: This option requires the least effort, can be finished within the shortest time frame, and needs the fewest staff members. The simplified spreadsheet-based LCM and focus on key life stages will require the least amount of data, would be easiest to fit data, and would be less sensitive to data gaps compared to the other options. However, the tasks outlined in this option form the foundation of Options 1 and 2, and therefore completion of Option 1 will support future development of Options 1 and 2. Ultimately, this option could provide a low-cost, high-level way to identify life stages limiting population goals and determine specific tactics and strategies to address those.

Cons: This approach will provide limited resolution in identifying which life stages and factors are limiting the population, necessitating additional analysis to examine life stages and factors in greater detail. Such in-depth evaluation would be undertaken in Option 2. Therefore, the improvement goals and specific tactics or strategies identified by this option may not provide high enough resolution to support detailed strategies or tactics. Moreover, if Option 1 is chosen initially, the expenses incurred in integrating the subsequent options later might exceed the costs of beginning with option 2 or 3.

Option 2

Overview of approach and objectives

This approach expands upon Option 1 by developing a comprehensive Life Cycle Model (LCM) that includes the entire life cycle complexity (refer to Figure 2) and incorporates a graphical user interface (GUI) to facilitate the model's use. The underlying LCM framework will be developed in open-source platforms such as R (R Core Team 2019) with an RShiny GUI (Chang et al. 2019) that will allow model transparency, a low barrier to users (e.g., would not require a user to know how to program or use R), and portability (ease of sharing within or outside of the Program). The initial step involves formulating hypotheses for specific life stages identified in Option 1, followed by identifying the data required to evaluate these hypotheses. An LCM framework will subsequently be developed for the entire lifecycle to test hypotheses and provide outputs that help identify and prioritize limiting factors. Based on the data available, information from reference systems or assumptions may be employed to fill in data gaps, though this approach may lessen the certainty of the outcomes. Nonetheless, the findings from this LFA Study Plan option can serve to identify and prioritize data gaps for future monitoring efforts. The LCM will be designed to incorporate new data as it becomes available. Further, it will support identification of future monitoring to address data gaps or new and emerging issues, as well as adapting to management actions as they are implemented (supporting adaptive management and evaluation of action effectiveness). The LCM supports the LFA by providing a framework to assess how various drivers and causes explain variance in life stage transition rates. Together with identifying bottlenecks through the LCM, this can help identify and prioritize potential limiting factors and, considering both the bottlenecks and the relative impact of factors, as well as the ability of management actions to influence the bottlenecks. While this approach requires significantly more effort and expertise compared to Option 1, it yields a quantitative and transparent tool based on the LCM. This tool supports the LFA in establishing improvement goals, formulating specific tactics and strategies to address limiting factors, assessing the success of these strategies, and adjusting to new information emerging issues.

Key tasks and deliverables

The key tasks for Option 2 are identified in Table 8, with more information provided here to support evaluation of each option. Note that the Tasks outlined for Option 2 are inclusive of the Tasks in Option 1, with the exceptions noted below.

1. ***Project kick-off meeting:*** Same as Option 1.

   Deliverables: Same as Option 1.

2. ***Develop population goals:*** Same as Option 1 but may be done at a finer life stage scale as determined in coordination with the TAG and based on available data.

   Deliverables: Same as Option 1.

3. ***Determine amount and quality of habitat needed to meet goals:*** same as Option 1.

   Deliverables: Same as Option 1.

4. ***Determine the data needed to evaluate modeled targets:*** Same as Option 1 but may be done at finer life stage scales as determined in Task 2.

   Deliverables: Same as Option 1.

5. ***Compare modeled targets to monitoring data:*** Same as Option 1 but may be done at finer life stage scales as determined in Task 2, and would require finer refinements of periodicity (including addressing data gaps and uncertainties identified in the LCD, see Figure 2).

   Deliverables: Same as Option 1 but may be done outside of a simple spreadsheet-based LCM and use a more complex, but still simplified, framework like that which will be used in the LCM developed in later tasks.

6. ***Set improvement goals and determine strategies:*** Like Option 1, this option will focus on initiating hypothesis development, data review, and LCM creation for later tasks. These activities would involve identifying which life stages to elaborate on or simplify, as well as setting goals for improving biological targets to meet Program goals.

Deliverables: Summary of results from previous tasks and strategies to address identified discrepancies with the LCM and LFA, and what is needed to meet goals.

7. ***Develop hypotheses for life stages limiting populations:*** In coordination with the TAG and based on the results of the previous tasks, develop hypotheses and determine required data and data quality to evaluate the hypotheses within the LCM framework. This will generally follow the recommendations in the *Hypotheses and Limiting Factors Analysis approach with a Life Cycle Model* section and *Considerations for required data and data quality*. This task will also identify data gaps that can be addressed by future monitoring or reference data.

   Deliverables: Refined hypotheses to be evaluated by the LCM and LFA, data requirements for the analyses, LCM, and LFA; data inventory and identified data gaps.

8. ***Build out full LCM:*** Translate the revised conceptual life cycle diagram (Figure 2) into full quantitative life cycle model (LCM) framework with all life stages. See *Considerations for selecting the appropriate model complexity* for more information on selecting and building an appropriate LCM. This task should include sufficient time to refine the model based on the outcomes of data analysis, hypothesis testing, and limiting factors analysis, which may include simplifying life stages based on available data.

   Deliverables: A quantitative LCM model framework developed in an open-source language (e.g., R) with supporting code documentation and notation (note this is different than the technical memo and user guide documentation described in subsequent tasks and is specific to notation within the code itself), with refinement based on TAG review and results. The LCM should be adaptable to new data, and able to support identification and prioritization of limiting factors as new data are added.

9. ***Parameterize LCM:*** After the core LCM framework has been developed, the outcomes of previous tasks will be used to parameterize the LCM. Data specific to the Trinity River population should be used where possible, but data gaps may be addressed through aggregation of life stages or use of reference data as determined in coordination with the TAG.

   Deliverables: LCM parameterized based on outcomes of previous tasks, model evaluation, identification of input refinements, model refinements, and model tuning/calibration to evaluate hypotheses and limiting factors.

10. ***Evaluate data and model:*** This task is an iterative process that involves several steps, starting with the evaluation of input data and model outputs through the lens of the scientific method. This involves assessing both the inputs and the model's results in conjunction with hypothesis testing to verify the success of the test or model. This step would include using empirical data and may include testing the model with training and test datasets. Should the test or model prove unsuccessful, both the input data and the model are re-evaluated and refined as needed, or the hypotheses may be revisited. Adjustments may include simplifying or detailing life stages in the Life Cycle Model (LCM) as needed. Additionally, this process includes general tuning and calibration of the LCM based on available data in addition to sensitivity analyses.

    Deliverables: Refined inputs, LCM framework, and parameterization.

11. ***Evaluate hypotheses and limiting factors:*** Using the refined model above, hypotheses can be evaluated using the LCM and bottlenecks identified among the life stages. Drivers and causes can be analyzed to determine how they explain variances in life stage transition rates, which can then be used to identify limiting factors. The degree to which the life stages contribute to limitations on the population, the relationships between the causes and the limiting life stage transitions, and the ability of management actions to influence those life stage transition rates will be considered in identifying and prioritizing limiting factors.

    Deliverables: Results of hypotheses evaluations and identified and prioritized limiting factors.

12. ***Build GUI:*** Develop a graphical user interface in an open-source platform (e.g., RShiny) that will allow the user to run the model and identify and prioritize limiting factors. The GUI should include sufficient notation to support usability, and this task should include sufficient time to allow for refinements to the GUI based on TAG feedback and the outcomes of the data analysis, hypothesis testing, LCM development, and the limiting factors analysis.

    Deliverables: As open-source GUI (e.g., RShiny) to support use of the model for the limiting factors analysis and to identify and prioritize limiting factors, including refinement of the GUI with TAG review. The GUI should include the ability to update inputs, expand or collapse life stages as needed, and the ability to output key demographic information as well as limiting factors and life stages. A user guide to support the use of the GUI.

13. ***Set improvement goals and determine strategies:*** Leveraging the outcomes of Task 12 and the Life Cycle Model (LCM), assess improvement goals and strategies to address the bottlenecks and limiting factors. This evaluation aids in identifying the most effective tactics or strategies to achieve the Program goals. Timelines for this task should provide sufficient time for review and revision of drafts with the TAG.

    Deliverables: Technical memo describing the overall methods, results, and findings of hypothesis testing, identified limiting factors and prioritization of factors, improvement goals and strategies, and next steps (e.g., data gaps and monitoring strategies to address data gaps).

Data requirements

This option will require more data compared to Option 1 to support the increased complexity of the model, and the supporting material covered in the *Considerations for required data and data quality* section should be considered for Option 2. For example, to fully parameterize the LCM based on the full conceptual life cycle diagram (see Figure 2), refined information on periodicity and abundance estimates are needed for each life stage as well as information on the drivers and causes at the same spatial and temporal scales (e.g., within the same geographic areas occupied by the life stages and during the times in which they occur). Reference data may be considered to address data gaps and/or life stages may be simplified or collapsed within the LCM until data gaps can be addressed by future monitoring or analysis. If the LCM and LFA results reveal data gaps and uncertainties necessitating further data collection, it's important to recognize that the new data might not be usable until sufficient timeseries are gathered with adequate accuracy for model updates. Nonetheless, both the LCM and GUI should be designed to facilitate the integration of new data, thereby enabling adaptive management of the LCM. This feature aims to assist the TRRP in identifying management actions for addressing both new and evolving challenges, as well as evaluating the outcomes of management actions applied over time.

