January 2026
Study of Physical Data Gaps to Inform the Implementation of Nur Rematriation Upstream of Shasta Dam
(AB 211 Drought Grant Agreement Number – Q2396040)

ANCHOR QEA

Appendix N
Nomtipom Waywaket (Sacramento River) Chinook Salmon Life History Summary

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Nomtipom Waywaket (Sacramento River) Chinook Salmon Life History Summary

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ABBREVIATIONS

7-DADM	7-day average of the daily maxima
Background Compendium	*Background Compendium and Design Criteria Report for the Feasibility of Volitional Fish Passage above Keswick and Shasta Dams*
CDFW	California Department of Fish and Wildlife
CESA	California Endangered Species Act
cm	centimeter
CNFH	Coleman National Fish Hatchery
Consultant Team	Anchor QEA; HDR Engineering, Inc.; and QEDA Consulting, LLC
Delta	Sacramento-San Joaquin River Delta
Fed. Reg.	*Federal Register*
FL	fork length
ESA	Endangered Species Act
ESU	evolutionarily significant unit
ITEK	Indigenous Traditional Ecological Knowledge
JPE	juvenile production estimate
JPI	juvenile production index
km	kilometer
NMFS	National Marine Fisheries Service
Nomtipom Waywaket	Winnemem Wintu words for Sacramento River
Nur	Winnemem Wintu word for Chinook Salmon
Project	studies to gather data, compile information, and identify data gaps related to physical and biological conditions in the Study Area
RBDD	Red Bluff Diversion Dam
Reclamation	U.S. Bureau of Reclamation
rkm	river kilometer
RM	river mile
STARS	Survival, Travel time, and Routing Simulation
TDM	temperature-dependent mortality
USEPA	U.S. Environmental Protection Agency
Winnemem Waywaket	Winnemem Wintu words for McCloud River

1 Introduction

A team of engineering and fisheries science consultants consisting of Anchor QEA; HDR Engineering, Inc.; U.S. Geological Survey (USGS) and QEDA Consulting, LLC, known herein as the "Consultant Team," has received funding from the California Department of Fish and Wildlife (CDFW) to implement studies to gather data, compile information, and identify data gaps related to physical and biological conditions in the Study Area. These studies are referred to as the "Project." The results of the Project will support an investigation of the feasibility of providing volitional passage for fish, particularly Chinook Salmon (*Oncorhynchus tshawytscha*), above Keswick and Shasta dams on the Nomtipom Waywaket (also known as the Sacramento River) in northern California. In this document, Chinook Salmon is used to generally describe the species because once connectivity is re-established through reintroduction, fish will adapt to the new environments and could display run timing consistent with multiple runs. It is inclusive of Nur, which the Winnemem Wintu Tribe uses for Chinook Salmon that have been raised by the Tribe. The formal, evolutionarily significant unit (ESU)-specific name (e.g., Sacramento River winter-run Chinook Salmon) is used when discussing federal Endangered Species Act (ESA)-listed Chinook Salmon or steelhead. The feasibility study will be reviewed by the salmon co-managers (Winnemem Wintu Tribe, CDFW, and National Marine Fisheries Service [NMFS]) and used to inform fish passage decisions.

The Study Area extends from the confluence of Cow Creek and the Nomtipom Waywaket and includes the Winnemem Waywaket (also known as the McCloud River) from Shasta Reservoir to the McCloud Dam (Figure 1). It includes portions of the Winnemem Waywaket and the Nomtipom Waywaket, including Keswick and Shasta dams and reservoirs, which currently block upstream migration of Chinook Salmon to their historic cold-water rearing areas (Yoshiyama and Fisher 2001). Additionally, the Study Area includes Cow Creek, Little Cow Creek, and Dry Creek.

The purpose of this document is to establish information on life history diversity and timing to inform potential donor populations for rematriating and reintroducing Chinook Salmon into the Winnemem Waywaket from local sources and the development of alternatives for passing adult and juvenile fish around Keswick and Shasta dams. For the Winnemem Wintu Tribe, rematriation means bringing the original salmon from the Winnemem Waywaket back home to their ancestral river. Rematriation also includes restoring the Tribe's spiritual, cultural, and ecological ties to their lands and waters, reasserting their role as stewards, and reweaving the salmon into their identity, ceremonies, and stories. This document was developed to provide the Consultant Team with an overview of life history and run-timing characteristics of the four runs of Chinook Salmon being considered by the Project and environmental factors affecting various life stages. The intent was to provide the Consultant Team with a common description and understanding of these characteristics and factors to use when developing multiple and varied Project products. This summary is an appendix to the overarching report documenting the results of the Project, which is called the

Background Compendium and Design Criteria Report for the Feasibility of Volitional Fish Passage above Keswick and Shasta Dams (Background Compendium). This larger report contains additional background information for the Project and this document should be considered within this context.

For potential donor population sources, the following types of information are needed to understand life history attributes and how they interact with the rematriation/reintroduction site. Life history behaviors can be driven by genetic predisposition and local adaptation, and salmonids also exhibit plasticity in their ability to adapt to environmental changes. For the selection of donor source populations, the following biological information is relevant to support a rematriation/reintroduction program:

- **Population Abundance:** Donor source population abundance and population status or viability thresholds (increasing or decreasing trend over time) based on annual and historical returns to understand the potential demographic risk (i.e. potential loss of genetic diversity or broodstock) associated with the removal of individuals from the source population. The annual abundance counts also inform the feasibility of collecting fish at collection facilities or in-river sites and equipment needs. Information on genetic or broodstock history can help assess the source as an ancestral or historical match to the rematriation/reintroduction site (Winnemem Waywaket) or whether it is associated with a conservation or integrated hatchery broodstock program.
- **Life History Attributes:** Spawn timing, migration timing, distances, and size at migration will inform how the source population is currently adapted to or interacting with the local river conditions and allow for an assessment of how these relate to the rematriation/reintroduction site conditions. Further, understanding the range of these life history metrics over a variety of environmental conditions (i.e., wet, cool years versus dry, warm years) will increase the understanding of the life history diversity exhibited by the donor source populations and how it may match with the rematriation/reintroduction site. Donor source populations' life history attributes can be compared to information from historical populations for the rematriation/reintroduction site as provided by references from before Shasta Dam was constructed and Indigenous science.

For the development of fish passage alternatives, the three primary types of biological design criteria that have the most influence on determining required conditions within fish passageways and facility type, size, and configuration relate to the following:

- **Selected Species, Run, and Migration Timing:** The species, run, and life stages being targeted for fish passage along with their seasonality allows anticipated hydrologic conditions to be estimated during the periods when the target fish are expected to migrate upstream and/or downstream at each location of interest.

- **Species Abundance:** Abundance informs the annual number of fish that require passage and the peak daily rate of migration that influences required conditions for passage, facility size, and operational requirements.
- **Trapping and Holding Criteria:** For trap and haul alternatives, trapping and holding criteria inform the requirements for holding volume, duration of operations, temperature in holding facilities, acclimation facilities, and water supply. Transport is also important when considering densities, duration, and temperature.

For the development of alternatives for passing adult and juvenile Chinook Salmon around Keswick and Shasta dams, the following points provide context for the information included in this document:

- Four runs of Chinook Salmon are being considered (winter, spring, fall, and late fall). This naming convention is based on adult migration periods and is useful for western science purposes but is very general and understates the variability in run timing of different populations in large river systems.
- The four runs are expected to migrate during large portions of each calendar year.
- One overall goal of alternative development for volitional fish passage is to have designs that result in passageways that allow for passage into the Winnemem Waywaket as we understand it might occur now, and how it might occur in the future, as the four runs adapt to the Winnemem Waywaket environment.
- Given these points and the current adult and juvenile migration timing of the four runs, the Consultant Team assumes that adult and juvenile passageways and facilities would operate year-round except for annual maintenance periods. Therefore, in this report we did not attempt to estimate future run timing once Chinook Salmon are rematriated/reintroduced into the Winnemem Waywaket. We assumed the co-managers' goal is to provide facilities and passageways that allow the four runs to adapt as needed to environmental conditions in the Winnemem Waywaket, which is best supported by broad, nonrestrictive, facility and passageway operational periods.

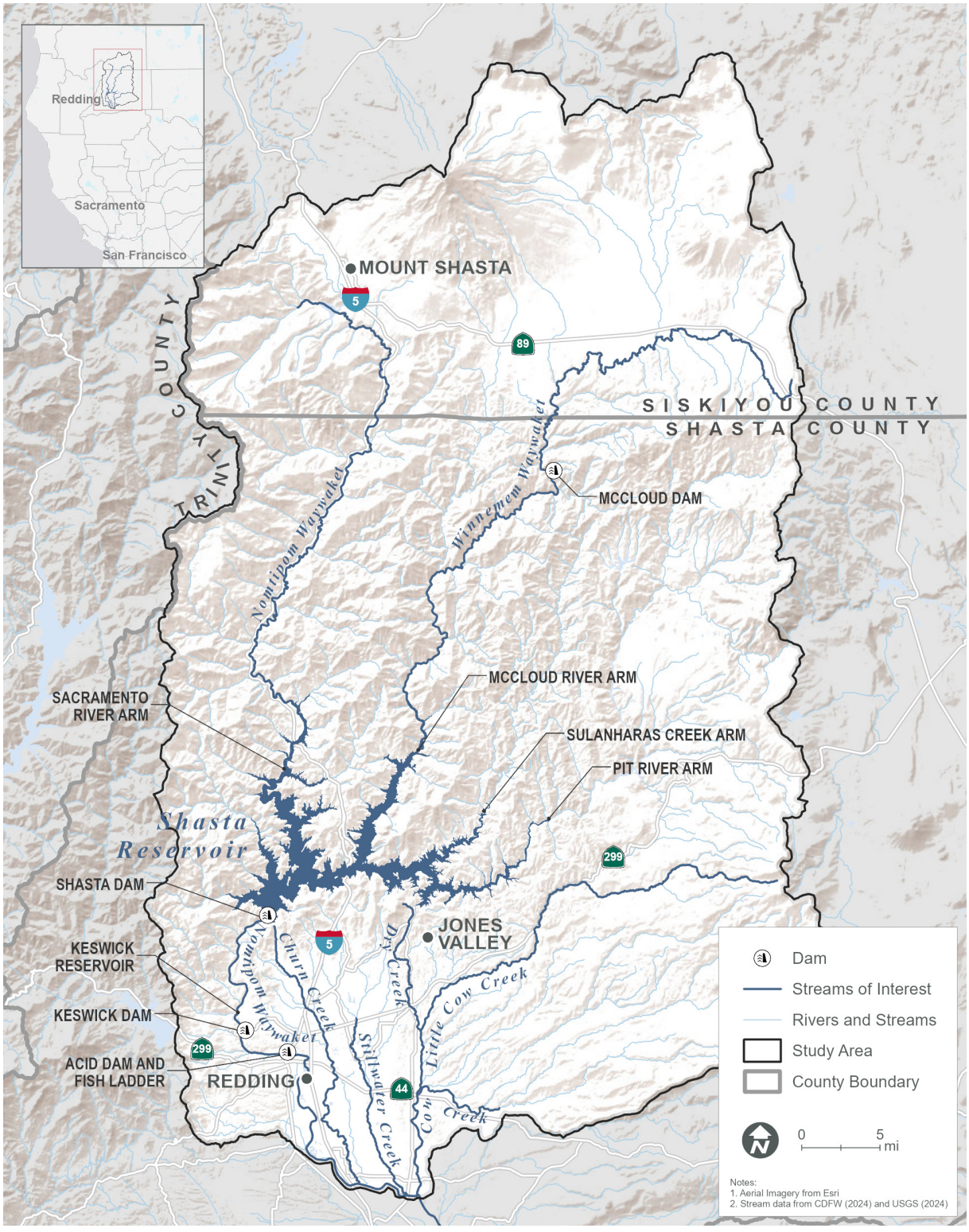
The remainder of this document provides life history summary information from a Western science perspective (unless otherwise stated) for all four Chinook Salmon populations that inhabit the Nomtipom Waywaket. Additionally, a summary of Chinook Salmon life history timing and thermal tolerances by life stage and run is provided.

Throughout the course of implementing the data gaps studies, the Consultant Team had numerous opportunities to hear from Winnemem Wintu Tribe members and Chief Sisk about Indigenous Traditional Ecological Knowledge (ITEK) and Tribal priorities. The Consultant Team understands that ITEK is spatially based (e.g., flows and temperature are expressed uniquely at different places throughout the system); thus it would not be appropriate to describe ITEK using a watershed-wide approach. The Consultant Team further understands that obtaining an adequate understanding of

ITEK will require in-person engagement with the Tribe as the reintroduction efforts are further developed. The Consultant Team acknowledges that full incorporation of ITEK into this document has not been accomplished, but emphasize the need to continue efforts to do so as Project activities progress forward.