Timelines and required level of expertise

Option 2 will require considerably more time to complete compared to Option 1.The project team will require more senior level biologists and biometricians to develop and program the LCM framework, evaluate and analyze data and hypotheses, refine the LCM, and identify and prioritize limiting factors, with support from a principal and/or senior scientist to oversee the Project and junior staff to support tasks throughout the Project. In addition, additional meetings and workshops with the TAG and senior project team members (Principal Scientist, Senior Scientist, Senior Biometrician, and Senior Biologist) will be required to work through the tasks at a higher level of detail.

The timeline and budget should include sufficient time for the kickoff meeting, 6-12 TAG meetings or workshops to support Tasks 2-13, and time to review and revise draft deliverables. This approach will likely require at least 12–18-months to complete, which would extend beyond the Phase 2 timelines identified during the Phase 1 kickoff meeting.

Pros and cons compared to other LFA Study Plan options

Pros: Option 2 builds on Option 1 by developing a full LCM that can be used to support the LFA with current data and future data collected to address data gaps, or as emerging issues are identified. This approach will also support finer scale evaluation and testing of hypotheses and identification/prioritization of limiting life stages and factors where sufficient data are available. Life stages lacking sufficient data can be collapsed and expanded later when data are developed to support the additional resolution or parameterized using reference data. The GUI can be built to identify and prioritize limiting factors, which can be used to support adaptive management of actions as new and emerging data and limiting factors are identified. The GUI is a significant pro for this option, as it will provide a low barrier to usability of the model (e.g., no requirement for programing experience to use the model) and would also support portability of the model (GUI can be webhosted to support outreach and transparency and easy use of the model).

Cons: Increased effort, timeline, staffing, and data requirements over Option 1. Increased complexity may introduce uncertainties if insufficient data are available and reference data are used and/or life stages collapsed/aggregated to address data gaps. The increased timeline required for Option 2 could also be a con if the Phase 2 timelines outlined by the TRRP in the kick-off meeting are rigid.

Option 3

Overview of approach and objectives

Option 3 builds on Option 2 by developing scenarios that can better inform management actions, adaptive management, and action effectiveness evaluation. Scenarios will be built into the GUI and use the underlying LCM framework to run “what-if” scenarios with respect to management actions, scenarios related to non-management or extrinsic factors (e.g., climate change, ocean productivity), or management actions outside of TRRP control (e.g., hatchery strategies, harvest and fisheries management, Klamath River dam removals). By building scenarios into the GUI, the TRRP can evaluate the effectiveness of previous, current, or future actions in the context of the full life cycle and other drivers and causes acting on the population and set improvement goals that consider more dynamic factors or scenarios. These scenarios would be built into the GUI and allow the user to run what-if scenarios or scenarios to evaluate action effectiveness. For example, if improvement goals are set under current conditions but underlying conditions shift or are changing due to changing conditions (e.g., ocean conditions, water year type, climate change, or harvest), identified actions may not be sufficient to address the limiting factors and attain Program goals. By considering extrinsic or what-if scenarios, the TRRP can potentially develop more robust strategies that will have a greater chance of attaining Program goals. This option represents the end game for the LFA Study Plans, with both Options 1 and 2 leading to the outcomes of Option 3. Although this option comes with the highest effort, longest timelines, and highest data needs, it produces the most useful tools to support the TRRP and LFA goals and objectives, including adaptive management and responding to new and emerging issues.

Key tasks and deliverables

The key tasks and deliverables for Option 3 are essentially the same as Option 2 Tasks 1-13, and therefore, only Tasks 14-16 that are specific to Option 3 are described here. The key tasks for Option 3 are identified in Table 8, which are inclusive of Option 2.

14. ***Identify scenarios and data requirements:*** Working in collaboration with the TAG, identify scenarios that should be included in the LCM. This will support the LFA and the TRRP's ability to assess limiting factors, as well as devising actions, tactics, or strategies to mitigate these limiting factors. This will also require determining the data requirements to support these scenarios, and scenarios may include management actions (both TRRP controlled or not within TRRP control, as well as past, current, or potential actions), non-management related or extrinsic factors or processes (e.g., climate change, water year type). For each scenario considered, the Project team should work with the TAG to clearly define the objectives of the scenarios and how they will be used to inform the model outputs and identification of limiting factors, evaluation of actions, or development of strategies and tactics to address improvement goals.

    Deliverables: Identification of scenarios and required data and data quality to develop scenarios, including the objectives of the scenarios.

15. ***Build scenarios into GUI:*** The identified scenarios will be coded into the GUI and use the underlying LCM framework, which will allow the evaluation of limiting factors and actions under a variety of conditions. The primary objectives of these scenarios are to provide context for planning in the face of extrinsic factors (e.g., climate change or shifts in ocean productivity), various management measures (e.g., harvest or hatchery management), or comprehensive management action plans (e.g., restoration strategies). Additionally, they aim to establish a framework for evaluating potential management actions or to support adaptive management. Note that depending on the scenarios selected, some refinements to the underlying LCM framework may be needed. In addition, sensitivity analyses should be completed as part of building out, evaluating, and testing the scenarios to inform interpretation and application of scenarios.

    Deliverables: Updated GUI with integrated scenarios that utilize the underlying LCM framework and work with desired outputs (e.g., demographics and limiting factors). This would also include updating the GUI user guide or creation of a separate user guide for the scenarios.

16. ***Develop strategies based on scenarios:*** Similar to Task 13, this task would use the results of the scenarios to develop strategies or specific tactics/actions or suites of actions to address goals in light of the scenario results. For example, this could include refinement of goals to buffer for potential climate change impacts in the system, planning for changes in harvest or fisheries management, or implementation of a suite of management actions (e.g., restoration actions). Given that the analysis and scenarios can also consider the effectiveness of previous, current, or future potential actions, the outcomes of this task can also inform selection of actions (or suites of actions) to address Program goals and population goals.

    Deliverables: Technical memo describing the outcomes of the scenarios, the approaches used to develop the scenarios, and the findings and strategies developed based on the outcomes of scenarios.

Data requirements

This option is inclusive of the data requirements outlined in Option 2, but also requires additional data to support development and parameterization of scenarios. In addition to the data requirements described for Option 2, the *Considerations for required data and data quality* section should also be considered when evaluating data for the scenarios with Option 3. Depending on the data required for the scenarios, some scenarios may be stochastic in nature (e.g., frequency of events) or based on multiple predictions with varying degrees of certainty (e.g., climate change scenarios). Therefore, the data required, the scenarios themselves, and the results of the scenarios should be evaluated/interpreted with consideration for introduced uncertainty and how they should be parameterized in the LCM and GUI (e.g., empirical distributions can be used to model variability in conditions rather than adding stochasticity to the model framework itself).

Timelines and required level of expertise

Option 3 will require the most effort, longest timelines, and most staffing at senior levels compared to the other two options. Staffing levels would be similar to Option 2 but will require additional time for more TAG meetings and workshops to support development of scenarios (10-14 TAG meetings or workshops in total). Overall, the timeline for Option 3 requires at least 18–24 months, which would extend beyond the Phase 2 timelines identified during the Phase 1 kickoff meeting.

Pros and cons compared to other LFA Study Plan options

<u>Pros</u>: The pros or Option 3 are similar to Option 2 (e.g., increased complexity of LCM and ability to evaluate and identify limiting factors at a finer scale, and a GUI to support usability), but would also allow the TRRP to use scenarios to support planning and evaluation of management actions in the context of the scenarios (e.g., climate change). This would provide a tool that can be used to support adaptive management as new and emerging issues are identified and actions are implemented over time.

<u>Cons</u>: Similar to Option 2, Option 3 requires additional effort and time to develop scenarios to best support management action planning and evaluation. Increased complexity may introduce uncertainties if insufficient data are available and reference data are used, or life stages

collapsed/aggregated to address data gaps. There is also potential for increased uncertainty in scenario-based results depending on the selected scenarios and underlying data. The increased timeline required for Option 3 could also be a con if the Phase 2 timelines outlined by the TRRP in the kick-off meeting are rigid.

Rationale for an LCM-based approach to the LFA

LCM-based approaches have been used for LFAs for salmonids in many systems (e.g., Scheurell et al. 2006; Zueg et al. 2012; Merz et al. 2013; Jorgensen et al. 2021. Model selection for managing a fishery's life cycle is instrumental in directing management goals (e.g., harvest goals), actions (e.g., restoration or flow regulation) and timelines (e.g., fishery goals success). Similar to life cycle modeling in system development, the chosen model for fisheries management has an impact on adaptive management by promoting or limiting flexibility, consistency, innovation capability, and maintainability, among other aspects. It is important for practitioners to holistically assess the value of each model in reaching their project goals. It is also important for practitioners to understand the purpose of each life cycle model (LCM) as well as their strengths and limitations to improve decision-making in the choice of model.

Practitioners are faced with increasingly difficult decisions in choosing a life cycle model for a project. Model choice is often influenced by factors like project length, team size and expertise, the rigidity of requirements, research questions and management constraints, stakeholder and comanager collaboration, and many other factors. Each life cycle model is developed for a specific purpose with its own set of advantages and disadvantages, and typically the model's development is in response to deficiencies in an existing model or previous approach. In fisheries population management, the most widely recognized and practical life cycle models or frameworks are general stock-recruitment models such as Ricker, Lotka-Volterra, or Leslie matrix models. Additionally, there are more specialized models like SHIRAZ (Scheurell et al. 2006) or HARP (Jorgensen et al. 2021), which incorporate elements from these generic approaches.

The TRRP used a conceptual framework from Hamilton and Murphy (2018) in the development of a conceptual life cycle diagram and initial approach to conceptualizing an LFA. This conceptual approach makes sense given their goal for a mechanistically defensible, conceptual ecological model that depicts the relationships between environmental factors and the fish's survival or reproduction during distinct life stages. The Hamilton and Murphy (2018) conceptual model provides the template for a stage-based life cycle model that explores annual variation in the abundance of a fish species and identifies the environmental factors that are associated with changes in abundance. In their analysis, Hamilton and Murphy (2018) built life-stage-specific quantitative candidate models by first articulating the hypothesized relationships between the species and environmental factors as equations. They then coded the models, ran analyses, and selected a model by sequentially evaluating the value of covariates in explaining population responses. They considered the validity of the models based on ecological plausibility and statistical strength. The goal of the Murphy and Hamilton (2018) exercise was to inform directed management actions that have potential to benefit their species of interest. However, unlike their target species (Delta Smelt *Hypomesus transpacificus*), Chinook Salmon have a much more complex life cycle, utilizing marine, estuary as well as lentic environments (Figure 2). Chinook also support subsistence, commercial and sport fisheries. Therefore, it is reasonable that a more complex model and approach is needed for the Trinity River Chinook LFA, but an important question is how much more complexity is needed?

Considerations for selecting the appropriate model complexity

LCMs can vary considerably in complexity, particularly in the number and specificity of life-stages included in the model. Model complexity is also strongly influenced by its purpose and the longevity of the program. In general, more complex models allow for a greater range of restoration scenario development or evaluation of hypotheses or research questions. However, with increased complexity comes increasing requirements for data to parameterize the model. Conversely, less complicated models have a more limited range of hypotheses, research questions, or scenarios that can be evaluated or developed, but would require less data to develop and parameterize. Therefore, selection of model complexity not only affects what data are needed to inform the model, but also what questions can be investigated and how the model can be used to inform management. In this way, it is important to align the goals of the LCM (and thereby the LFA) to the complexity needed to achieve those goals in a defensible and timely manner.

Simple models

Simplicity in LCMs often translates to models with fewer parameters and assumptions. These models are generally more user-friendly and require less data, making them advantageous for quick assessments or in situations with limited data availability. They provide a broad overview of the population dynamics, allowing for rapid decision-making. However, this simplicity can also be a downside. The lack of detail may lead to oversimplification of complex ecological interactions, potentially resulting in inaccurate predictions, overlooked subtleties in salmonid behavior and environmental interactions, or uncertainties in which factors and underlying mechanisms are driving population demographics.

Complex models

On the other end of the spectrum, complex models offer a detailed and nuanced understanding of salmonid life cycles. These models may incorporate a multitude of factors including genetic diversity, detailed age-class structures, life-stage specific habitat requirements, intricate predator-prey relationships, as well as more factors and mechanisms driving population demographics. The depth provided by these models can be invaluable for thorough, long-term management plans and understanding the impact of environmental changes on populations. However, complexity brings its own set of challenges. These models often require extensive and detailed data, are more time-consuming to develop and analyze, and necessitate a higher level of expertise to both develop and interpret correctly. Additionally, the risk of 'overfitting'—creating a model so tailored to specific data that it fails to generalize well to other scenarios—can be a significant drawback.

Common simple versus complex dichotomies

There are also many nuisances to the ways in which LCMs can be either simple or complex, and these represent important decision points that help determine the appropriate complexity of an LCM given the objectives of the model, availability of data, and available resources. Common factors that come up in many LCM models include:

- *Deterministic vs Stochastic*: Are parameters fixed, or are they drawn from distributions? Stochasticity can improve a model’s ability to consider natural variation in a system, while deterministic models can produce repeatable results.

- *Spatial vs State-space*: Are individuals tracked along actual spatial extents or aggregated into "buckets" representing spatial groupings? Spatially explicit models can better describe movement through systems at finer scales (e.g., reaches), while aggregations can improve the efficiency of model calculations.
- *Time-step vs Transition focused*: Is the model calculated by small times steps, or are broad transitions used to model the population? Time-steps allow a model to capture variations in periodicity and responses that can occur at smaller (e.g., daily or weekly) or larger (e.g., monthly or annual) time-steps, whereas a life stage transition focus may aggregate across the full periodicity of a life stage.
- *Static vs Dynamic*: Is the parameterization of the model fixed, or do values change over time? Static models are simpler while dynamic models can include feedbacks whereby outputs and factors can interact over time.
- *Individual vs Cohort*: Are individuals modeled, or are larger representative groups (cohorts) tracked in the model? Both individual-based and cohort models can be both simple or complex, but using individual-based models to inform population management can be very complicated. Cohort models can also be broken down into increasingly smaller sub-cohorts to track groups over space and time.

These choices help determine the overall complexity of the model and what kind of questions can be investigated through its use and exploration. As noted previously, increasing complexity requires increasingly more data. If a system is data poor, a complex model may require use of external data or waiting years for data to be available. We might also consider how we can build a complex model that can work under data-poor conditions and expand as data or more information on the system becomes available? This balancing among complexity, data, and parsimony is sometimes referred to as "the art of modeling."

According to Rose et al. (2011), the most useful models are those that are developed to address a specific question or application. The question or application then guides the decisions and judgments made as to the detail needed, what can be greatly simplified or ignored, and the resolution (time and space scales) needed in the model. There are risks in developing a general model and then trying to use it to answer specific questions when a different model would have been developed if one started with the specific question. All models are approximations and thus model answers to specific questions are already inexact. Use of overly general models for specific questions can make this situation worse by resulting in greater inaccuracy in model answers (i.e., above and beyond what a well-suited model would generate). One can end up in a situation of a single, general model that provides inadequate answers to all specific questions of interest. At the other extreme, there cannot be a new model for each specific question. Therefore, formulation of hypotheses and questions ahead of model selection and development is important (see *Hypotheses and Limiting Factors Analysis approach with a Life Cycle Model* section).

In the context of Trinity River Chinook LFA objectives, the issue of knowing the question(s) and hypothesis(es) is complicated and points to another nuisance of model complexity and data availability. The TRRP and TRRP Scientist have developed extensive research to address questions related to the Program and specific actions (e.g., see Trinity River Restoration Program Synthesis Reports and Science Symposium), For example, changes to flow regulation with the Record of Decision (ROD) after 2004 (Pinnix et al. 2022), influence of sedimentation and gravel augmentation (e.g., Gaeuman 2020; Buxton 2021; HVTFD and McBain Associates 2023); influence of water temperatures (Asarian et al. 2023), and monitoring and trends and habitat associations in fisheries demographics (e.g., Boyce et al. 2020; Rupert et al. 2017; Cooper-Hertel et al. 2022; Pinnex et al. 2022). In some ways, specific questions related to the Program and management are well known and actions have been refined over time as the Program undergone extensive review and scrutiny. This scrutiny and refinement tends to focus the details and expected effects of the Program actions and results in synthesis of the available data involved, and should greatly help in model design, development, and scenario analysis.

However, several aspects can complicate the issue of knowing the questions, even in the situation of a well-reviewed Program action. Even with well-defined questions now, questions will continue to evolve over time. For example, a partial impetus for the Trinity River Chinook LFA was to address new and emerging questions such as increases in juvenile production that were linked to changes in management actions but a commensurate increase in adult production was not detected (e.g., see Pinnex et al. 2022 and Pickard et al. 2022). At some conceivable point, the questions evolve to the point where a model becomes poorly scaled and must be modified to address the new version of the questions or emerging issues. Also, while the Program actions may be known, there is the issue of whether there are better alternative Program actions, which pushes the modeling into a very broad arena (i.e., the universe of what else could be done as Trinity Program actions), and these alternatives have had much less scrutiny. And finally, there are potential for many extrinsic factors not related to management actions that can introduce uncertainty and may necessitate a more complex model framework to understand interactions between management and non-management related drivers.

In addition, there may be situations in which a combination or sequence of models or model complexities are most appropriate. For instance, a simple matrix model might be used to identify life stages with particularly strong influence on overall population productivity, or to quantify the general magnitude of change that is needed to achieve population viability from current conditions. Then, a mechanistic model or statistical approaches aimed at that life stage, might be used to evaluate particular suites of actions or combinations of conditions for their likelihood of attaining those goals. Similarly, a more complex model could be developed to address the identified life stages and factors in the context of the full life cycle with dynamic components that allow the next most limiting factors to be identified as manage actions address limiting factors or conditions change over time.