Readers should also understand that on December 12, 2025, the Consultant Team received an email stating that the Winnemem Wintu Tribe does not endorse these reports (referring to the Background Compendium and appendices and *Alternatives Formulation and Evaluation Report* [Anchor QEA and HDR 2026]).

Figure 1
Study Area



2 Winter-Run Chinook Salmon

The following sections describe background and historical conditions, current abundance, and available information on life history attributes by life stage for winter-run Chinook Salmon.

2.1 Background and Historical Conditions

Estimates of Chinook Salmon abundance (all Chinook Salmon runs within the Central Valley) prior to European colonization in the 1800s may have been as high as 1 to 2 million spawners (Fisher 1994; Yoshiyama et al. 1998), with winter-run Chinook Salmon numbering in the high tens of thousands (Yoshiyama et al. 1998). Chinook Salmon have been excluded from historical spawning habitat in the upper Nomtipom Waywaket and the Winnemem Waywaket since the construction of Shasta and Keswick dams between 1945 and 1950 (NMFS 2014). Prior to the impacts of dam construction, overfishing, and habitat degradation, the Winnemem Waywaket in the upper Sacramento Basin above the current location of Shasta Dam was one of the most productive Chinook Salmon bearing rivers in existence (Stone 1880).

In 1872, Livingston Stone established the Baird Fish Hatchery on the Winnemem Waywaket. This hatchery was the first salmon breeding station in the United States. Livingston Stone reported seeing tens of thousands, and perhaps hundreds of thousands, of spawners in the 1870s, though it was unclear which runs they were from (Stone 1874, 1880). However, Winnemem Wintu Tribal members in the late 1800s and early 1900s reported that winter-run Chinook Salmon were more abundant than the other Chinook Salmon runs in the Winnemem Waywaket (Stone 1874; Schofield 1900; USFC 1900, 1904; Hanson 1940). Hanson (1940) estimated that before being cut off by dams, the Winnemem Waywaket could support approximately 25,000 Chinook Salmon redds, and the lower 8 kilometers (km; 5 miles) of Yet Atwam Creek could support approximately 830 redds.

Salmon historically had access to the Winnemem Waywaket up to an impassible barrier at Lower Falls (Rutter 1904; Hanson 1940). However, there was a partial barrier below the falls at Big Springs (river kilometer [rkm] 79, river mile [RM] 49), which contributed over half the streamflow of the river. This natural reduction in streamflow served as an "ecological" migration barrier for salmon (Wales 1939). Further, ethnographic information collected by Guilford-Kardell and Dotta (1980) indicated that a bend in the Winnemem Waywaket about 1.6 km (1 mile) below present-day McCloud Reservoir prevented most salmon from ascending further and that the habitat upriver of rkm 66 (RM 41) was less suitable than the area below (Yoshiyama and Fisher 2001). This location on the river was also the location of a Wintu village named Nurumwitipom ("salmon come back") or Nurunwititeke ("falls back where the salmon turn back"; Guilford-Kardell and Dotta 1980). Despite most salmon not moving above rkm 66 (RM 41), some spawning was documented from rkm 66 (RM 41) to Lower Falls (Hanson 1940). For context, the pre-dammed upper Nomtipom Waywaket was

regarded as an "ideal spawning stream" with "wonderful spawning beds along its entire length" (Clark 1929).

Before access to the Winnemem Waywaket was blocked (Hanson 1940), observations of winter-run Chinook Salmon spawning were reported during May and June 1939 between Big Springs and Lower Falls. Big Springs is particularly important to the winter-run Chinook Salmon due to the year-round abundant, stable cold water (Waring 1915). Spawn timing in the Winnemem Waywaket above the Baird Fish Hatchery was also described as abundant in early May (Schofield 1900). Stone (1880) reported vast numbers of winter-run Chinook Salmon spawning throughout the Winnemem Waywaket in early July 1878. This further suggests that spawn timing appears to have remained fairly consistent since the first observations were recorded in the 1870s and that historical spawn timing in the Winnemem Waywaket was consistent with present-day spawn timing below Keswick Dam (Section 2.2.2).

2.1.1 Endangered Species Act

As detailed in NMFS (2014), the Sacramento River winter-run Chinook Salmon ESU, currently listed as endangered, was listed as a threatened species under emergency provisions of the ESA in August 1989 (54 *Federal Register* [Fed. Reg.] 32085; August 4, 1989) and listed as a threatened species in a final rule in November 1990 (55 Fed. Reg. 46515; November 5, 1990). In June 1992, NMFS proposed that the winter-run be reclassified as an "endangered" species (57 Fed. Reg. 27416; June 19, 1992). NMFS finalized its proposed rule and reclassified the winter-run as an endangered species on January 4, 1994 (59 Fed. Reg. 440). NMFS concluded that the winter-run in the Nomtipom Waywaket warranted listing as an endangered species due to several factors, including the following: 1) the continued decline and increased variability of run sizes since its first listing as a threatened species in 1989; 2) the expectation of weak returns in future years as the result of two small year classes (1991 and 1993); and 3) continued threats to the winter-run. This ESU includes all spawned winter-run originating from the Nomtipom Waywaket and its tributaries. It also includes winter-run from the Livingston Stone National Fish Hatchery Supplementation and Captive Broodstock artificial propagation programs. On May 16, 1989, the California Fish and Game Commission listed the Sacramento River winter-run Chinook Salmon as endangered under the California Endangered Species Act (CESA).

2.2 Adult Return Migration and Spawning

This section summarizes available information on adult winter-run Chinook Salmon abundance and life history attributes, including migration and holding timing, spawn timing, adult size, age structure, and body condition.

2.2.1 Adult Abundance

Over the past 150 years, Nomtipom Waywaket winter-run Chinook Salmon populations have declined both in the Winnemem Waywaket and across the Central Valley. Mean annual adult returns were 4,589 fish during 2013-2022 (Azat 2024), 22,500 fish during 1971-1975 (Yoshiyama et. al. 2000), and approximately 45,000 fish during the mid-1960s through the 1970s (Fisher 1994).

Currently, winter-run Chinook Salmon exhibit the lowest adult age structure diversity of all Central Valley Chinook Salmon runs, with over 90% of adults returning as age-3 fish (Satterthwaite et al. 2017). However, a small percentage (i.e., 10%) of spawners still return as age-1 or 2, age-4, and age-5+ years (Satterthwaite et al. 2017). Because of the high percentage (i.e., 90%) of age-3 spawners, the cohort replacement rate, a measure of population growth, can be estimated by dividing the total number of adult spawners by the total number of adult spawners from 3 years prior. Values greater than one are representative of population growth, although this metric should be used with caution because there are a myriad of factors involved in spawner counts each year, such as number of hatchery spawners (Killam 2023) and because there is a very small percentage of fish that do not return as age-3 spawners (Satterthwaite et al. 2017). From 1996 to 2021, the cohort replacement rate ranged from 0.2 to 6.5, with an average of 2.3. There have been two periods of notably low replacement rates: 2007 to 2012 and 2016 to 2018. The two highest replacement rates were observed in 2003 (6.1) and 2020 (6.5; Killam 2023).

2.2.2 Migration and Holding Timing

Currently, winter-run Chinook Salmon generally leave the ocean and begin arriving at their spawning grounds in the upper Nomtipom Waywaket between December and July (Azat 2023; Fisher 1994). Historical data (1970 through 1988) show that the first 10% of adult winter-run Chinook Salmon arrive above Red Bluff Diversion Dam (RBDD) by the second week of February, and 90% have passed by early June (Killam 2023). Prior to dam construction, winter-run Chinook Salmon historically used higher-elevation reaches of the Sacramento drainage to hold for several months before spawning (Yoshiyama et al. 2000). Spring-fed headwaters were traditionally important holding and spawning habitats (Fisher 1994), and the run was historically restricted to the upper Sacramento drainage (Yoshiyama et al. 2000) above the current location of Shasta Dam. Today, most spawning occurs between Keswick Dam and Clear Creek, though spawning below RBDD was common until the mid-2000s (Azat 2023; CDFW 2024).

2.2.3 Spawn Timing

Since regular monitoring began in the 1970s, spawning below Keswick Dam has begun in late April and continued through August (Crozier et al. 2019; Azat 2023; CDFW 2024). Starting in 2000, aerial redd surveys of the upper Nomtipom Waywaket have observed the first winter-run Chinook Salmon redds from late April through mid-June (CDFW 2024). Carcass surveys conducted during the same

period have detected the first 1% of fresh female carcasses between mid-May and early June. Peak spawning occurs between late June through early July based on CDFW carcass surveys conducted from 2000 to 2021 (Anchor QEA 2024; CDFW 2024). The 2000 to 2024 redd surveys have observed new redds through late August (CDFW 2024).

As climate change continues to affect temperature and precipitation patterns, warmer spring water temperatures may affect spawn timing. A study by Jennings and Hendrix (2020) found that while the winter-run spawning start date remained relatively constant from year to year, the timing of peak spawning was earlier in years with cooler springtime water temperatures and later in years with warmer water temperatures. Water temperatures in the lower mainstem Nomtipom Waywaket, such as below Wilkins Slough and near Freeport, regularly reach 20°C (68°F) by late spring (Myrick and Cech 2004; SacPAS 2024a). The lower river can be expected to reach these suboptimal temperatures earlier in the season as climate change continues to alter thermal regimes in the Nomtipom Waywaket system.

2.2.4 Adult Size, Age Structure, and Body Condition

As discussed in Section 2.2.1, 90% of adult spawners are age-3 and 7% are age-2 (Satterthwaite et al. 2017). Age-1, age-4, and age-5+ spawners make up the remaining 3% of spawners (Satterthwaite et al. 2017). In addition, up to 85% of hatchery-origin adult returners have been documented as age-2 fish based on genetic analysis (Thompson 2020) and are less likely to return as age-4 fish than natural-origin fish (Chen et al. 2023). Natural-origin age-2 adults, called jacks and jills, are identified during annual Chinook Salmon redd and carcass surveys along the upper Nomtipom Waywaket, which have been conducted by the CDFW since 1996 (Killam 2023). Since 1996, the in-river percentage of jacks has ranged from 1.1% (in 2009) to 36% (in 2017), with an average of 10%. The percentage of jills is generally lower, with a range of 0% (in 2021) to 14.4% (in 2017) and an average of 2.0% since 1996 (Killam 2023). In annual carcass surveys conducted by CDFW from 2003 to 2021, the average fresh female carcasses fork length (FL) has ranged from 674 millimeters (mm; 26.5 inches) in 2017 to 806 mm (31.7 inches) in 2013 (Killam 2023). In 2021, the average fresh male carcass FL was 832 mm (32.8 inches; CDFW 2022a).

Historically, the annual returns of Central Valley Chinook Salmon adult spawners consisted of a diverse age structure, with a majority of adults being age-4 or age-5, based on data from 1919 to 1921. Winnemem Wintu knowledge indicates Chinook Salmon used to return to the Winnemem Waywaket at ages between 5 and 7 years old. Satterthwaite et al. (2017) suggest that winter- and spring-run Chinook Salmon are unlikely to regain age -structure diversity without access to historical upstream habitats. Currently, approximately 90% of the Chinook Salmon have been identified as age-3 or younger (Satterthwaite et al. 2017; Killam 2023; Cavallo 2024).

Pre-spawn mortality of female winter-run Chinook Salmon has ranged from 0% (in 2000) to 5.5% (in 2021) with an average of 1.9% from 1996 to 2021 (Killam 2023). Recent observations suggest that higher pre-spawn mortality may coincide with reduced body condition caused by stressors, including warmer spring water temperatures and adult thiamine deficiency. For example, in spring 2021, a period of warm water releases from Shasta Dam occurred. During the same time, pre-spawn mortality averaged 47% over the first 6 weeks of spawning, during which there was also high prevalence of fungal and other types of infections in carcasses sent for autopsy (Killam 2023; Austing 2024; Foott 2021). In addition, starting in 2020, in-river female spawners trapped for hatchery broodstock exhibited low egg thiamine levels, indicating that female spawners not trapped for hatchery broodstock may also be low in thiamine levels (Johnson 2023).

2.3 Egg Incubation and Hatching

This section summarizes available information on the winter-run egg incubation and hatching life stage, including redd and egg abundance and survival and emergence timing.

2.3.1 Redd and Egg Abundance and Survival

From 2000 to 2021, Nomtipom Waywaket winter-run Chinook Salmon had an average fecundity of approximately 5,000 eggs per female, dispersed across an average of 490 redds per year below Keswick Dam (Killam 2023; CDFW 2024). Hanson (1940) estimated that the Winnemem Waywaket could support approximately 25,000 redds, and its tributary Yet Atwam Creek could support up to 830 redds in the lower 8 km (5 miles) of suitable spawning habitat. Both estimates greatly exceed the annual average number of 490 redds observed below Keswick Dam from 2000 to 2021. Historical fry abundance and fecundity are difficult to accurately estimate, but fecundity for all runs of Chinook Salmon may have had an average range of 3,743 to 5,806 eggs per female, based on information from approximately the late 1800s through the early 1990s compiled by Fisher (1994).