Considerations for resolution, uncertainty, and interpretation of results

The resolution and uncertainties of the model results must be clearly stated. There is often confusion among the audience about the proper interpretation of model results that potentially arise from several perspectives. One of these comes from the distinction between prediction versus forecasting and relative versus absolute responses. A predictive model provides results under existing or new conditions, with forecasting models associate specific years to the model results. Forecasting models provide results of what we would expect to observe in the field in that specific year or after a certain period of time. Thus, predictions are more general (e.g., more vague) than forecasts.

Rose et al. (2011) recommends that when model results are presented, the appropriate level of interpretation must be clearly stated. Relative responses mean that model results (e.g., number of fish) are only interpretable when compared to a modeling baseline, rather than to the number of fish observed in the field. Absolute results mean the number of fish predicted by the model is the actual number expected to be observed in the field. While there is a continuum between prediction versus forecasting and between relative versus absolute results, it is easier to consider these as discrete categories for discussion purposes. Stating whether model results are predictions or forecasts and whether they are relative or absolute results is a good start towards proper interpretation and communication of the model results. In addition, spatially-explicit results should also be put into the proper context. The confidence of spatial differences in model results should be described. The objectives and power of the modeling should be clearly stated in order to manage expectations. This is especially important for populations like Trinity River Chinook where data availability may vary greatly at different spatial extents and geographic areas.

In addition, model results can appear to be too disconnected from reality to be useful to some people, while the same results can appear to be sufficiently accurate depictions of the future state of the system to other people. It is important to present model results with a clear discussion of the strengths and weaknesses, acknowledging both and ensuring that users clearly understand the underlying assumptions, data, and applications of the model and results. Some measure of uncertainty, which is not always possible, helps put modeling results into context. When presenting results with uncertainty, it is important to explain what sources of uncertainty are included in the outputs and which sources are not included. Uncertainty estimates will almost always be underestimates of the true uncertainty associated with modeling results. Also, there can be confusion about uncertainty versus stochasticity. Uncertainty arises from ignorance and more data would presumably reduce the uncertainty (e.g., relationship between temperature and mortality rate). Stochasticity is inherent variability (e.g., occurrence of a low flow year) that cannot be reduced with more information but can be used to put model results in more practical context if stochasticity is parameterized and used appropriately for the questions (e.g., considering the potential effect of climate change impacts or episodic events that occur infrequently or may change in frequency over time).

Considerations for developing a new model and using previously developed models

Rose et al. (2011) recommends that a model (or models) should be developed from the beginning and existing models should be used as guidance and foundational support, but one should not try to modify existing models to evaluate new or different questions or applications. As noted earlier, the Hamilton and Murphy (2018) approach is not completely appropriate for the complexities of the Trinity River Chinook life cycle. Furthermore, the codes from such existing models would not likely work well for a Trinity River Chinook LCM given the specificity of questions, hypotheses, available data, and population demographics.

There are, however, advantages and disadvantages to developing a new model versus modifying an existing model. The benefits of developing a new model include the ability for the Program to determine every aspect of the model's design, eliminating any uncertainty regarding the version of the existing model in use, and ensuring that stakeholders are familiar with every part of the code. This approach reduces the risk of inheriting hidden assumptions or calculations. According to Rose et al. (2011), with a new model, there is no explanation needed as to why a particular existing model was selected to be modified over another. Also, all existing models evolve over time and so the point of reference changes and, at some point, sufficient modification of an existing model really means you have a new model in the end.

Developing a new model comes with drawbacks, such as the increased effort required and the lack of historical context that could be obtained by adapting an existing model. On the other hand, the advantages of utilizing an existing model include access to its track record, code, and prior testing outcomes, demonstrating how all the equations fit together. In the Salmonid Integrated Life Cycle Models Workshop Report of the Independent Workshop Panel (Rose et al. 2011), they determined that the benefits of developing a new model (with the existing models as the foundation and proper documentation) outweighed the advantages of modifying an existing model when discussing Central Valley salmon management. To understand responses of species over evolutionary scales, which may be as short as a few decades, a model must deal with the inherent heterogeneity in fish physiology and life history strategies. Indeed, the complexity of migration timings and size of Central Valley Chinook are strongly suggestive that strategies are complex, varied, and under constant selection pressure. Models that consider only single cohorts and overly fixed-in-space life-stages are simply inadequate to project the impact of future environmental changes on individual salmon populations. In fact, they suggest the pertinent question is not about adapting an existing model to different species but how a population's physiological and behavioral heterogeneity can be incorporated into a framework to model the effects of environmental changes on population success.

However, previously developed models should be considered and evaluated as part of the process for determining the appropriate model complexity and framework (e.g., the S3 model in development for the Klamath River and Trinity Rivers, see Pickard et al. 2022). Even if an entirely new model framework is developed for the Trinity LFA, previously developed models like the S3 could provide important context as well as inputs or outputs that can be used to learn from and build on previously developed efforts.

Considerations for identifying limiting factors analyses with LCMs

Identification of limiting factors is a primary objective of the Trinity River Chinook LFA, and Murphy and Hamilton (2018) identified three categories of environmental factors as they relate to the target fish's survival/reproduction during distinct life stages. Although Chinook Salmon and Delta Smelt have distinctly different life histories, these distinctions are useful from the context of describing factors within an LCM analysis framework. The three categories of factors considered include: limiting, controlling, and modifying factors.

<u>Limiting Factors</u> are a set of factors that may potentially limit a species' abundance or population size, or factors that may determine the maximum abundance of a given life stage, such as prior abundance, food availability, extent of habitat. The abundance of a species at any point in time is a consequence of a previously manifested controlling factor and subsequent <u>Modifying Factors</u>. A <u>Controlling Factor</u> is one of the limiting factors that regulates abundance at a given time, and hence is more limiting than the other modifying factors (which reduce abundance from a level previously established by a controlling factor).

Controlling factors can create bottlenecks wherein a large population may suddenly be reduced by a stressor that occurs seasonally or infrequently (Bisson 1989). Controlling factors can confound the detection of population-dynamic thresholds or change points, such that small changes in an environmental driver may suddenly appear to produce large responses by a species of concern (Dodds et al. 2010). The abundance of a species at any point in time is a consequence of a previously manifested controlling factor and subsequent Modifying Factors. The presence and manifestation of limiting factors can be difficult to detect because they do not always control the response variable. When they do not control the observed response, those data points should not be given weight in a factor analysis (Kaiser et al. 1994; Cade et al. 1999); yet conventional additive approaches do just that (Augspurger 1996; Thomson et al. 1996, Murphy and Hamilton 2018). This highlights the importance of hypotheses development that considers mechanistic linkages between factors and responses rather than, for example, model selection approaches that consider all possible combinations of potential covariates.

An objective of the Trinity River Chinook LFA Study Plan is to offer an approach to identifying the factors that limit Chinook Salmon (both Spring-run and Fall-run Chinook) populations only during certain seasons or stages and apply the approach to explain variation and trends in abundance for Chinook Salmon in the Trinity River California. While limiting factors can be identified and prioritized with a relatively simple LCM, more complex model frameworks would allow the Program to determine restoration actions to ameliorate those factors/stressors, and tests scenarios to simulate the effects of actions or a suite of actions. Further, should the model be complex enough to allow for the stakeholders to identify and prioritize the limiting factors, act upon them, and continuously reevaluate the system (e.g., dynamic model with feedback loops) to support long-term restoration planning and continued determination of new factors in a changing world?

General LCM approach and structure

The complexity of a LCM is scalable to level of effort, and the following describes the general LCM approach and structure that would apply to all effort levels identified in the draft study plans. The Trinity River Chinook LCM should generally follow a multistage Beverton-Holt model, similar to the SHIRAZ (Scheurell et al. 2006) and EDT (Blair et al. 2009) modeling frameworks developed for salmonids in the Pacific Northwest. The model structure should essentially model salmon as they transition between and within life stages, which should follow the conceptual LCD Trinity River Chinook Salmon (Figure 2), with the application of a Beverton-Holt stock-recruitment model that includes intraspecific competition for habitat:

$$N_{s+1} = \frac{N_s}{\frac{1}{p_{s\rightarrow s+1}} + \frac{1}{c_{s+1}} N_s}$$

where the number of fish surviving to their next life stage or time step (N_{s+1}) is a function of the number alive at the current life stage or time step (N_s), the survival to the next life stage or time step ($p_{s\rightarrow s+1}$), and the capacity of the environment (can include both quantity and quality of habitat) to support them (c_{s+1}). The survival/productivity parameter (p) and capacity parameter (c) can assume fixed values or be functions of age/stage and/or the environment (e.g., drivers and causes described in Table 7). Environmental factors that affect p alter the recruitment rate to the next life stage or time step (slope), and factors that affect c alter the maximum number of fish that can be produced in the next life stage or time step in the model (Figure 5). The time steps should be sufficiently detailed to capture important variations in periodicity among life stages and life history variations (see Figure 2), and may vary among life stages (e.g., weekly time steps for juvenile rearing and emigration life stages compared to yearly time steps for ocean maturation life stages).

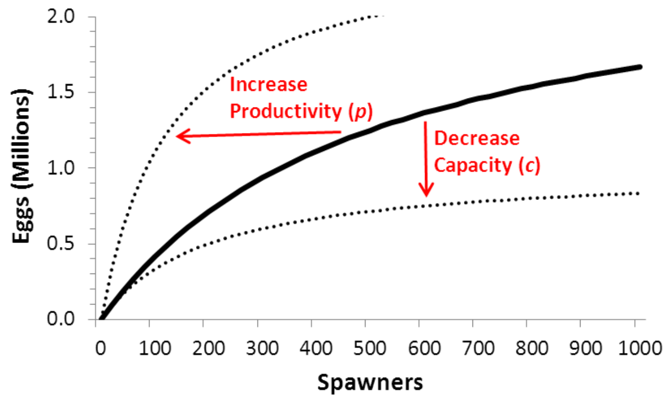

Figure 5. An example of a Beverton-Holt stock-recruitment relationship for the spawning life stage. A change in survival or productivity of spawners alters the slope of the relationship (p), while a change in habitat capacity alters the maximum number of eggs that can be supported (c).

For life stages where capacity is not assumed to be limiting, the life stage transition equation can be simplified to the following form:

$$N_{s+1} = N_s * p_{s \to s+1}.$$

where the number of fish surviving to their next life stage or time step (N_{s+1}) is a function of the number alive at the current life stage or time step (N_s) and the survival to the next life stage or time step ($p_{s \to s+1}$). As part of the parameterization process, the inputs and outputs should be evaluated for sensitivity, and calibrations or tuning can be used to fit models to observed data. The results of sensitivity testing and calibration/tuning can also be used to inform model refinements were needed.

In addition, the LCM should be constructed to track each pathway in the conceptual LCD (Figure 2) at each life stage and for each broodyear or cohort wherever possible. This is a key aspect to using the LCM to evaluate LFs and support identification of the life stage(s) and factors are limiting the population. For example, the LCM should track natal and non-natal rearing migrants and Spring-run and Fall-run adults separately.

Aside from Option 1 (which would be developed in a spreadsheet interface), the LCM and its interface should be developed using open-source platforms like R (R Core Team 2019) with an RShiny graphical user interface (GUI) (Chang et al. 2019). Paired with an open-source platform and interface, the LCM should include explicit descriptions of the assumptions, rules, inputs, and/or equations used. This transparency is critical to encouraging usability and buy in, as well as supporting future refinement and expansion of the tools.

Considerations for required data and data quality

The required data to develop the LCM will vary depending on level of effort and specific hypotheses being tested by the LCM and LFA. However, data specific to the population of interest will be critical to successful development and completion of any of the LFA Study Plan options. Therefore, a data inventory, evaluation, analysis tasks in conjunction with hypothesis development and testing are central tasks to all three LFA Study Plan options.

While the required amount of data, level of detail, and data quality may vary among LFA Study Plan options, some general requirements include abundance estimates at each life stage or between key life stages being modeled by the LCM to estimate transition rates (e.g., T1-T11, see Figure 2). For example, to estimate the transition rate (or survival rate) of juvenile Chinook emigrating from the Trinity River, abundance estimates of juveniles would be needed in both the Trinity and Klamath River (e.g., from Rotary Screw Traps). The cohort reconstruction that is currently underway (see Lindke 2021) will be key to all LFA Study Plan options, and results from the Cohort reconstruction will likely be required to support parameterization of LCMs for the population.

In addition, the abundance estimates would ideally be derived from monitoring methods with sufficient spatial and temporal resolution and accuracy to detect changes in survival rate over time and quantity survival rates from one life stage to another (Merz et al. 2013). For example, long term monitoring programs that provide multiple years of data that cover the periodicity of the life stage would provide more useful data for the LCM and hypothesis testing compared to discrete point estimates. Furthermore, if the error associated with abundance estimates exceeds the transition rates or effect of a driver, the analyses and model will not be able to detect or describe an effect or relationship.

In addition to the demographic data required to estimate transition rates between life stages described above, data describing the drivers and causes identified with the conceptual LCD will also be required to test hypotheses and evaluate LFs (Table 7). Similar to the demographic data, environmental data should be of sufficient spatial and temporal resolution and accuracy to detect changes in conditions that can be linked to changes in transition rates. In this way, the LCM can be used to test hypotheses about LFs and compare their potential effects on the populations. Based on the hypotheses identified in the Science Plan, environmental data describing habitat extent and quality downstream of the Trinity River confluence will likely be an important consideration for the LFA. This includes the Klamath River, the estuary, and nearshore or ocean conditions (e.g., see NOAA Ocean Ecosystem Indicators).

Where monitoring data specific to Trinity River Chinook Salmon populations are not available, reference data from other systems or populations may be used, but this may introduce uncertainty and reduce the ability to identify LFs with confidence. The TRRP should consider if reference data will be used to address data gaps, or when development of monitoring plans are warranted to address data gaps and uncertainties identified by the data compilation, synthesis, and hypothesis testing/analysis phases of the model development. Like the limiting factors themselves, data gaps and monitoring needs can be prioritized to increase the benefits of monitoring data to address critical areas in the model. However, it should be noted that monitoring may require multiple years to collect sufficient data to inform updating of the LCM and LFA. Therefore, while additional monitoring recommendations may be an outcome of the LFA, these are not described with respect to either of the three level of effort options (i.e., additional monitoring would be in addition to the effort described for the LFA Study Plan options).

Hypotheses and Limiting Factors Analysis approach with a Life Cycle Model

The LCM can be used to test hypotheses regarding limiting factors following the scientific method, which is both a stepwise and iterative process. With a properly constructed LCM and sufficient data to evaluate transition rates and potential drivers, the LCM can be used to ask questions about what life stage or stages are limited by which factors. The LCM framework can be used to test these hypotheses, and depending on the result, the data or the model may need to be re-evaluated or new hypotheses derived.

Once functional relationships are understood, whether they be mechanistic or correlative, and we have confidence in the model and underlying data, the LCM can then be used with its multistage functionality to identify the life stages and associated factors that are most limiting the population. Formulating hypotheses will be a key step in the LFA and LCM development process that is applicable to all levels of effort described in this memo. The hypothesis development and evaluation process should also leverage previously developed work (see TRRP 2023), and therefore we provide a brief overview of previous working hypotheses to support the LFA. However, the hypotheses described here are not intended to represent the full list of hypotheses that can or should be considered in Phase 2 as these should be developed in coordination with the TAG during Phase 2 as outlined in the LFA Study Plans.

The Science Plan described a previous analysis that was a limiting factors analysis in some sense, and considered juvenile rearing habitat availability, juvenile habitat quality (temperature and flow), water temperatures for adult salmonids and during juvenile outmigration, and poor spawning habitat (Pickard et al. 2022). They hypothesized that juvenile rearing habitat was the factor most limiting Trinity River salmonid production, which was largely based on channel form, usable area, and habitat suitability criteria. The Science Plan suggested that these findings were correlative to the mechanisms that control productivity, and that habitat suitability criteria approaches may not reflect the fitness consequences of habitat preference and use (Pickard et al. 2022). In addition, such habitat suitability criteria approaches do not consider both productivity (survival) and capacity and how changes in these at different life stages can propagate through the complex life cycle and life history pathways expressed by Chinook Salmon.

In addition, new and emerging issues can negate the potential benefits of management actions focused on addressing limiting factors, and therefore having an adaptable framework like an LCM that fully describes the complex life history pathways and key transitions between life stages can be used to adapt to new and emerging issues (as well as new data) as they are identified. For example, previous analyses "…hypothesized that juvenile rearing habitat was the factor most limiting salmonid production in the Trinity River" and the Science Plan (Pickard et al. 2022) identified several examples of new or emerging limiting factors not previous considered including:

- Change in the percentage of water year types that has or will occur resulting from climate change.
- Poor ocean productivity which is less productive than any historical time in the period of record or less productive for longer time periods than in the historical record.
- Food for juvenile salmonids in the upper Trinity River (i.e., too little food).
- Water temperature for rearing juveniles (i.e., too cold).
- Poor water quality during the summer months in the lower Klamath River.
- Juvenile fish disease in the lower Klamath River.
- Adult fish disease in the lower Klamath River.
- Not enough fine sediment.
- Predation (birds, marine mammals, brown trout).

In addition, the Science Plan outlines the TRFE Central Hypotheses that included (Pickard et al. 2022):

1. Habitat diversity in the upper Trinity River, both on the meso- and micro-habitat scale, will increase following the implementation of the recommendations. Although the changes in habitat diversity are expected to be obvious, there will remain a question as to the degree of change.
2. Juvenile salmonid rearing habitat, believed to be limiting smolt production in the Trinity River, will increase in both quantity and quality following the creation of a more complex and dynamic channel form. Rearing habitat area, which at present is highly variable depending on streamflow, will increase (at least a doubling) and become more stable over a wide range of flows.
3. Salmonid smolt survival will improve as a result of better temperature conditions that increase growth and promote smoltification and reduced travel time associated with emigration.