Egg-to-fry survival rates averaged 22.3% between 2002 to 2021 (Poytress et al. 2014; Voss and Poytress 2023). Fry survival in the drought years of 2014 and 2015 resulted in some of the lowest juvenile survival on record, at 4% to 6% to RBDD, which is well below the long-term average of approximately 25% survival to the diversion dam (Williams et al. 2016). In 2021, egg-to-fry survival was only 2.5%, largely due to temperature-dependent mortality during a critical water year (Voss and Poytress 2023) and was exacerbated by the effects of thiamine deficiency complex (NMFS 2022a).

2.3.2 Emergence Timing

Based on historical water temperatures, the average time from winter-run Chinook Salmon egg deposition to emergence is usually 80 to 91 days but can be as short as 70 days and as long as 110 days (Killam 2021). Given the current spawning period (Section 2.2.3), fry emergence is estimated to start in July and continue through mid-November. Modeled results from brood years 2010 to 2021, based

on redd survey data, predicted a fry emergence period of mid-August through mid-November, with a peak in late September (SacPAS 2024b; Anchor QEA 2024). Based on recent historical information (late 1800s through the early 1990s), Nomtipom Waywaket winter-run Chinook Salmon have had a fry emergence time of July through October, with a residence time in freshwater of approximately 5 to 10 months (Fisher 1994).

2.4 Juvenile Rearing and Out-Migration

This section summarizes available information on juvenile winter-run Chinook Salmon abundance and life history attributes, including migration timing and size of juveniles.

2.4.1 Juvenile Abundance

Annual winter-run Chinook Salmon passage estimates of fry equivalents at RBDD (juvenile production index [JPI]) between 2002 and 2023 averaged 2,796,026 juveniles and ranged from 311,058 to 8,943,194 (Voss and Poytress 2023; NMFS 2023a, 2024a). A juvenile production study from 1995 to 1999 yielded lower juvenile production estimates (JPEs) of an average of 1,900,000 fry per year, with a range of 384,000 to 4,600,000 fry per year (Martin et al. 2001).

Since 2019, when updated methods for forecasting fry-to-smolt survival and smolt survival were introduced (NMFS 2020; O'Farrell et al. 2018), fry-to-smolt survival has ranged from 44.3% to 50.7%, with an average of 47.1%, while smolt survival has ranged from 31.8% to 38.6%, with an average of 34.3% (NMFS 2020, 2021, 2022b, 2023, 2024a). Annual fry-to-smolt survival is forecasted using a coded-wire-tag and modeling method with data collected since brood year 1998, and smolt survival is forecasted using hatchery-origin acoustic telemetry data collected in the middle Nomtipom Waywaket since brood year 2012 (O'Farrell et al. 2012, 2018; NMFS 2024a). Both survivals are used to estimate juvenile production entering the Sacramento-San Joaquin River Delta (Delta) at the Tower Bridge in Sacramento. From 2007 to 2023, winter-run Chinook Salmon smolt production averaged 425,407 smolts entering the Delta annually and ranged from 49,924 to 1,196,387 (NOAA 2024).

Survival estimates of natural-origin winter-run Chinook Salmon juveniles through the Delta are not currently available. Acoustic-tagged hatchery-origin fish are often used as a proxy to help understand survival conditions for juvenile winter-run Chinook Salmon. These data have been used to develop the Survival, Travel time, and Routing Simulation (STARS) model, which estimates survival through the Delta, from Knights Landing to Chipps Island, based on acoustic telemetry data from 2014 to 2018 (Perry et al. 2018; Hance et al. 2022; CBR 2024). From 2018 to 2021, the STARS model estimated average daily survival rates through the Delta of 19% (2021) to 45% (2019), with an average of 30% based on Knights Landing passage dates of October 1 to May 1 (CBR 2024). In studies from 2012 to 2021, survival of juvenile, hatchery-origin, acoustic-tagged winter-run Chinook Salmon from their release site in Redding, California, to the Delta exit at Benicia Bridge ranged from 3.8%

(2020) to 36.4% (2017) (CVEATP 2024). Survival rates through the Delta for natural-origin winter-run Chinook Salmon is an ongoing area of research.

2.4.2 Migration Timing

Juvenile migration timing varies greatly among years. Juveniles begin arriving at RBDD (lower extent of the upper Nomtipom Waywaket) in the first or second week of July and generally finish passing RBDD between late March and mid-May of the following year. By December, almost all out-migrating fry and smolts have already passed RBDD, with passage peaking in September and October based on data from 2002 to 2023 (Poytress et al. 2014; SacPAS 2024a). The response of juvenile salmon to rear below RBDD within the middle and lower Nomtipom Waywaket or to migrate is likely influenced by many physical and biological cues, with river flows being a major driver (Windell et al. 2017; Hassrick et al. 2022). Annual variation in migration timing getting to and through the Delta is influenced primarily by hydrology, migration route selection, habitat opportunity (e.g., access to off-channel habitat), and habitat capacity (Windell et al. 2017; Hassrick et al. 2022). Downstream migration into the Delta is stimulated by flow pulses; numbers of out-migrants tend to exhibit a bimodal distribution, with initial pulses in the late fall following large precipitation events and another broad peak in the spring (Windell et al. 2017; Michel et al. 2021). In years lacking major precipitation events, out-migration timing tends to be unimodal, with Delta entry occurring in the late winter to early spring months between November and May (Fisher 1994; Windell et al. 2017). From 1999 to 2023, Delta exit at Chipps Island began between November and March and ended between April and May, with median passage occurring between March and early April (SacPAS 2024a). Ocean entry occurs between November and May (Fisher 1994).

Pacific salmon exhibit considerable plasticity with respect to run timing (Taylor 1991). Run timing of Central Valley Chinook Salmon, including the Nomtipom Waywaket winter-run Chinook Salmon, may have shifted since the 1800s given that river hydrology has been altered through diversions and dams and the lack of access to historical spring-fed habitats (Yoshiyama et al. 1998). For example, the juvenile-rearing period may be shorter now that winter-run Chinook Salmon are forced to spawn at lower elevations, based on a pattern seen in high- and low-elevation spring-run spawners on Deer and Mill Creek (Yoshiyama et al. 1998).

2.4.3 Size of Juveniles

A portion of out-migrating juveniles are surveyed at RBDD each year. Fry are defined as fish <46 mm (1.8 inches) in FL, and pre-smolts and smolts are defined as fish ≥46 mm (1.8 inches) in FL (Anchor QEA 2024). On average (from 2002 to 2021), fry composed approximately 74% and smolts comprised 26% of all out-migrating juveniles at RBDD based on data compiled from Martin et al. (2001), Poytress et al. (2014), Poytress and Gruber (2015), Poytress (2016), and Voss and Poytress (2017, 2018, 2019, 2020, 2022a, 2022b, 2023).

Trawl surveys at Chipps Island capture winter-run Chinook Salmon later in the season as they move through the Delta. From 2016 to 2022, genetically confirmed juvenile winter-run Chinook Salmon FLs at Chipps Island have been between 80 mm (3.1 inches) and 160 mm (6.3 inches), with the majority between 100 mm (3.9 inches) and 130 mm (5.1 inches; IEP 2023).

2.5 Summary of In-River Timing by Life Stage

As shown in Table 1, adult winter-run Chinook Salmon are historically known to migrate from the ocean and arrive at their natal spawning grounds between December and July (Azat 2023; Killam 2023). Spawning is observed to begin in mid-April and end in mid-to-late August, based on redd and carcass survey data from 2000 to 2021 and historical monitoring (CDFW 2024; Azat 2023). Fry typically emerge from redds after 80 to 91 days, although environmental conditions can cause this duration to range from 70 to 110 days (Killam 2023). Thus, fry are expected to emerge between July and mid-November and begin rearing in the upper Nomtipom Waywaket (Fisher 1994; Anchor QEA 2024; SacPAS 2024b). Out-migrating juveniles have been detected at RBDD between July and mid-May of the following year, with passage peaking in September and October. Passing downstream of RBDD marks the beginning of rearing and out-migration in the middle and lower Nomtipom Waywaket (SacPAS 2024a). Juvenile rearing and out-migration through the Delta continues through mid-May as well, based on trawl sampling at Chipps Island (SacPAS 2024a). Ocean entry occurs between November and May (Fisher 1994; SacPAS 2024a).

Table 1
In-River Timing of Winter-Run Chinook Salmon by Life Stage

Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Reference
Adult Migration and Holding													Historical data: Azat (2023), Killam (2023), and Fisher (1994)
Spawning													Carcass and redd survey data: Azat (2023) and CDFW (2024)
Fry Emergence													Estimated from model results (SacPAS 2024b), genetic summaries of out-migrating juveniles (Anchor QEA 2024), and historical data (Fisher 1994)
Smolt Stream Residency													Passage at RBDD: SacPAS (2024a) and Poytress et al. (2014)
Smolt Out-Migration													Passage through RBDD and Chipps Island Trawls: SacPAS (2024a). Peak timing of RBDD passage is shown.
Smolt Ocean Entry													Fisher (1994) and passage through Chipps Island Trawls (SacPAS 2024a)

Note:
Shading within each group indicates temporal range and darkening in shading and addition of cross-hatching indicate peak timing.

3 Spring-Run Chinook Salmon

The following sections describe background and historical conditions, current abundance, and available information on life history attributes by life stage for spring-run Chinook Salmon.

3.1 Background and Historical Conditions

Spring-run Chinook Salmon have evolved a life history that is dependent on access to cold, high-elevation headwaters for over-summering and spawning (SWFSC 2023). Before dams were constructed, the various Chinook Salmon runs in the Nomtipom Waywaket system could be identified based on spawning habitat, with spring-run Chinook Salmon occupying the high-elevation streams that were often inaccessible for the other runs (CFC 1900; Rutter 1904; Fisher 1994). Yoshiyama et al. (2001) noted that spring-run Chinook Salmon utilized high spring-flow conditions to ascend above 1,500 feet (457 meters) in elevation, using abundant fat reserves to avoid high summer water temperatures. Undeveloped gonads, high fat reserves, and smaller body sizes relative to fall-run Chinook Salmon helped them migrate higher than other runs. By utilizing peak spring flows to reach headwater streams, spring-run Chinook Salmon gained access to areas that would otherwise be inaccessible during the rest of the year (Yoshiyama and Fisher 2001; CFC 1890). While there is some spatial overlap in spawning habitat with winter-run Chinook Salmon, differences in peak spawn timing historically helped reinforce the reproductive isolation between spring- and winter- runs (Lindley et al. 2004).

The Central Valley was estimated to produce up to 600,000 spring-run Chinook Salmon per year (CDFG 1998) from 18 or 19 independent populations (Johnson 2024; Lindley et al. 2007). For example, one particularly abundant year in 1883 yielded over 500,000 spring-run Chinook Salmon for the fishery (Yoshiyama et al. 1998). By the 1940s, the population ranged from 19,000 to 222,000; a reduction attributed to overfishing, dam building, and habitat degradation (CDFG 1998). There are no definitive estimates of historical fry or smolt abundance in the 1800s.

Without access to their historical range, the ability of spring-run Chinook Salmon to use tributaries in the lower and mid-Nomtipom Waywaket will always be tenuous, particularly in the face of a warming climate that will bring elevated summer temperatures and less snowmelt derived water (Alston 2016). Wild Central Valley spring-run Chinook Salmon currently have three independent populations in Butte Creek, Deer Creek, and Mill Creek[1] (NMFS 2014) and a smaller dependent population in Antelope Creek (Johnson 2024). The Mill and Deer creeks populations are at high risk of extinction due to decreases in population size (NMFS 2014; SWFSC 2023). The only population of spring-run Chinook Salmon not currently at high risk of extinction is the Butte Creek population (SWFSC 2023).

[1] The Mill Creek and Deer Creek populations are not genetically distinct from one another but are typically considered to be two separate populations because they inhabit two separate spawning areas with unique population dynamics (Lindley et al. 2004; NMFS 2014; SWFSC 2023).

This population is reliant on cold-water releases from the nearby DeSabla Centerville Project (SWFSC 2023), which helps mitigate summer peak heat that would otherwise make the stream less suitable for spawning.

3.1.1 Endangered Species Act Status

In 1999, NMFS listed the natural-origin Central Valley ESU of spring-run Chinook Salmon as a "threatened" species under the federal ESA after initially evaluating it for "endangered" status (Fed. Reg. 50394; September 16, 1999). The ESU was identified as at-risk for "endangered" status in the foreseeable future, but large runs in Butte Creek have kept the ESU listed as "threatened" rather than "endangered" for over a decade (NMFS 2014; SWFSC 2023). The California Fish and Game Commission affirmed the threatened status of Central Valley spring-run Chinook Salmon under the CESA (NMFS 2014). The primary threats to the ESU include the following: 1) warm water temperatures; 2) limited spawning habitat due to dams; 3) loss of rearing habitat in the middle and lower Nomtipom Waywaket; 4) ocean harvest; and 5) predation (NMFS 2014). This ESU includes naturally spawned spring-run originating from the Nomtipom Waywaket and its tributaries and spring-run from the Feather River Hatchery spring-run program. This ESU does not include fish that are designated as part of an experimental population.