These central hypotheses as well as the approaches to measure these and what the TRRP has learned so far through monitoring are outlined in Appendix A of the Science Plan.

In addition, a cohort reconstruction analysis is currently underway and should be completed to support Phase 2 (see Lindke 2021), and analysis of juvenile abundance and size estimates at rotary screw trap monitoring sites has pointed to interesting patterns related to changes in productivity in relation to implementation of the ROD (see Pinnex et al. 2022 and Pickard et al. 2022 and discussion in the *Trinity River Juvenile Life Stages* section). These analyses should be considered with the cohort reconstruction within the LCM framework to evaluate questions and hypotheses related to changes in juvenile productivity and demographics linked to management actions are influencing survival in subsequent life stages and the factors acting on those life stages.

The hypotheses identified in the Science Plan and previous analyses briefly described above are examples of the hypotheses and information that should be considered in Phase 2 as part of the LFA Study Plans regardless of which option is selected. The LFA should not only consider new and emerging factors or hypotheses but should build on and test previously developed hypotheses and current assumptions. The drivers and causes identified through Phase 1 attempt to capture potential limiting factors, as well as drivers or causes that influence productivity at various life stages and should support development and testing of hypotheses (Table 7). However, the hypothesis development process, data analysis, and LFA itself may identify the need to look at other potential drivers or causes in Phase 2 and therefore Table 7 is intended as a starting point.

LITERATURE CITED

Asarian, J. E., K. De Juilio, S. Naman, D. Gaeuman, and T. Buxton. 2023. Synthesizing 87 years of scientific inquiry into Trinity River water temperatures. Report for the Trinity River Restoration Program (TRRP). Riverbend Sciences, Eureka, California.

Augspurger, C. 1996. Editor’s note. Ecology. 77:1698.

Beamer, E. M., A. McBride, C. Greene, R. Henderson, G. Hood, K. Wolf, K. Larsen, C. Rice, and K. Fresh. 2005a. Delta and nearshore restoration for the recovery of wild Skagit River Chinook salmon: linking estuary restoration to wild Chinook salmon populations. Supplement to the Skagit Chinook Recovery Plan. Skagit River System Cooperative, LaConner, Washington.

Beamer, E. M., B. Hayman, and D. Smith. 2005b. Linking freshwater rearing habitat to Skagit Chinook salmon recovery. Appendix C of the Skagit Chinook Recovery Plan. Skagit River System Cooperative, LaConner, Washington.

Bisson, P. 1996. Importance of the identification of limiting factors in an evaluation program. Unpublished manuscript. Available from P. Bisson, Weyerhaeuser C.

Blair, G. R., L. C. Lestelle, and L. E. Mobrand. 2009. The ecosystem diagnosis and treatment model: a tool for assessing salmonid performance potential based on habitat conditions. In American Fisheries Society Symposium 71:2008.

Boyce, J., D. H Goodman, N. A Som, J. Alvarez, K. Hopkins, and A. Martin. 2020. Streamflow and juvenile salmonid habitat availability at six rehabilitation sites on the Trinity River, California, 2008-2017. Arcata Fisheries Technical Report Number TR 2020-39 for the Trinity River Restoration Program (TRRP). U.S. Fish and Wildlife Service, Arcata, California.

Buxton, T. H. 2021. History of fine sediment and its impacts on physical processes and biological populations in the restoration reach of the Trinity River, CA. Report TRRP-2021-1 for the Trinity River Restoration Program (TRRP). Trinity River Restoration Program, Weaverville, California.

Cade, B. S., J. W. Terrell, and R. L. Schroeder. 1999. Estimating effects of limiting factors with regression quantiles. Ecology. 80:311–323.

Chang, W. J. Cheng, J.J. Allaire, Y. Xie, and J. McPherson. 2020. Shiny: Web Application Framework for R. R package version 1.5.0. Available at URL: https://CRAN.R-project.org/package=shiny

Cooper-Hertel, E. J., K. T. Lindke, T. Daley, K. De Juilio, and K. Hopkins. 2022. Assessing temperature regimes and juvenile Chinook salmon growth in Trinity River off-channel and mainstem habitats. Report for the Trinity River Restoration Program (TRRP). Yurok Tribe Fisheries Department, Klamath, California.

Dodds, W. K., W. H. Clements, K. Gido, R. H. Hilderbrand, and R. S. King. 2010. Thresholds, breakpoints, and nonlinearity in freshwaters as related to management. Journal of the North American Benthological Society. 29:988–997.

Ford, M. D., K. M. Nichols, R. S. Waples, E. C. Anderson, M. Kardos, I. Koch, G. McKinney, M. R. Miller, J. Myers, K. Naish, and S. R. Narum. 2020. Reviewing and synthesizing the state of the science regarding associations between adult run timing and specific genotypes in Chinook salmon and steelhead: report of a workshop held in Seattle, Washington 27–28 February 2020.

Gaeuman, D. 2020. WY2016-2017 Trinity River gravel augmentation monitoring report. Report for the Trinity River Restoration Program (TRRP). Yurok Tribal Fisheries Program, Klamath, California.

Gaeuman, D., and K. De Julio. 2023. Stream bed disturbance and risk of salmonid redds scour in the Trinity River, CA. Technical Report to the Trinity River Restoration Program. Weaverville, CA.

Gough, S., N. Som, K. Lindke, K. Dejuilio, C. Laskodi, G. Kautsky, and B. Matilton. 2021. Assessment of adult salmonid spawning in the Trinity River. Presentation.

Greene, C. M., J. E. Hall, K. R. Guilbault, and T. P. Quinn. 2010. Improved viability of populations with diverse life-history portfolios. Biology Letters 6(3):382-386.

Groot, C., and L. Margolis, editors. 1991. Pacific salmon life histories. UBC Press, Vancouver.

Hamilton, S.A., and Murphy, D.D., 2018. Analysis of limiting factors across the life cycle of delta smelt (*Hypomesus transpacificus*). Environmental management, 62(2), pp.365-382.

Healey, M. C. 1991. Life history of Chinook salmon (*Oncorhynchus tshawytscha*). In Pacific salmon life histories, pp. 311-394. UBC Press, Vancouver.

Hoopa Valley Tribal Fisheries Department (HVTFD) and McBain Associates. 2023. Coarse sediment storage on the Trinity River: recommendations and correlations to juvenile Chinook salmon rearing habitat. Report for the Trinity River Restoration Program (TRRP). HVTFD, Hoopa, California.

Jorgensen, J. C., C. Nicol, C. Fogel, and T. J. Beechie. 2021. Identifying the potential of anadromous salmonid habitat restoration with life cycle models. PLOS ONE 16(9):e0256792.

Kaiser, M. S., P. Speckman, and J. R. Jones. 1994. Statistical models for limiting nutrient relationships in inland waters. Journal of the American Statistical Association. 89:410–423.

Lisi, P. J., T. Anderson, M. Zackey, E. Pouley, J. Seay, K. Keith, J. Nelson, K. Griffith, C. Konoski, A. Scofield, A. Voloshin, A. Berger, M. McHenry, M. Elofson, G. Liermann, P. Pess, C. Topping, M. Kinsel, A. Klungle, and J. Weinheimer. 2022. Synchrony of freshwater and marine survival among Chinook salmon populations in Puget Sound. Report submitted to Puget Sound Partnership under the Puget Sound Ecosystem Monitoring Program.

Limm, M. P., and M. P. Marchetti. 2009. Juvenile Chinook salmon (Oncorhynchus tshawytscha) growth in off-channel and main-channel habitats on the Sacramento River, CA using otolith increment widths. Environmental Biology of Fishes. 85: 141-151.

Lindke, K. 2021. Introduction to cohort reconstruction for Trinity River naturally produced fall Chinook salmon. Presentation.

Merz, J. E., T. M. Garrison, P. S. Bergman, S. Blankenship, and J. C. Garza. 2014. Morphological discrimination of genetically distinct Chinook salmon populations: An example from California's Central Valley. North American Journal of Fisheries Management. 34(6): 1259-1269. doi:10.1080/02755947.2014.956161

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

Miller, J. A., A. Gray, and J. Merz. 2010. Quantifying the contribution of juvenile migratory phenotypes in a population of Chinook salmon Oncorhynchus tshawytscha. Marine Ecology Progress Series. 408: 227-240.

Murray, C. B., and M. L. Rosenau. 1989. Rearing of juvenile Chinook salmon in nonnatal tributaries of the lower Fraser River, British Columbia. Transactions of the American Fisheries Society. 118(3): 284-289.

Pickard, D. (ed.), 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.

Pinnix, B. 2021. Long term analyses of juvenile Chinook salmon abundance estimates. Presentation at the Trinity River Science Symposium, December 2021.

Pinnix, W. D., S. P. Boyle, T. Wallin, T. Daley, and N. A. Som. 2022. Long-term analyses of estimates of abundance of juvenile Chinook salmon on the Trinity River 1989-2018. U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata Fisheries Technical Report Number TS 2022-40, Arcata, California.

R Core Team. 2019. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.