3.2 Adult Return Migration and Spawning

This section summarizes available information on adult spring-run Chinook Salmon abundance and life history attributes, including migration and holding timing, spawn timing, and adult size, age structure, and body condition.

3.2.1 Adult Abundance

Spring-run Chinook Salmon populations in the Nomtipom Waywaket are a fraction of their former size (Yoshiyama et al. 1998). Historically, spring-run Chinook Salmon populations were found in most of the eastern tributaries of the Sacramento and San Joaquin rivers, and large dams and water development eliminated access to all but the few remaining self-sustaining tributaries (CDFG 1998). From the 1970s to the mid-2010s, annual returns have fluctuated between 3,000 to 30,000 adults per year across the entire Central Valley (NMFS 2014). Since the mid-2010s, the spring-run Chinook Salmon population has declined sharply. In 2023, the total number of natural-origin spring-run Chinook Salmon adult spawners was 167, with a 10-year average of 6,814 and a 20-year average of 9,236 (Azat 2024). Of the 18 or 19 historical spring-run Chinook Salmon populations in the Central Valley, 15 are likely extinct (Lindley et al. 2004; Lindley et al. 2007).[2]

[2] See Footnote 1.

On the Nomtipom Waywaket, adult fish can volitionally migrate upstream as far as Keswick Dam, which forms a complete barrier preventing access to the high-elevation spawning habitat used historically by spring-run Chinook Salmon. There are now only a few extant populations of spring-run Chinook Salmon spawning below barriers, and the overall Central Valley spring-run Chinook Salmon ESU is now at moderate to high risk of extinction (SWFSC 2023). Wild Central Valley spring-run Chinook Salmon have three independent populations in Butte Creek, Deer Creek, and Mill Creek (NMFS 2014). Surveys of these populations from 2014 to 2023 show a population decline among all three, with average escapement of 5,605 adults at Butte Creek, 265 adults at Mill Creek, and 352 adults at Deer Creek (Azat 2024). Population estimates for Mill Creek spring-run Chinook Salmon have declined from an average of 936 fish from 2000 to 2009 to 250 fish in 2022 and 18 fish in 2024 (Johnson 2024; Revnak 2025). Similarly, the Deer Creek population estimates have declined from an average of 1,369 fish in 2000 to 2009 to 127 fish in 2022 and 33 fish in 2024 (Johnson 2024). The 2024 data are preliminary, but the low counts are likely due to the Park Fire of 2024, in which nearly 100% of Mill Creek and 70% of Deer Creek spawning habitats were within the fire perimeter (Johnson 2024; Revnak 2025). The average escapement above RBDD (including fish in the mainstem Nomtipom Waywaket above RBDD, Battle Creek, Clear Creek, and Cottonwood Creek) from 2014 to 2023 was 553 fish (Azat 2024). Below RBDD (in Antelope Creek, Mill Creek, Deer Creek, Big Chico Creek, and Butte Creek), the average total escapement was 6,262 fish (Azat 2024). No spring-run Chinook Salmon have been observed in the mainstem Nomtipom Waywaket below RBDD since 2008 (Azat 2024). This decline in escapement since around 2014 is driven in part by drought and high summer temperatures (SWFSC 2023). The low population size, pre-existing vulnerability, and the rapidity of the decline have all contributed to the high extinction risk designation. Continued high rates of natural-origin fish interbreeding with strays from the Feather River Fish Hatchery remain an additional concern for spring-run Chinook Salmon abundance and population viability across the Central Valley (Williams et al. 2016).

As discussed in Section 2.2.1, the metric of cohort replacement rates may be used to evaluate population growth (or decline) for each generation of Chinook Salmon, with replacement rates greater than 1 representing a growing population (i.e., the number of offspring is greater than the number of parents). Like winter-run Chinook Salmon, the majority of spring-run Chinook Salmon return to spawn at 3 years of age, with 73% age-3 returns, 17% age-4 returns, 9% age-1 or age-2 returns, and less than 1% age-5+ returns (Satterthwaite et al. 2017). Therefore, a 3-year life cycle is often used in the cohort replacement rate estimate. Cohort replacement rates of spring-run Chinook Salmon have ranged from 0.14 (in 2015) to 8.68 (in 2013), with most values being near 1 (Alston 2016). The low returns in 2015 were observed alongside high water temperatures and high rates of pre-spawn mortality; the Butte Creek cohort replacement rate in 2015 was calculated at 0.02 based on carcass survey results (Alston 2016).

There have been several spring-run Chinook Salmon recolonization attempts in recent years in Battle Creek, Clear Creek, and the San Joaquin River, where populations have previously been extirpated. For instance, the San Joaquin Restoration Program initiated a reintroduction program in 2014 that resulted in numerous redd and carcass observations in 2017 and 2019 (SWFSC 2023). In Clear Creek, 374 spring-run Chinook Salmon adults were captured at Keswick Dam in 2022 and transferred to Clear Creek, where environmental conditions were expected to be more favorable. However, monitoring efforts showed that environmental conditions were not better, and these fish experienced fungal infections and low redd counts (Provins 2023). Additionally, in 2024, an emergency action was conducted by CDFW, with cooperation from the U.S. Fish and Wildlife Service, Bureau of Land Management, and Bureau of Reclamation (Reclamation), in which approximately 11,000 fry from unmarked Feather River Hatchery-origin spring-run Chinook Salmon were incubated and then released into Clear Creek (Memeo 2025). At Battle Creek, escapement is monitored by CDFW (Moreno 2024) and reported by Azat (2024). Adult run-size varies greatly year to year, but these populations have the potential to establish self-sustaining populations (Williams et al. 2016).

3.2.2 Migration and Holding Timing

Spring-run Chinook Salmon migration into their natal spawning grounds occurs from March through July, with a peak in late May and June (Fisher 1994; Moyle 2002). Winter-run and spring-run Chinook Salmon in the Nomtipom Waywaket Basin have run times that partially overlap (Fisher 1994); thus, a late-arriving winter-run Chinook Salmon could possibly be categorized as an early spring-run Chinook Salmon if run timing was the only determinant of stock status. The spring-run generally holds for several months in the river before spawning (Rutter 1904; Killam 2023). This over-summering behavior is one reason why spring-run Chinook Salmon historically used cold, high-elevation streams for spawning, because temperatures in the lower river reaches usually move above their thermal optima during peak summer heat (Yoshiyama and Fisher 2001). Due to their over-summer holding time, spring-run Chinook Salmon may be misidentified as fall-run Chinook Salmon at the later end of their holding and spawning periods, which makes abundance estimates difficult to report accurately (Killam 2023).

Currently, spring-run Chinook Salmon in the Nomtipom Waywaket spawn below Keswick Dam, which blocks access to the rest of the Nomtipom Waywaket Basin where high-elevation spawning historically occurred. Spring-run Chinook Salmon are also found in many tributaries along the Nomtipom Waywaket. Battle Creek, Clear Creek, Butte Creek, Deer Creek, and Mill Creek have documented hundreds to thousands of spawners in total annually since 2004, ranging from 157 adults (in 2023) to 25,402 adults (in 2021), with 48% (in 2015) to 95% (in 2019) of total spawners returning to Butte Creek (Azat 2024). There are only three independent populations of spring-run Chinook Salmon left in the Sacramento River Basin; these populations are in Deer, Mill, and Butte creeks (NMFS 2014). Additionally, adults in most years may return to spawn in Antelope, Big Chico,

Little Chico, Beegum, Battle, and Clear creeks. However, these populations are not considered self-sustaining. For instance, the adults that return to Battle Creek are generally strays from the Feather River Hatchery or other populations (Alston 2016; Lindley et al. 2004). The spring-run and winter-run populations of Chinook Salmon have experienced far greater spawning habitat losses than the fall-run populations, and the corresponding population decreases have been significant (Yoshiyama et al. 1998; NMFS 2014).

3.2.3 Spawn Timing

Spring-run Chinook Salmon currently have a spawn time ranging from mid-August to early October, with peak spawning in mid-September (Fisher 1994; Moyle 2002; Killam 2023). Because spawn timing overlaps with fall-run Chinook Salmon, run identification of carcasses and redds is difficult. Additionally, genetic hybridization may occur (Killam 2023).

Historically, the spring-run Chinook Salmon spawning season in the Winnemem Waywaket spanned August through September (Yoshiyama et al. 1998). Yoshiyama and Fisher (2001) reported that spawning spring-run Chinook Salmon were the primary salmon that the Winnemem Wintu Tribe caught and dried for their winter food stores.

3.2.4 Adult Size, Age Structure, and Body Condition

Pre-spawn mortality carcasses were used to indicate the potential size of spring-run spawners. Spawner surveys are conducted independently for the different tributaries with spring-run Chinook Salmon. For instance, Butte Creek has conducted pre-spawn mortality surveys from 2002 to present, with data from 2002 to 2015 available online. The pre-spawn carcasses are expected to be similar in size to the successfully spawned carcasses, given that they are from the same cohorts (McReynolds 2024). These data show that female carcasses from fish that died prior to spawning range from 473 mm (18.6 inches) to 961 mm (37.8 inches) and male carcasses from fish that died before spawning range from 400 mm (15.7 inches) to 1,171 mm (46.1 inches) in length (Garmin 2016). Data on body size for fish that successfully spawned in Butte Creek are only available for 2021 and 2022 and show that female FLs ranged from 600 mm (23.6 inches) to 945 mm (37.2 inches), and male FLs ranged from 630 mm (24.8 inches) to 1,035 mm (40.7 inches; Nichols 2022; Henley 2024).

In Battle Creek, adult spawner surveys from 2001 to 2024 show an average body size ranging from 670 mm (26.4 inches) in 2009 to 855 mm (33.7 inches) in 2015. In 2024, the average body size was 725 mm (28.5 inches). Data from 2011 to 2012 and 2017 to 2019 were not available, and data in 2015 to 2016 were determined from only 1 month of monitoring (Moreno 2024).

Very little information is currently available on the age structure and body condition of adult spring-run Chinook Salmon. An evaluation of data from 1998 to 2004 shows approximately 73% of spring-run

Chinook Salmon return to spawn as age-3 adults, and approximately 17% return as age-4 adults (Satterthwaite et al. 2017).

3.3 Egg Incubation and Hatching

This section summarizes available information on the spring-run egg incubation and hatching life stage, including redd and egg abundance and survival and emergence timing.

3.3.1 Redd and Egg Abundance and Survival

As of the 1990s, spring-run Chinook Salmon across the Central Valley had an average female fecundity of 4,895 eggs per female (Fisher 1994). Spring-run spawners in Mill and Deer creeks in the 1990s had an average fecundity of 4,161 eggs per female. Similar fecundity estimates of 4,159 eggs per female were made at the Baird Fish Hatchery in the 1800s (CDFG 1998). Poytress et al. (2014) estimated average fecundity to be 5,078 eggs per female from 2002 to 2012. Fecundity has not been measured in recent years (Voss and Poytress 2023). The Feather River Hatchery reported a fecundity of 6,070 eggs per female for their 2022 spring-run brood year that consisted of 520 hatchery-origin and 8 wild adult females (McNabb and Julienne 2023). Redd abundance is not routinely monitored, but adult carcass monitoring is described in Section 3.2.1.

Egg-to-fry survival rates are also considered a data gap due to inaccuracies in adult counts and run identification (Poytress et al. 2014). However, egg-to-fry survival is expected to follow similar trends to fall-run Chinook Salmon (Section 4.3.1) due to similar spawn timing.

3.3.2 Emergence Timing

Spring-run Chinook Salmon across the Central Valley have an average fry emergence timing from November to March or April, with freshwater residence time varying from 3 to 15 months (Fisher 1994; Moyle 2002; Cordoleani et al. 2020). The length of time required for Chinook Salmon embryo incubation and emergence from the gravel is dependent on water temperature, but maximum embryo survival occurs with water temperatures between 5°C and 13°C (41°F and 55.4°F) and near-saturation dissolved oxygen levels (Moyle 2002). Under these preferred conditions, embryos hatch in 40 to 60 days but may remain in the gravel as alevins for another 4 to 6 weeks (30 to 45 days) before emergence (Moyle 2002).

3.4 Juvenile Rearing and Out-Migration

This section summarizes available information on juvenile spring-run Chinook Salmon juvenile abundance and life history attributes, including migration timing and size of juveniles.

3.4.1 Juvenile Abundance

Spring-run Chinook fry-equivalent production estimates between 2002 and 2021 ranged from 187,027 (in 2014) to 2,806,514 (in 2015), with an average JPI of 664,651 (Poytress et al. 2014; Poytress and Gruber 2015; Poytress 2016; Voss and Poytress 2017, 2018, 2019, 2020, 2022a, 2022b, 2023). Prior to 2017, RBDD estimates were made using length-at-date run identification. Beginning in 2017, genetic identification has been used to verify length-at-date methods (Voss and Poytress 2019). These genetic corrections show that late-arriving winter-run juveniles have been misidentified as spring-run using length-at-date methods. Since 2017, the genetically corrected data have been published (Voss and Poytress 2019, 2020, 2022a, 2022b, 2023). Yearling fish are not surveyed and potentially represent a large portion of juvenile out-migrants that are not included in abundance estimates (Voss and Poytress 2023; Allison 2024).

Juvenile abundance past RBDD is difficult to estimate due to the overlap in migration timing with winter, fall, and late-fall Chinook Salmon. Length-at-date models are not fully accurate and lead to erroneous run identifications (Boro et al. 2023). In addition, there is also expected to be a bias in juvenile spring-run counts at RBDD because of overlap with unmarked hatchery fall-run releases on Battle Creek (Voss and Poytress 2023). However, estimates have improved with the use of genetic run typing and bias correction (Voss and Poytress 2023). There is an ongoing effort by CDFW, California Department of Water Resources, private consulting companies, and academic institutions to develop a spring-run JPE, which will aid in determining incidental take limits for the State Water Project and establishing other protective management measures for juvenile spring-run Chinook Salmon (Nelson and Harvey 2020; Horndeski 2022; Boro et al. 2023).

Juvenile survival was very low during the 2012 to 2016 period, driven in part by drought in the Central Valley and unusually warm ocean conditions (SWFSC 2023). Natural-origin spring-run Chinook Salmon from Butte Creek have been acoustic tagged and monitored from 2015 to 2019 and again in 2023. Cumulative survival from release site near Sutter Bypass to Delta exit at the Benicia Bridge ranges from 0.7% (2015) to 40.6% (2023) (CVEATP 2024).

3.4.2 Migration Timing

Spring-run Chinook Salmon in the Sacramento River and tributaries exhibit a diverse range of life history strategies (Cordoleani et al. 2021). Juveniles may reside in freshwater for 3 to 15 months, with a subset migrating to the ocean as young-of-the-year in the winter or spring months within 8 months of hatching (Fisher 1994; CALFED 2000). The yearling life history is more common in spring-run Chinook Salmon because eggs and juveniles of spring-run Chinook Salmon experience cooler waters at higher elevations compared to fall-run Chinook Salmon, which can delay maturation (Lindley et al. 2004).

The young-of-the-year (fry and smolts) generally migrate downstream from November to June, with peak migration occurring in December through April (Cordoleani et al. 2020; SacPAS 2024a). Yearlings migrate downstream in October to June of the following year, with peak migration occurring in October through December (Cordoleani et al. 2020). In Mill and Deer creeks, which are both at high elevation, yearlings make up a small proportion of the observed out-migrating juveniles but go on to represent a majority of returning adults (Cordoleani et al. 2021). The yearling strategy is critical for population survival during periods of drought and warming because these Chinook Salmon migrate during the cooler months and may be able to survive predation better than their earlier-migrating counterparts (Cordoleani et al. 2021). In Butte Creek, which is at lower elevation, there are very few yearlings observed (Cordoleani et al. 2024). In Butte Creek, juveniles have access to food-rich floodplains and are able to grow at higher rates than the juvenile spring-run Chinook Salmon of Mill and Deer creeks. These fast-growing juveniles most often exit their natal tributaries within their first year (Cordoleani et al. 2024).

Studies in Butte Creek found most of these spring-run migrants to be fry moving downstream primarily during December, January, and February and that these movements were influenced by flow (Ward et al. 2003). Small numbers of spring-run juveniles remained in Butte Creek to rear for under 1 year and migrate later in the spring (Ward et al. 2003). Yearlings at Butte Creek have been observed to migrate from September to May, which is consistent with the general trends of spring-run Chinook Salmon (Cordoleani et al. 2020; Ward et al. 2003). Juvenile emigration patterns in Mill and Deer creeks are very similar to patterns observed in Butte Creek, with the exception that Mill and Deer creeks juveniles typically exhibit a later young-of-the-year migration and an earlier yearling migration (Lindley et al. 2004).

Current monitoring efforts (2002 to 2021) show that spring-run fry and smolt migration timing through RBDD begins in late October and is mostly complete by June, with a large pulse of out-migrants in December and another in April (Poytress et al. 2014; Voss and Poytress 2017, 2018, 2019, 2020, 2022a, 2022b, 2023). The middle 95% of fry- and smolt-sized spring-run Chinook Salmon have passed through the Delta at Chipps Island Trawls from mid-March to mid-May based on available data from 2000 to 2022 using length-at-date identification (SacPAS 2024a). Of the 229 genetically confirmed spring-run juveniles sampled at Chipps Island Trawls from 2016 to 2022, the majority were observed at Chipps Island Trawls in March and April (IEP 2023).This genetic dataset indicates that larger juveniles exit the Delta between December and March, and smaller-sized juveniles exit the Delta between March and May (IEP 2023). Although the study does not explicitly identify juveniles as young-of-the-year or yearlings, the FL distribution suggests that the yearlings exit the Delta between December and March, and young-of-the-year exit the Delta between March and May. Currently, there are no routine monitoring programs that fully capture yearling out-migrations, making it difficult to fully understand their timing and abundance.

3.4.3 Size of Juveniles

Fry migrants from spring-run Chinook Salmon rearing streams average approximately 40 mm (1.6 inches) between December and April, indicating a prolonged fry emergence period (Lindley et al. 2004). From 2002 to 2012, 54%, of the juvenile spring-run Chinook Salmon (on average) passing RBDD were fry sized (<46 mm [1.8 inches]), and 46%, (on average) were pre-smolt/smolt-sized fish (≥46 mm [1.8 inches]; Poytress et al. 2014). Approximately 90% of fry-sized fish were <40 mm (1.6 inches) in FL, while approximately 70% of pre-smolt/smolt-sized fish were between 70 mm (2.8 inches) and 89 mm (3.5 inches; Poytress et al. 2014). Overall, spring-run Chinook Salmon FLs were between 28 mm (1.1 inches) and 143 mm (5.6 inches) annually (Poytress et al. 2014). Between 2015 and 2021, size estimates at RBDD remained largely similar to the 2002 to 2012 period. Juvenile size ranged from 28 mm (1.1 inches) to 142 mm (5.5 inches) in FL, with the majority of out-migrants classified as smolts/pre-smolt-sized fish between 60 mm (2.4 inches) and 100 mm (3.9 inches) in FL (Voss and Poytress 2017, 2018, 2019, 2020, 2022a, 2022b, 2023). Across the Central Valley, young-of-the-year spring-run Chinook Salmon have an average ocean entry size of 80 mm (3.1 inches) in FL (Fisher 1994). Trawl sampling of genetically identified spring-run Chinook Salmon juveniles at Chipps Island from 2016 to 2021 has shown juveniles to range from 53 mm (2.1 inches) to 185 mm (7.3 inches) in FL, with an average of 101 mm (4.0 inches; IEP 2023). Out-migrating yearlings are generally not captured in juvenile monitoring efforts due to their size (Voss and Poytress 2023).

3.5 Summary of In-River Timing by Life Stage

As shown in Table 2, spring-run Chinook Salmon migrate to their spawning grounds in March through July (Fisher 1994). They hold in cold, deep pools over the summer months and spawn from mid-August through early October (Fisher 1994; Moyle 2002; Killam 2023). Fry generally emerge 68 to 102 days after redd creation (Moyle 2002). Juveniles exhibit a diverse range of rearing strategies, with out-migration either occurring several months after fry emergence or 12 to 15 months after fry emergence. The young-of-the-year (fry and smolts) generally migrate downstream from November to June, with peak migration occurring in December through April (Poytress et al. 2014; Voss and Poytress 2017, 2018, 2019, 2020, 2022a, 2022b, 2023). The yearlings that reared in their natal tributaries for an entire year out-migrate from October to June, with peak migration occurring in October through December (Cordoleani et al. 2020). Juveniles will enter the ocean between March through June (young-of-the-year) and November through March (yearlings) (Fisher 1994; IEP 2023).

Table 2
In-River Timing of Spring-Run Chinook Salmon by Life Stage

Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Reference
Adult Migration													Historical data: Fisher (1994)
Adult Holding													Cordoleani et al. (2020)
Spawning													Fisher (1994), Moyle (2002), and Killam (2023)
Fry Emergence													Fisher (1994), Moyle (2002), and Cordoleani et al. (2020)
Juvenile Stream Residency													Fisher (1994), Moyle (2002), and Cordoleani et al. (2020)
Smolt Out-Migration													Cordoleani et al. (2020) indicates peak passage as December through March. RBDD passage from Poytress et al. (2014) and Voss and Poytress (2017, 2018, 2019, 2020, 2022a, 2022b, 2023) and Chipps Island passage from SacPAS (2024a) indicate peak passage as December through April.
Yearling Out-Migration													Cordoleani et al. (2020)
Smolt Ocean Entry													Fisher (1994) and IEP (2023)

Note:
Shading within each group indicates temporal range and darkening in shading and addition of cross-hatching indicate peak timing.

4 Fall-and Late–Fall-Run Chinook Salmon

The following sections describe historical conditions, current abundance, and available information on life history attributes by life stage for Central Valley fall- and late-fall-run Chinook Salmon.

4.1 Background and Historical Conditions

It is recognized that designation of the four Central Valley seasonal Chinook Salmon runs is biologically valid; however, it is also recognized that there is wide variation in life history timing among the individual runs, allowing for considerable temporal overlap between them (Yoshiyama et al. 1998). Central Valley fall- and late-fall Chinook Salmon can be differentiated from the winter- and spring-run Chinook Salmon by genetic differences, timing of spawning migrations, maturity of fish when entering freshwater, spawning location, incubation duration, and out-migration timing of juveniles (Fisher 1994; Meek et al. 2016; Moyle 2002; Moyle et al. 2017). Historically, spatial separation between runs was more pronounced pre-dam construction. For example, there is overlap of spawn timing of fall- and spring-run Chinook Salmon (Tables 3, 4, and 5); however, spawning locations were spatially isolated because spring-run Chinook Salmon occupied the headwaters, and fall-run Chinook Salmon remained in the lower portions of streams near the valley floor (Fisher 1994).

NMFS recognizes winter- and spring-run Chinook Salmon as distinct ESUs, while the fall- and late-fall-run Chinook Salmon are grouped into a single ESU (NMFS 2014). For management purposes the NMFS Southwest Fisheries Science Center considers fall- and late-fall-run Chinook Salmon as two separate races under a single ESU, and CDFW also recognizes late-fall-run Chinook Salmon as a unique life history strategy (Moyle et al. 2017). Late-fall-run Chinook Salmon were the last of the four distinct Central Valley Chinook Salmon runs to be recognized because their spawning migration was obscured by the more abundant and widespread fall-run Chinook Salmon with whom they have a temporal overlap (Table 5). In 1966, after completion of RBDD, two distinct peaks in run timing were observed passing over the fish ladder; the latter was recognized to be late-fall-run (Fisher 1994; Moyle et al. 2017). Presently, all four runs occur together in the Nomtipom Waywaket and are constricted to habitat downstream of Keswick Dam (Yoshiyama et al. 1998; Williams 2006).

Historical distribution for Central Valley fall-run Chinook Salmon likely occurred in all major rivers of the Central Valley, including the upper Nomtipom Waywaket, Pit River, and the Winnemem Waywaket (Yoshiyama et al. 1998; Williams 2006; Moyle et al. 2017). It appears they historically spawned in the lower-elevation reaches up to about 500 to 1,000 feet above sea level (Yoshiyama et al. 1998, 2001). The historic distribution of late-fall-run Chinook Salmon is not well documented, but they most likely spawned in the Nomtipom Waywaket and Winnemem Waywaket and in portions of major tributaries that provided adequate cold water in summer (Moyle et al. 2017). The late-fall-run was known to be historically present in the San Joaquin River in addition to the Nomtipom Waywaket system; however, construction of Friant Dam eliminated access to habitat in the upper San Joaquin River

(Fisher 1994). Late-fall-run Chinook Salmon have been extirpated from much of their native spawning habitat in tributaries upstream of Shasta Dam.