Rose, K., Anderson, J., McClure, M. and Ruggerone, G., 2011. Salmonid integrated life cycle models workshop. Report of the Independent Science Panel prepared for the Delta Science Program, CA.

Ruff, C. P., J. H. Anderson, I. M. Kemp, N. W. Kendall, P. A. McHugh, A. Velez-Espino, C. M. Greene, M. Trudel, C. A. Holt, K. E. Ryding, and K. Rawson. 2017. Salish Sea Chinook salmon exhibit weaker coherence in early marine survival trends than coastal populations. Fisheries Oceanography 26(6):625-637.

Rupert, D. L., S. A. Gough, N. A. Som, N. J. Davids, W. C. Matilton, A. M. Hill, and J. L. Pabich. 2017. Mainstem Trinity River Chinook salmon spawning survey 2015 and 2016. U.S. Fish and Wildlife Service, Arcata Fish and Wildlife Office, Arcata Fisheries Data Series Report Number DS2017–56, Arcata, California.

Satterthwaite, W. H., and S. M. Carlson. 2015. Weakening portfolio effect strength in a hatchery-supplemented Chinook salmon population complex. Canadian Journal of Fisheries and Aquatic Science 72:1860–1875. https://doi.org/10.1139/cjfas-2015-0169

Scheuerell, M. D., R. Hilborn, M. H. Ruckelshaus, K. K. Bartz, K. M. Lagueux, A. D. Haas, and K. Rawson. 2006. The Shiraz model: a tool for incorporating anthropogenic effects and fish–habitat relationships in conservation planning. Canadian Journal of Fisheries and Aquatic Sciences 63(7):1596-1607.

Sturrock, A. M., W. H. Satterthwaite, K. M. Cervantes-Yoshida, E. R. Huber, H. J. W. Sturrock, S. Nusslé, and S. M. Carlson. 2019. Eight decades of hatchery Salmon releases in the California central valley: Factors influencing straying and resilience. Fisheries 44(9):433–444 https://doi.org/10.1002/fsh.10267

Sturrock, A. M., J. D. Wikert, T. Heyne, C. Mesick, A. E. Hubbard, T. M. Hinkelman, …, R. C. Johnson. 2015. Reconstructing the migratory behavior and long-term survivorship of Juvenile Chinook Salmon under contrasting hydrologic regimes. PLoS One 10(5):1–23. https://doi.org/10.5061/dryad.c56rk

Tear, T. H., P. Kareiva, P. L. Angermeier, P. Comer, B. Czech, R. Kautz, L. Landon, D. Mehlman, K. Murphy, M. Ruckelshaus, and J. M. Scott. 2005. How much is enough? The recurrent problem of setting measurable objectives in conservation. BioScience 55(10):835-849.

Teper, T., Campo, K. and Eaton, C., 2022. Qualifying the value of life cycle process models in system development: an investigation into perceptions in academic literature. In Proceedings of the International Annual Conference of the American Society for Engineering Management. (pp. 1-11). American Society for Engineering Management (ASEM).

Thomson, J. D., G. Weiblen, B. A. Thomson, S. Alfaro, and P. Legendre. 1996. Untangling multiple factors in spatial distributions: lilies, gophers, and rocks. Ecology. 77:1698–1715.

Thompson, T. Q., M. R. Bellinger, S. M. O'Rourke, D. J. Prince, A. E. Stevenson, A. T. Rodrigues, M. R. Sloat, C. F. Speller, D. Y. Yang, V. L. Butler, M. A. Banks, and M. R. Miller. 2019. Anthropogenic habitat alteration leads to rapid loss of adaptive variation and restoration potential in wild salmon populations. Proceedings of the National Academy of Sciences 116(1):177–186.

TRRP (Trinity River Restoration Program). 2023. Synthesis Reports available at: https://www.trrp.net/restoration/adaptive-management/synthesis-reports/

Williams, B. K., R. C. Szaro, and C. D. Shapiro. 2009. Adaptive management: the US Department of the Interior technical guide. US Department of the Interior.

Zeug, S. C., P. S. Bergman, B. J. Cavallo, and K. S. Jones. 2012. Application of a life cycle simulation model to evaluate impacts of water management and conservation actions on an endangered population of Chinook salmon. Environmental Modeling & Assessment. 17(5): 455-467.

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.

APPENDIX A: KICK-OFF MEETING SUMMARY

LFA of Chinook Salmon in the Trinity River – Kick-Off Meeting
Thursday, October 19, 2023, 9:00 am-1:00 pm
Meeting Summary

Attendance

Eric Peterson – U.S. Bureau of Reclamation
Chris Laskodi – U.S. Bureau of Reclamation
Jeanne McSloy – U.S. Bureau of Reclamation
Todd Buxton – U.S. Bureau of Reclamation
Oliver Rogers – U.S. Bureau of Reclamation
James Lee – U.S. Bureau of Reclamation
Kiana Abel – U.S. Bureau of Reclamation
Elliot Sarnacki – U.S. Bureau of Reclamation
Kyle De Juilio – Yurok Tribal Fisheries Program
Karl Seitz – Hoopa Valley Tribal Fisheries Department
Galen Anderson – U.S. Forest Service
John Buffington – U.S. Forest Service
Ken Lindke – California Department of Fish and Wildlife
Trevor Morgan – Department of Water Resources
Scott McBain – McBain Associates (contractor to Hoopa Valley Tribe)
Andrew Paul – Alberta Environment and Parks
Bill Pinnix – U.S. Fish and Wildlife Service
Erica Engstrom – Nation Fish and Wildlife Foundation

Facilitation Team:
Joe Merz, Cramer Fish Sciences
Jason Hall, Cramer Fish Sciences
Meghan Camp, Cramer Fish Sciences

Meeting Objectives

- Introduce team members.
- Review project objectives and goals.
- Review recommended changes to the existing life cycle diagram.
- Determine next steps.

Action Items:

Action	**Responsibility**	**Deadline**
Provide PDF of updated life cycle diagram for the group to provide feedback	Jason Hall	October 25th
TRRP and IDT provide feedback and	TAG	November 15th

recommendations on updated life cycle diagram		
TRRP and IDT provide rationale/notes on the original life cycle diagram	TAG	November 15th

Summary of Key Points from Discussion

- **Background of need for LFA of Chinook Salmon in the Trinity River:**
  - Restoration has been occurring in the Trinity River for 20+ years. Efforts were made to manipulate physical habitat and flows were kept at a minimum during that time.
  - In the 90's there was a flow study which made recommendations for restoration flows. Full ROD restoration flows began in 2005 with the conclusion of federal litigation.
  - Outmigration increased after 2005, apparently in response to the large increase in water released during the spring outmigration period – numbers of juvenile Chinook Salmon outmigrants doubled and fish/spawner also increased.
  - Weirs have not shown a corresponding increase in returning adults and the size of young fish has also decreased. Lack of returning adults could possibly be due to issues in the Klamath and/or issues in the ocean.
  - The TRRP came up with the strategy to conduct a limiting factors analysis (LFA) to determine potential reasons for why there are more young fish leaving the system, but they aren't seeing them come back.
    - The LFA will be done in two phases: 1) identifying what needs to be done via development of a study plan for three different levels of effort and cost, and 2) implementing the study plan with the desired level of effort, which could be done by a different contractor.
  - The TRRP wanted outside consultants to conduct the LFA so they can get a fresh set of eyes on the situation and not be biased by what they already know. The TRRP wants to make sure they aren't missing anything.
  - The IDT drafted a list of people that will be working directly with CFS on the LFA plan – Ken Lindke (CFDW), Chris Laskodi (Yurok Tribe), Bill Pinnix (USFWS), Scott McBain (Hoopa Valley Tribe). These individuals will coordinate the LFA technical effort on behalf of the TRRP with CFS and will be called the Technical Advisory Group (TAG).
- **Measures of success for the program and this project:**
  - Put ocean productivity on the West Coast in context of how it might be affecting adult returns instead of just focusing on the upper forty miles of the Trinity River.
  - If limiting factors are identified that can be addressed (flow, temperature), those could be addressed through current management. Issues in the lower Klamath and ocean need to be considered. Some could potentially be avoided but others are out of their control.
  - A list of several limiting factors is desired, ranked in order of importance. They want a list so they can focus on the limiting factors they have control over. Yet, they want a list of all factors, not just the ones they have control over.