The recent historical (pre-1950s) abundance of fall- and late-fall-run Chinook Salmon has been difficult to estimate because populations declined before extensive monitoring and good record keeping as well as the late recognition of the late-fall-run unique life history type. The fall-run has been monitored since 1952, and late-fall-run since 1970 (Azat 2024). Earlier historical records relied on harvest estimates from commercial fisheries. In the late 1800s a gillnet fishery was already well established with annual landings from the Sacramento and San Joaquin rivers, with emphasis on the winter- and spring-runs because of their fresh appearance and body condition (Clark 1929; Fisher 1994; Stone 1874). The fall- and late-fall-runs were less desirable due to their advanced spawning conditions as they returned to the rivers. Fisher (1994) estimated abundance of the four Central Valley runs before the twentieth century using annual landings, a run index, and harvest estimates to be 2,000,000 fish, consisting of 100,000 late-fall-run, 200,000 winter-run, 700,000 spring-run, and 900,000 fall-run salmon. This is consistent with other historical estimates of 1 to 2 million total spawners annually with estimates that fall-run Chinook Salmon were historically one of the largest runs in the Central Valley, with about 1 million spawners returning each year (Yoshiyama et al. 1998).

4.1.1 Endangered Species Act Status

Both the Central Valley fall- and late-fall-run Chinook Salmon are classified as a Species of Concern by NMFS under the federal ESA and by CDFW under the CESA (CDFW 2015). They have also been assigned a status of High Concern in the *State of the Salmonids: Status of California's Emblematic Fishes 2017* report (Moyle et al. 2017).

4.2 Adult Return Migration and Spawning

This section summarizes available information on adult fall- and late-fall-run Chinook Salmon abundance and life history attributes, including migration and holding timing, spawn timing and adult size, age structure, and body condition.

4.2.1 Abundance

The annual abundance of Central Valley fall-run Chinook Salmon has varied significantly in recent years (PFMC 2024). However, the run is widespread, and typically the number of spawners annually exceeds 100,000 fish, but it is highly supported by hatcheries (Moyle et al. 2017; PFMC 2024). In 2016 and 2017, Nomtipom Waywaket fall-run Chinook Salmon total adult returns (hatchery and natural combined) were 89,699 and 44,329 respectively. In 2018, they met the criteria for overfished status, and by 2021 they were considered rebuilt (PFMC 2024). In 2023, it was estimated that the Nomtipom Waywaket fall-run Chinook Salmon escapement for total adults was 133,638, which exceeded the floor of the management goal of a minimum escapement of 122,000. The Nomtipom Waywaket fall-

run Chinook Salmon hatchery-origin fish generally constitute a large portion of the naturally spawning fall-run Chinook Salmon populations (PFMC 2024). Further, there is evidence to suggest that the fall-run Chinook Salmon throughout the Central Valley comprise a genetically homogenous population that has lower among-population genetic diversity than fall-run Chinook Salmon populations examined in other similar geographic scales (Williamson and May 2005). The fall-run population continues to be of concern due to its heavy reliance on hatchery production and concern over ecological and genetic impacts on the sustainability of the run (Moyle et al. 2017).

The Nomtipom Waywaket late-fall-run Chinook Salmon spawning escapement estimate for 2023 was 2,972 adults (PFMC 2024). These late-fall-run Chinook Salmon primarily return to the U.S. Fish and Wildlife Service's Coleman National Fish Hatchery (CNFH) and the Nomtipom Waywaket below Keswick Dam. Since 2011, late-fall-run Chinook Salmon annual spawning escapement estimates in the Nomtipom Waywaket were less than 10,000, ranging between 2,972 and 9,965 in every year except 2014, when the escapement estimate was 11,792. There has been a general decrease in return numbers from 1996 to 2010, when average annual estimates ranged from 11,004 to 19,012 adults. The late-fall-run remains of ongoing concern due to the strong influence of hatchery stocks and the potential for ecological and genetic impacts to the sustainability of this run (Moyle et al. 2017).

Fall- and late-fall-run Chinook Salmon are produced at the CNFH to contribute to harvest and provide adequate returns for hatchery broodstock. The hatchery annually produces approximately 12 million fall-run Chinook Salmon and 1 million late-fall-run Chinook Salmon (USFWS 2025).

4.2.2 Migration and Holding Timing

The Central Valley fall-run Chinook Salmon spawn in the Nomtipom Waywaket and San Joaquin River watersheds, upstream as far as the first impassible dams (Moyle et al. 2017). Fall-run Chinook Salmon have a life history that minimizes time spent in fresh water. As such, fall-run Chinook Salmon begin entering fresh water in summer and early fall as mature individuals and move relatively quickly to spawning grounds (Moyle et al. 2017). Adult migration typically spans from June to December, but can extend into January, with peak migration occurring September to October (Fisher 1994; FitzGerald et al. 2021). Late-fall-run Chinook Salmon also spend little time holding in river but migrate as mature adults and move to spawn quickly (Moyle et al. 2017).

The late-fall-run Chinook Salmon are in tributaries of the Nomtipom Waywaket but primarily spawn in the mainstem river, where most spawning and rearing of juveniles occurs in the reach between RBDD and Keswick Dam in Redding, California (Moyle et al. 2017). Late-fall-run Chinook Salmon migrate upstream in December and January as mature fish, with peak migration occurring in December, though their migration has been documented to span October through April (Fisher 1994; Williams 2006; Moyle et al. 2017; FitzGerald et al. 2021). In the mainstem Nomtipom Waywaket,

late-fall-run Chinook Salmon are dependent on flow releases from dams for maintenance of suitable spawning habitat, much like the other Chinook Salmon runs.

4.2.3 Spawn Timing

Spawning usually occurs within several weeks to 2 months of freshwater entry. Fall-run Chinook Salmon peak spawning is typically in late October to November but can continue through to January and start as early as late September (Fisher 1994; Yoshiyama et al. 1998; Moyle et al. 2017).

Late-fall-run Chinook Salmon spawning occurs primarily in December and January, shortly after arrival, but may extend into April in some years (Fisher 1994; Williams 2006; Moyle et al. 2017; FitzGerald et al. 2021).

4.2.4 Adult Size, Age Structure, and Body Condition

Historically, fall- and late-fall-run Chinook Salmon spawning adults in the Central Valley were composed of a mixture of age classes from age-2 to age-5. However, these populations are subject to fisheries impacts where larger and older individuals are removed, resulting in spawning runs being composed of younger age classes relative to historical runs (Williams 2006). Gillnet fishery data for ocean-type (fall or late-fall) Chinook Salmon caught in the Delta from 1919 to 1921 were composed of 17.2% age-3 and younger, 47.7% age-4, and 35.1% age-5 or older (Clark 1929). By 1947 to 1951, age structure had shifted to 37% age-3 and younger, 50% age-4, and 11% age-5 and older (Cope and Slater 1957; Reisenbichler 1986). Ocean fishery data from 1955 (Kutkuhn 1963) were predominantly composed of age-3 fish, followed by age-4, and age-5 composed only 10% of the catch.

Data on fall-run Chinook Salmon returns to the Tehama Colusa Fish Facility (located at RBDD) and to the American and Feather rivers (Dettman et al. 1987) indicate that the trend of younger adult returns continued through at least the early 1980s, with age-4+ fish composing only 18% to 19% of the fall- run during this period (Williams 2006). However, data for fall-run fish returning to the Feather River in 2002 suggested that age-4 fish had rebounded, composing 41% of the run. This increase in age-4 fish was likely due to reduced harvest (Williams 2006). However, most of the run was still composed of age-3 and younger fish, and age-5 were exceedingly rare. In summary, although average age at return may have increased slightly since the 1970s through 1980s, fall-run fish still appear to have a restricted age structure diversity relative to historical runs.

Escapement surveys conducted by CDFW for fall-run Chinook Salmon from October 2021 to January 2022 on the Lower American River found that average FL for females and males was 76 centimeters (cm; 29.9 inches), with the range for females being 50 to 100 cm (19.7 inches to 39.4 inches) and the range for males being 50 to 111 cm (19.7 inches to 43.7 inches; Grimes and Galinat 2022). Similar sizes were reported from the Lower American River in 2019 to 2020 (Kelly and Phillips 2019). In Butte

Creek, between 2002 to 2009, the average FL for all fish was 81 cm (31.9 inches; ranging from 43 to 168 cm [16.9 inches to 66.1 inches]). For females, the average FL was 80 cm (31.5 inches; ranging from 50 to 112 cm [19.7 inches to 44.1 inches]), and for males, the average FL was 82 cm (32.3 inches; ranging from 43 to 168 cm [16.9 inches to 66.1 inches]; McReynolds 2024). Surveys of fall-run escapement on the upper Nomtipom Waywaket from September to December of 1999 found that the average FL for carcasses was 78.9 cm (31.1 inches; ranging from 35 to 110 cm [13.8 inches to 43.3 inches]). Females averaged 80.5 cm (31.7 inches) in FL (ranging from 45 to 98 cm [17.7 inches to 38.6 inches]), and males averaged 77.3 cm (30.4 inches) in FL (ranging from 35 and 110 cm [13.8 inches to 43.3 inches]; Snider et al. 2000a).

Central Valley late-fall-run Chinook Salmon tend to have a higher proportion of age-4+ adult spawners (41%) relative to other runs in the Central Valley; however, the age-3 fish still have the highest age at return percentage (57%; Fisher 1994). As a result of the higher proportion of older age classes, late-fall-run fish might be expected to have a larger average body size than other Central Valley runs, as stated by Moyle et al. (2017). However, escapement surveys of late-fall-run Chinook Salmon from the upper Nomtipom Waywaket from December 1999 to April 2000 found that average size for all carcasses was similar to fall-run Chinook Salmon. Average FL for males and females was 79.5 cm (31.3 inches; ranging from 45 to 108 cm [17.7 inches to 42.5 inches]). Males averaged 77.1 cm (30.4 inches) in FL (ranging from 45 to 108 cm [17.7 inches to 42.5 inches]), and females averaged 81.7 cm (32.2 inches) in FL (ranging 62 to 99 cm [24.4 inches to 39.0 inches]; Snider et al. 2000b). As a result of their older age structure and potentially larger size, late-fall-run adults tend to be the most fecund of the California Chinook Salmon runs (Moyle 2002).

4.3 Egg Incubation and Hatching

This section summarizes available information on the fall- and late-fall-run egg incubation and hatching life stage, including redd and egg abundance and emergence timing.

4.3.1 Redd and Egg Abundance

As of the 1990s, fall-run Chinook Salmon across the Central Valley had an average fecundity of 5,498 eggs per adult female, and late-fall-run fish had an average fecundity of 5,806 eggs per adult female (Fisher 1994). Fecundity for fall-run fish between Keswick Dam and RBDD was similar, but with a lower average of 5,074 eggs per adult female between 2012 and 2021, (ranging from 4,455 to 5,453 eggs per adult female; Voss and Poytress 2023). To our knowledge, recent estimates of late-fall-run fish are not available.

Egg-to-fry survival estimates for fall-run Chinook Salmon between Keswick Dam and RBDD averaged 12.8% from 2012 to 2021 and were highly variable, generally ranging between 2.3% and 16.8% but with an outlying value of 39.5% in 2016 (Voss and Poytress 2023). Estimates from the three most

recent years were lower than average: 6.4% in 2019, 8.1% in 2020, and 5.1% in 2021. To our knowledge, egg-to-fry survival estimates are not available for late-fall-run fish during this period.

4.3.2 Emergence Timing

Juvenile fall-run Chinook Salmon typically emerge from the gravel in December through April and rear in fresh water for 1 to 7 months (Fisher 1994; Yoshiyama et al. 1998; Williams 2006; Moyle et al. 2017). They usually move downstream into lower-elevation reaches within a few weeks (Moyle 2002). Late-fall-run juvenile emergence occurs between April and June, and juveniles may spend from 7 to 13 months in the river system (Yoshiyama et al. 1998).

Recent historic records suggest that emergence timing for fall- and late-fall-run juveniles in the late nineteenth and early twentieth centuries was like present-day timing. However, these conclusions are based on records of juvenile average size and date observed, and they are speculative because the late-fall-run was not yet recognized or monitored. For example, two populations of juveniles were observed at the same time in the Winnemem Waywaket in June of 1898—newly emerged fry (about 38 mm [1.5 inches]), likely late-fall-run juveniles, and larger juveniles (about 76 to 102 mm [3.0 inches to 4.0 inches]), likely corresponding to juvenile fall-run fish that had emerged several months earlier (USFC 1899).

In 1939, newly emerged juvenile Chinook Salmon (38 mm [1.5 inches]) in the Winnemem Waywaket were sampled on March 1, likely corresponding to the fall-run (Hanson 1940). Data prior to March 1 were not available. Juveniles of a similar size were also collected in April and May, likely corresponding to newly emerged late-fall-run juveniles, though it is possible that late-emerging fall-run juveniles were among these fish.

4.4 Juvenile Rearing and Out-Migration

This section summarizes available information on juvenile fall- and late-fall-run Chinook Salmon abundance and life history attributes, including migration timing and size of juveniles.