- Identify scenarios for restoration or other management actions to increase adult population. Other management actions other than restoration could be elimination of ocean harvest for three generations, for example, as suggested by Bill Pinnix.
- They are not an endangered species program – they are focused on maintaining a robust fishery for tribal harvest and protecting a way of life.
- In the next 3-5 years they want to see a sustainable fishery. Bill Pinnix said this is a pie-in-sky goal.
- Where to go next, are the tools they have enough to rebound the fishery in 10 years?
- What are the next steps, should they refine what they are doing in the Trinity River?
- This project will help understand limiting factors which may affect the way the Klamath is managed as well as ocean harvest through the Pacific Fishery Management Council. That's not the primary goal, but it should be kept in mind.
- They don't have control over what happens to fish in the lower Klamath, but they do have some control over how large the fish are when they go out, which may help them survive in the lower Klamath.
- TRRP doesn't have the tools to affect management of the Klamath River, but nearly all partners of the TRRP are also part of the management team that controls water releases to the Klamath River. So, any information that would aid overall Klamath River Basin management could be a useful outcome of this LFA exercise.
- By the end of this process, they want to have a better understanding of what is limiting production and be able to put that in context of what management tools they have at their disposal.
- They hope this exercise can support other things they have cooking such as infrastructure improvements at the hatchery, the large channel rehabilitation project they just completed, and new tools in gravel augmentation.
- Their program is focusing on natural Chinook production and the hatchery may be liming natural production, but they won't be able to address that directly.
- They want to find out if physical habitat is liming production or is there something else that could be limiting? They have made changes to the physical habitat and are wondering if the changes to the physical habitat are not effective at increasing production.
- This exercise will hopefully reveal data gaps. Where should they focus resources to better understand what is limiting? They want a model that can evolve, that has shelf-life.

- **Phase 1 of the LFA Project:**
  - The TRRP is implementing a two-phased approach that includes development of a LFA study plan with options for three levels of effort (Phase 1), and selection and completion of one LFA study plan option (Phase 2). Put ideas of success in quantifiable terms which will help guide the possibilities for model development.
  - Identify needed components for each phase in the life cycle so they know what pieces will be needed to implement during Phase 2.

    - They want three levels of effort for implementation so they can allocate funding. What is the appropriate level of effort? What is needed for each level of effort, what kind of data? The three levels of effort might build on one another.
    - CFS wants to build a model that is not black box so it can be built upon in the future.
    - They will pick the level of effort they are comfortable with and create an RFP based on the selected level.
    - They would like CFS to make recommendations on the level of effort and include pros and cons and needs for each level.
- **Preliminary life-cycle diagram changes/questions/recommendations:**
    - Adaptive management has been a challenge in this program.
    - Long term plans require data and time. Models can provide information in a shorter period of time and can support adaptive management.
    - Turning too many dials at once has been an impediment to understanding what specifically is causing change.
    - High-level recommendations and questions on the life-cycle diagram (LCD):
        - Break adult return and migration life stage into Klamath and Trinity.
            - Potentially not possible to split because of mixed stock fishery.
        - Add diversity of life history strategies.
        - Add holding to adult in-river life stages.
        - Add spawning to adult in-river Trinity life stage.
        - Add estuary rearing and transition life stage.
            - Noted some previous and more recent data potentially available for estuary life stage monitoring.
        - Add spatial structure element to LCD.
        - Add life stage element to LCD.
            - Potential to add natal/non-natal and extended FW life history pathways.
        - Visual components help orient the reader.
        - Add drivers and causes – consistency within the LCD, additions based on science plan, big picture additions, climate (linked to flow, wet/dry years, climate change), water withdrawals (quantity, flow), wildfire (sentiment inputs, organic inputs, cover, riparian, temperature).
        - Add estuary stage for adult returns/spatial structure.
    - **Conclusions:**
        - In general – split transitions where recommended but lump later if there is lack of information/data.
        - IDT will provide their notes/rationale for original LCD.
        - Jason will provide PDF of updated LCD to TRRP and IDT so they can provide feedback and recommendations.
        - TRRP and IDT will provide feedback to CFS in about two weeks.

APPENDIX B: RESPONSE TO COMMENTS ON DRAFT STUDY PLAN

The following is a summary of the questions and comments received in response to the Draft Trinity River LFA Study Plan memo submitted to the TAG for review on February 5, 2024. Where responses included a revision to the draft, the revisions are underlined in the responses.

Questions:

- The Study Plan still states "draft", but is there more to do? Is it just a matter of confirming that this fits our needs for deliverables?

Response: Following revision in response to the comments listed here, the draft watermark will be removed, and a final version will be provided in Word and 508-compliant PDF formats.

- Another question... could this fit a multi-year contracting approach with Option 1 as the first year, Option 2 as an (optional) second/third year, the potentially option 3 as a final year or two?

Response: The Options can be viewed as phases that can be sequenced as the options build on each other, with some differences noted in the memo if starting with Option 2 instead of Option 1.

- Consider addressing how S3 should be used in this process. A lot has been invested in S3 model development and it is the most sophisticated fish production model we have specific to the Trinity. We will be asked the obvious question of "why aren't we using it?". We don't think you're recommending NOT using it, but the absence of an S3 discussion/context with respect to the LCM/LFA study plans may give the impression that we're developing a new fancy (expensive) toy and abandoning our existing S3 model. However, one very important limitation of the current implementation of S3 is that it does not consider variable food ration so there is no way to evaluate whether food is limiting production. This is a major question for us.

Response: Based on our understanding of the S3 model and its current applications in the Trinity and Klamath basin, we do think the model can and should be considered along with other existing model frameworks. The draft LFA Study Plan memo includes a discussion on considerations for using existing models and building new models (see Considerations for selecting the appropriate model complexity section, and specifically Considerations for developing a new model and using previously developed models). Based on the guidance provided there, we feel that the S3 model can certainly be considered for guidance and foundational support at the very least, but its ability to address the goals and objectives of the LFA at the full spatial, temporal, and life history scales should also be considered. Although we did not have sufficient time/budget to do a deep dive review of the S3 model during Phase 1, some potential limitations to consider with the S3 model (along with the one you mentioned above) are its ability to account marine maturation life stages, upriver migration and holding, and juvenile life history variations of interest in the Trinity. <u>That being said, language was added to the sections referenced above to specifically point to the S3 model as something that should be</u>

considered during the selection and development of a model framework (but we noted that the documentation we found in the Science Plan just points to the Klamath document (Perry et al. 2018), and that the Trinity report is still in review).

- Task 3 is to determine the amount and quality of habitat needed to meet goals. Isn't this a potential outcome of the LFA, not an initial step? We don't know the quantity/quality of habitat needed to meet goals, or if habitat is even the limiting factor (in the sense of physical Capacity). That is a question we need to ask of the analysis.

Response: This step is intended to identify the theoretical habitat requirements to support or meet the population goals (or Biological Targets). This can be done at a higher level as outlined in Option 1 and can be used to inform development of the hypotheses and building/selection of the LCM. However, you are also correct that the amount and quality of habitat needed to meet goals would also be an outcome of the LFA, with LCM enabling the development of more refined estimates and "gaming" of limiting factors.

- We're a little concerned about how focused this is on quantitative goals (Tasks 2, 3, and 5). Since we're looking at limiting factors, can't we just say "lots" and not get too wrapped around the axle on quantitative goals? Of course, assessing limiting factors for an adult escapement of 10,000 versus 1 million may be different due to density dependence, but maybe just something that is a rough scale (50,000-100,000 adults) is good enough? We'd hate to get bogged down by quantitative goals at the expense of analyzing what is limiting a substantial increase in adult escapement, which is ultimately our priority question.

Response: You could certainly define "rougher" targets or ranges, and you can evaluate limiting factors outside of the context of a population goal or targets. But defining quantitative goals is considered a critical step to evaluating and prioritizing limiting factors in the context of what factors are most limiting a population from reaching a desired target. We don't think defining these goals would get in the way of or bog down the process of determining where substantial increases can be gained; rather the step of defining the quantitative targets for the population and life stages would support that end goal.

- Consider adding sensitivity analyses to the LFA's as part of Task 4 so that we can (1) prioritize what data we gather/feed into the model based on sensitivity of those metrics to the output, and (2) get more informed on the scale of how the performance metrics may change based on priority stressors.

Response: Sensitivity analyses are an important step in developing and parameterizing an LCM, as well as evaluating data needed to assess targets. We noted the importance of evaluating sensitivity and model tuning during the parameterization process for the LCM (see General LCM approach and structure section), but the language in Task 4 was updated to specifically identify/evaluate sensitivities when assessing potential data. In addition, Task 10 for Option 2 includes general tuning and calibration, which would be inclusive of evaluating sensitivities. We also added language there to indicate sensitivity analyses should be completed as part of Task 10.

Lastly, we added a note to Task 15 for Option 3 to indicate that sensitivity analyses should also be completed as part of the scenario development and testing processes.

- Task 5 is to compare modeled targets to monitoring data. There's not enough detail to know for sure, but it sounds like the proposed approach would be to build the model based on the LCM, available data, and assumptions, then just run it and compare it to empirical data. S3 was calibrated to empirical data then validated with a separate set of empirical data. We envisioned a similar process for translating the LCM to the LFA, then running scenarios ("turning the knobs") to evaluate limiting factors (part or all of options 2 and 3).

Response: Empirical data would certainly be used to inform building and parameterization, as well as tuning and calibration. A subset of empirical data can be used for this if independent datasets are not available, but Task 5 is specifically intended to compare the "modeled targets" from Task 2 and 3 (the Biological and Physical Targets) and is not referring to the LCM modeling specifically. The steps you are highlighting would apply to Options 2-3 and would generally follow what you have outlined. Language was added to Task 5 to help clarify that point, and we also added language to Task 10 in Option 2 to further clarify this.

- Should change "rational" to "rationale" throughout document (saw at least two)

Response: The memo was updated to correct the typo.