4.4.1 Juvenile Abundance

Annual fry-equivalent passage estimates (JPI) for fall-run Chinook Salmon at RBDD averaged 12,224,829 and ranged from 1,723,831 to 33,201,448 between 2012 and 2021 after removing unmarked hatchery smolts to reduce bias (Voss and Poytress 2023). Annual JPI for late-fall-run Chinook Salmon averaged 133,875 and ranged between 81,629 and 193,758 between 2012 and 2021 (Poytress et al. 2014, Voss and Poytress 2023, 2022a, 2020, 2019, 2018, 2017). This average excludes 2013, for which late-fall JPI estimates were not available, and 2020, when estimates were heavily influenced by missing data due to the COVID-19 pandemic (Voss and Poytress 2022b). As described in Section 3.4, for spring-run fry and smolt abundance, abundance of fall- and late-fall-run juveniles

past RBDD is difficult to estimate due to overlap between runs. Fry-to-smolt survival estimates (JPE) have not been developed specifically for fall- or late-fall-run juveniles.

Survival of fall-run and late-fall-run hatchery juveniles in the Nomtipom Waywaket Basin has been estimated in several acoustic tag studies, but results from these studies may not translate well to natural-origin fish due to differences in fish size and environmental conditions. Fall-run hatchery juveniles released from CNFH tend to have high survival in the early part of their migration route, with standardized estimates between 94% to 99% per 10 km (6.2 miles) from hatchery release (rkm 517, RM 322) to Woodson Bridge (rkm 425, RM 265; Zeug et al. 2020). Survival progressively decreases as fish move downstream to the lower Nomtipom Waywaket and through the Delta. Survival through the Delta is extremely low for fall-run juveniles, estimated between 0 to 0.05 from 2010 to 2015 (Buchanan et al. 2018). In contrast, hatchery-origin late-fall-run juveniles tend to have lower survival in the upper river and higher survival in the channelized lower river and the Delta (Michel et al. 2015). The survival of hatchery-origin late-fall-run juveniles through the Delta was estimated between 17% and 54% between 2006 and 2010 (Perry 2010; Perry et al. 2013). However, overall migration survival is still low for late-fall-run juveniles, with estimates ranging from 2.8% to 5.9% in low-water years and up to 15.9% in a high-water year (Michel et al. 2015).

4.4.2 Migration Timing

Fall-run fry and smolts out-migrate in the spring before water temperatures begin to exceed thermal tolerances (Moyle et al. 2017). Between 2002 and 2012, peak migration past RBDD occurred during January and February, but lower rates of emigration continued through July (Poytress et al. 2014). Fisher (1994) indicated peak migration timing occurred in March; this shift to earlier migration timing could be influenced by hatchery release practices (Huber and Carlson 2015). Freshwater residency time for fall-run juveniles is generally between 1 to 7 months, and fish typically enter the ocean between March and July (Fisher 1994). Recent historical records suggest that emigration timing in the upper Nomtipom Waywaket is like historical timing in the Winnemem Waywaket; juveniles of an average size corresponding to the fall-run were present in the Winnemem Waywaket from March to July in 1939 (data prior to March were not available; Hanson 1940).

Late-fall-run Chinook Salmon are considered intermediate to “ocean-type” fall-run and “stream-type” spring-run and, as such, exhibit some life history characteristics of each. Juveniles may regularly over-summer and out-migrate in their second year of life (like spring-run; Moyle et al. 2017). Late-fall-run juvenile emigration occurs later and over a longer period. Between 2002 and 2012, migration past RBDD was highest between April and August but was highly variable within this period and between years (Poytress et al. 2014). Williams (2006) reported that peak migration was in October; however, it was also indicated that there was high variability with younger ages and smaller sizes present during most months of the year. Late-fall-run juveniles spend a longer period in freshwater streams relative to fall-run juveniles, ranging from 7 to 13 months, prior to entering the ocean between October and

May (Fisher 1994). Recent historical records indicate that fish of an average size corresponding to late-fall-run juveniles (90.33 mm [3.6 inches]) were present in the Winnemem Waywaket from May until at least September 3, 1939 (Hanson 1940).

Similar to other runs, fall- and late-fall-run juvenile out-migration timing is heavily dependent on flow. Smolts tend to initiate migration during storm events, and flow and turbidity are positively correlated with migration rate (Poytress et al. 2014; Michel et al. 2013). Interannual variability of high-flow events therefore contributes significantly to observed variation in emigration timing (Poytress et al. 2014).

4.4.3 Size of Juveniles

The downstream migration of fall-run juveniles below Keswick Dam is heavily weighted toward fry (<46 mm [1.8 inches]) versus smolts. For example, from December 2021 through November 2022, fry accounted for 85.6% of the fall-run juveniles that passed RBDD, and pre-smolts and smolts accounted for 14.4% of juveniles (Voss and Poytress 2023). Between 2002 and 2012, an average of 75.5% of all fall-run juveniles fell into the fry size category, and 24.3% were classified as pre-smolts and smolts (Poytress et al. 2014). Typically, fall-run juveniles enter the ocean by the time they reach approximately 80 mm (3.1 inches; Fisher 1994). Prior to large-scale river development in the Central Valley, juvenile fall-run Chinook Salmon likely reared for 1 to 2 months in floodplains, thereby achieving faster growth and entering at a larger size than present-day juveniles that lack access to floodplain habitat (Sommer et al. 2001). In the Nomtipom Waywaket, fall-run juveniles typically move downstream at small sizes (30 to 50 mm [1.2 inches to 2.0 inches] in FL) and rear in freshwater portions of the estuary, including Yolo Bypass. This strategy allows juveniles to reach approximately 80 to 100 mm (3.1 inches to 3.9 inches) in FL before smolting and migrating to sea (Moyle 2002).

In contrast, late-fall-run fish are much more likely to begin out-migration as pre-smolts and smolts versus fry. In 2021, 92% of the late-fall-run brood year was represented by pre-smolts and smolts versus 8% fry (Voss and Poytress 2023). Between 2002 and 2012, 24.9% of late-fall-run juveniles sampled at RBDD were fry sized (<45 mm [1.8 inches]), versus 75.1% that were pre-smolt and smolt sized (Poytress et al. 2014). Juvenile late-fall-run fish rear in mainstem rivers, such as the upper Nomtipom Waywaket, that are cold and deep enough for fish to remain in throughout the summer. This allows late-fall-run Chinook Salmon to grow rapidly, and they often measure 150 to 170 mm (5.9 inches to 6.7 inches) in FL when they migrate to the ocean after 7 to 13 months in fresh water (Moyle 2002; Fisher 1994). Once juveniles reach Chipps Island, there may be substantial overlap in size between fall-run and spring-run fish, and between late-fall-run and fall-run fish, potentially leading to underestimation of ocean-phase juvenile populations of both runs if length-at-date criteria are used (Brandes et al. 2021).

Recent historical data from the Winnemem Waywaket indicates that populations of fry-sized fish (<46 mm [1.8 inches]) were present in the Winnemem Waywaket from at least March 1 to June 26 of 1939. Pre-smolt- and smolt-sized fish (>45 mm [1.8 inches]) were present from at least June 4 to September 3 (Hanson 1940), likely representing a mix of fall- and late-fall-run juveniles.

4.5 Summary of In-River Timing by Life Stage

As shown in Table 3, adult fall-run Chinook Salmon migrate from the ocean and arrive at their natal spawning grounds between June and December, but can extend into January, with peak migration from September to October (Fisher 1994; Williams 2006; Moyle et al. 2017; FitzGerald et al. 2021). Spawning occurs within several weeks to 2 months after arrival in natal streams (Moyle et al. 2017). Fry emerge between December and March and typically begin emigration within a few weeks. Peak out-migration occurs from January to March, and juveniles enter the ocean typically between March and July.

As shown in Table 4, adult late-fall-run fish migrate upstream from October through April, with peak returns occurring in December and January. Similar to fall-run fish, late-fall-run adults do not hold in freshwater for extended periods but spawn soon after arrival at their natal streams. Fry emerge between April and June and rear in freshwater streams for an extended period of 7 to 13 months (Fisher 1994; Williams 2006; Moyle et al. 2017). Ocean entry occurs between October and May (Fisher 1994; FitzGerald et al. 2021).

Table 3
In-River Timing of Fall-Run Chinook Salmon by Life Stage

Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Reference
Adult Migration													Fisher (1994), Moyle et al. (2017), and FitzGerald et al. (2021)
Spawning													Fisher (1994), Moyle et al. (2017), and FitzGerald et al. (2021)
Fry Emergence													Fisher (1994), Williams (2006), and Moyle et al. (2017)
Juvenile Stream Residency													Fisher (1994), Williams (2006), Moyle et al. (2017), and FitzGerald et al. (2021)
Juvenile Out-Migration													Fisher (1994), Poytress et al. (2014), and FitzGerald et al. (2021)
Juvenile Ocean Entry													Fisher (1994) and FitzGerald et al. (2021)

Note:
Shading within each group indicates temporal range and darkening in shading and addition of cross-hatching indicate peak timing.

Table 4
In-River Timing of Late-Fall-Run Chinook Salmon by Life Stage

Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Reference
Adult Migration													Fisher (1994), Williams (2006), Moyle et al. (2017), and FitzGerald et al. (2021)
Spawning													Fisher (1994), Williams (2006), Moyle et al. (2017) and FitzGerald et al. (2021)
Fry Emergence													Fisher (1994), Moyle et al. (2017), and FitzGerald et al. (2021)
Juvenile Stream Residency													Fisher (1994), Williams (2006), and FitzGerald et al. (2021)
Juvenile Out-Migration													Fisher (1994), Williams (2006), and Moyle et al. (2017)
Juvenile Ocean Entry													Fisher (1994) and FitzGerald et al. (2021)

Note:
Shading within each group indicates temporal range and darkening in shading and addition of cross-hatching indicate peak timing.

5 Summary of Chinook Salmon Occurrence in the Nomtipom Waywaket

Table 5 combines the timing of occurrence of each run of Chinook Salmon by life stage in the Nomtipom Waywaket. The timing included in Table 5 confirms that the four runs of Chinook Salmon will migrate during a large portion of each calendar year. As such, adult and juvenile passageways and facilities contemplated as volitional passage alternatives would all need to operate year-round except for annual maintenance periods (as needed).

Table 5
In-River Timing of Winter-Run, Spring-Run, Fall-Run, and Late-Fall-Run Chinook Salmon by Life Stage

Run	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Reference
Winter-Run	Adult Migration and Holding													Historical data: Azat (2023), Killam (2023), and Fisher (1994)
	Spawning													Carcass and redd survey data: Azat (2023) and CDFW (2024)
	Fry Emergence													Estimated from model results (SacPAS 2024b), genetic summaries of out-migrating juveniles (Anchor QEA 2024), and historical data (Fisher 1994).
	Smolt Stream Residency													Passage at RBDD: SacPAS (2024a) and Poytress et al. (2014)
	Smolt Out-Migration													Passage through RBDD and Chipps Island Trawls: SacPAS (2024a). Peak timing of RBDD passage is shown.
	Smolt Ocean Entry													Fisher (1994) and passage through Chipps Island Trawls (SacPAS 2024a)
Spring-Run	Adult Migration													Historical data: Fisher (1994)
	Adult Holding													Cordoleani et al. (2020)
	Spawning													Fisher (1994), Moyle (2002), and Killam (2023)
	Fry Emergence													Fisher (1994), Moyle (2002), and Cordoleani et al. (2020)
	Juvenile Stream Residency													Fisher (1994), Moyle (2002), and Cordoleani et al. (2020)
	Smolt Out-Migration													Cordoleani et al. (2020) indicates peak passage as December through March. RBDD passage from Poytress et al. (2014) and Voss and Poytress (2017, 2018, 2019, 2020, 2022a, 2022b, 2023) and Chipps Island passage from SacPAS (2024a) indicate peak passage as December through April.
	Yearling Out-Migration													Cordoleani et al. (2020)
	Smolt Ocean Entry													Fisher (1994) and IEP (2023)
Fall-Run	Adult Migration													Fisher (1994), Moyle et al. (2017), and FitzGerald et al. (2021)
	Spawning													Fisher (1994), Moyle et al. (2017), and FitzGerald et al. (2021)
	Fry Emergence													Fisher (1994), Williams (2006), and Moyle et al. (2017)
	Juvenile Stream Residency													Fisher (1994), Williams (2006), Moyle et al. (2017), and FitzGerald et al. (2021)
	Juvenile Out-Migration													Fisher (1994), Poytress et al. (2014), and FitzGerald et al. (2021)
	Juvenile Ocean Entry													Fisher (1994) and FitzGerald et al. (2021)

Run	Life Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Reference
Late-Fall-Run	Adult Migration													Fisher (1994), Williams (2006), Moyle et al. (2017), and FitzGerald et al. (2021)
	Spawning													Fisher (1994), Williams (2006), Moyle et al. (2017), and FitzGerald et al. (2021)
	Fry Emergence													Fisher (1994), Moyle et al. (1997), and FitzGerald et al. (2021)
	Juvenile Stream Residency													Fisher (1994), Williams (2006), and FitzGerald et al. (2021)
	Juvenile Out-Migration													Fisher (1994), Williams (2006), and Moyle et al. (2017)
	Juvenile Ocean Entry													Fisher (1994) and FitzGerald et al. (2021)

Note:
Shading within each group indicates temporal range and darkening in shading and addition of cross-hatching indicate peak timing.

6 Chinook Salmon Thermal Tolerances

The following section summarizes thermal tolerances for Chinook Salmon inhabiting the Nomtipom Waywaket and Winnemem Waywaket. Generally, there is not enough conclusive data to indicate differences in thermal tolerances between runs, although known run sensitivities are noted in the text below. Therefore, the thermal tolerance data described below apply to all runs of Chinook Salmon. Table 6 summarizes the maximum optimal temperature by life stage identified for this Project, with additional detail described in Sections 6.1 through 6.3. The thermal tolerances provided in Table 6 are mostly used for regulatory purposes. However, from a biological perspective, there is additional context to consider. It is important to note that comparative water temperature analysis often represents conditions at a single point in the stream system. Water temperature varies throughout the Study Area and may be warmer or cooler than shown at other locations. There could be micro-habitat conditions that have lower temperature that Chinook Salmon would seek and find. Additionally, recent laboratory studies on hatchery-origin Chinook Salmon from along the Pacific Coast have identified population-specific thermal tolerances suggesting that fish evolve to survive in local thermal conditions (Zillig 2022; Zillig et al. 2023; Zillig et al. 2025). Therefore, it is difficult to generally apply thermal tolerances based on studies from a range of different conditions across broad areas. As such, comparisons of collected or compiled temperature data to thermal tolerances should consider these important factors when making conclusions.

Table 6
Summary of Thermal Tolerance by Life Stage

Life Stage	Maximum Optimal Temperature (°C)	Maximum Optimal Temperature (°F)	Description	Reference
Adult Migration (Summertime)[1]	20.0	68	Maximum 7-DADM thermal threshold for physical harm, passage barrier, and increased predation.	USEPA (2003) and Carter (2008)
Adult Spawning	12.8	55	Upper limit of suitable temperature for spawning initiation, based on field observations and previous USEPA and NMFS recommendations.	McCullough (1999) presented by Reclamation (2023)
Egg Incubation and Fry Emergence	12.0	53.5	Daily average temperature threshold established in temperature-dependent mortality modeling. This threshold is also identified as the upper limit of successful egg incubation in various laboratory studies.	Anderson (2018), Anderson et al. (2022), Martin et al. (2017), and Myrick and Cech (2004)

Life Stage	Maximum Optimal Temperature (°C)	(°F)	Description	Reference
Juvenile Core[2] Rearing (Summertime)[1]	16.0	60.8	Recommended 7-DADM for core rearing (protects against lethal conditions, provides optimal growth under limited food conditions, protects against temperature-induced diseases, avoids temperatures that would put juvenile salmonid at a competitive disadvantage) per USEPA (2003). Additionally, this temperature was identified as the upper limit of optimal growth and smoltification in a laboratory study by Marine and Cech (2004).	USEPA (2003); Marine and Cech (2004); Myrick and Cech (2004)
Juvenile Non-core Rearing[3] and Out-Migration (Summertime)[1]	18	64.4	Recommended 7-DADM to protect against lethal conditions for juveniles and adults, provide optimal or near-optimal growth under limited food conditions during most of the summer, and protect against temperature-induced diseases.	USEPA (2003)

Notes:
Maximum optimal temperature indicates the temperature above which negative effects or non-optimal conditions are expected to occur.

1. The USEPA (2003) temperature criteria shown here are recommended during summertime, when water temperatures are at their highest and cold-water salmonids are most vulnerable. USEPA recommends that non-summer criteria be established for cases when temperature-sensitive activities occur in spring/fall/winter. Otherwise, USEPA states qualitatively that "if the criterion is met at the summer maximum, then temperatures will be lower than the criterion during most of the year" to explain how these summertime criteria may still be protective in the off-season (USEPA 2003).
2. Core rearing is defined by a moderate to high density of juveniles or by a habitat that is degraded but has the potential to support moderate to high density of juveniles (USEPA 2003).
3. Non-core rearing describes rearing conditions of moderate to low density of juveniles. This use designation incorporates the fact that juveniles will use waters with higher-than-optimal temperatures (USEPA 2003).

6.1 Adult Thermal Tolerances

Chinook Salmon are highly sensitive to elevated water temperatures, which can impact their survival, migration, and spawning success. Ultimately, there is no exact threshold number that is certain to cause serious harm to salmonids. Responses to temperature are dependent on numerous factors, and changes in temperature can directly or indirectly impact other critical environmental variables. For instance, dissolved oxygen is an important covariable that has an inverse relationship with temperature, contributing to increased organismal stress (Windell et al. 2017). Additionally, physical river features, such as thermal and velocity refugia, will mitigate some impacts, such as heat stress and metabolic demand (Berman and Quinn 1991; Baird and Krueger 2003). Fish may modify their

behavior to seek out thermal refuges (Brewitt et al. 2017), though this may come at the cost of decreased foraging opportunities (Sutton et al. 2007).

Temperatures at or exceeding 20°C (68°F) as a maximum 7-day average of the daily maxima (7-DADM) can cause serious physical harm, act as barriers to passage, and increase predation rates for Chinook Salmon (USEPA 2003). A number of sources indicate that temperatures above 21ºC (69.8ºF) act as thermal barriers to Chinook Salmon, although this threshold varies from 19ºC to 23.9ºC (66.2ºF to 75.0ºF; Carter 2008). Further, homogenized systems without thermal refugia may worsen the effects of elevated temperatures, even below 20°C 7-DADM (68°F; USEPA 2003; Carter 2008). For example, NMFS (2023b) identifies 10°C (50°F) as the point at which temperature stress begins when fish are overcrowded in holding pools for barrier passage. The threshold of 20°C (68°F) 7-DADM is recommended for waterbodies that are used almost exclusively for migration during the period of summer maximum temperatures (USEPA 2003). The metric of 7-DADM is generally protective of acute effects to fish because it reflects the weekly average maximum temperature (USEPA 2003). As noted previously, there are conditions in which this threshold may not be sufficient, particularly in waterbodies that lack thermal refugia (USEPA 2003).

Spawning initiation requires temperatures from 5.6°C to 12.8°C (42°F to 55°F) based on a literature review by McCullough (1999) presented in Reclamation (2023). The upper limit of this range, 12.8°C (55°F), represents the upper range of optimal temperatures for the production of fish resources in the Columbia Basin identified by Pacific Northwest fishery agencies (USEPA and NMFS 1971). Spawn timing is also temperature dependent. For instance, winter-run Chinook Salmon have been observed to begin spawning in late April, regardless of springtime water temperatures, although the end of spawning is generally later in the summer when springtime temperatures are cooler (Jennings and Hendrix 2020). Peak spawn timing of winter-run Chinook Salmon also depends on water temperature, with cooler temperatures leading to earlier peak spawning windows (Jennings and Hendrix 2020).

Ideally, winter-run Chinook Salmon spawn in spring-fed rivers in the upper Nomtipom Waywaket Basin with temperatures between 10°C to 15°C (50°F to 59°F), the historical temperature range the species is adapted to (NMFS 2014). Spring-run Chinook Salmon adapted their life history to take advantage of the cold, high-elevation headwaters for over-summering and spawning. Fall- and late-fall-run Chinook Salmon in the Central Valley spend relatively less time in freshwater than spring- or winter-run Chinook Salmon (Moyle et al. 2017) and are able to avoid peak summer temperatures. However, fall-run adults may still experience thermal stress and pre-spawn mortality when excessive temperatures extend into fall. For example, in 2021, water temperatures below Keswick Dam remained above 13.3°C (55.9°F) through mid-November, resulting in high rates of temperature-related mortality among fall-run adults (CDFW 2022b). The late-fall-run Chinook Salmon timing is

generally during cooler water temperatures, and this run is least susceptible to temperature-related pre-spawn mortality but can still be impacted by environmental conditions.

6.2 Egg Thermal Tolerances

Chinook Salmon eggs have a limited thermal tolerance before they become susceptible to mortality. Water temperatures between 6°C and 12°C (42.8°F and 53.5°F) appear to be best suited to Central Valley Chinook Salmon egg and larval development, based on numerous laboratory experiments (Myrick and Cech 2004). The optimal temperature range for spring- and fall-run Chinook Salmon embryo survival may be slightly broader at 5°C to 13°C (41°F to 55.4°F), with oxygen levels close to saturation (Moyle 2002; CDFW 2015). Because winter-run Chinook Salmon egg incubation takes place during summer, winter-run Chinook Salmon historically utilized spawning streams that were fed by year-round cold-water springs to provide the necessary thermal and flow regime for egg development (Yoshiyama et al. 2000).

Current modeling of temperature-dependent mortality for winter-run Chinook Salmon in the upper Nomtipom Waywaket is based on work from Anderson (2018), Anderson et al. (2022), and Martin et al. (2017). These papers define a temperature threshold of approximately 12°C (53.5°F) daily average in the field. Although this model was specific to winter-run Chinook Salmon, other populations are expected to have similar temperature thresholds, as demonstrated by Myrick and Cech's (2004) compilation of laboratory data. The Martin model is stage-independent, while the Anderson model is stage-dependent and defines a critical period of development during which the eggs are most sensitive. Stage refers to the age of incubation. However, Martin et al. (2017) showed a strong relationship between thermal tolerance, intra-gravel flow, and intra-gravel dissolved oxygen, with warmer water temperatures being more tolerated with higher oxygen availability. In general, Chinook Salmon eggs are more temperature resilient in instances when the water is saturated with oxygen. Additional laboratory studies have supported the observation that embryo development is sensitive to the combination of warm water temperatures and hypoxic conditions, and that the timing of warm and/or hypoxic conditions plays a significant role in an embryo's ability to adapt (Del Rio et al. 2021). Given the difficulty in managing Shasta-Keswick releases for water temperatures in recent drought years, there has been an increased focus on understanding how these other variables contribute to egg and early juvenile mortality (Martin et al. 2020; Kearns & West 2023).

Water temperature is currently managed under several programs to protect this sensitive life stage. For instance, the DeSabla Centerville Project releases cold water to support spring-run Chinook Salmon eggs in Butte Creek (SWFSC 2023). Additionally, Shasta and Keswick dams are controlled in part by Water Right Order 90-5, which originally required a daily average temperature of ≤13.3°C (56°F) in the Nomtipom Waywaket from Keswick Dam (rkm 486, RM 302) to RBDD (rkm 389, RM 242) during the temperature management season from May 15 through October 31 (State Water Board 1990). In the 2024 NMFS biological opinion, cold-water pool management utilizes a binned

approach. Each water year is classified as Bin 1 through 3, based on temperature-related impacts. Bin 1 years will meet the target of 11.9°C (53.5°F) daily average temperature at or downstream of the Sacramento River above Clear Creek (CCR) gauge, with temperature-dependent mortality (TDM) expected to be less than or equal to 3%. Bin 3 years will only be able to meet the target of 11.9°C (53.5°F) daily average temperature upstream of the CCR gauge and are expected to have TDM rates of less than or equal to 30%, although higher rates may be possible (NMFS 2024b).

Lastly, the updated Water Quality Control Plan (Longley et al. 2019), sets different temperature limits for different reaches and different times of year, with emphasis placed on limiting temperatures from Keswick Dam to I Street Bridge in Sacramento (rkm 95, RM 59) during periods when temperature increases would be detrimental to the fish. This temperature limit is intended to minimize negative impacts on salmonids resulting from thermal stress. In recent years, this maximum temperature requirement has not been consistently met, causing significant losses of developing eggs and alevins (State Water Board 2024).

6.3 Juvenile Thermal Tolerances

Juvenile salmon are less thermally sensitive than eggs or alevin stages (Myrick and Cech 2004) but are still vulnerable to elevated water temperatures during peak summer heat. If juveniles are being trapped and held for transport, densities should be reduced at water temperatures above 10°C (50°F) due to the potential for overcrowding to exacerbate thermal stress, and extreme care must be taken if trapping or handling individuals above 20°C (68°F; NMFS 2023b). Incipient upper lethal temperature for juvenile salmon may be expected to be around 24°C to 25°C (75.2°F to 77.0°F), based on studies performed on northern Pacific Chinook Salmon (Myrick and Cech 2004). In the Nomtipom Waywaket system, water that is too cold to be thermally optimal (below 5°C or 41°F) is rarely, if ever, a concern (Myrick and Cech 2004). High temperatures and drought conditions in recent years are associated with the observed low juvenile survival rates (SWFSC 2023). Fry survival to RBDD was approximately 20% lower in 2014 and 2015 due to decreased cold-water releases from Shasta Dam used to reduce downstream temperatures (Williams et al. 2016).

6.3.1 Rearing

The optimal rearing temperature range for smolts is 13°C to 16°C (55.4°F to 60.8°F) based on an experiment with Nomtipom Waywaket fall-run Chinook Salmon (Marine and Cech 2004). Laboratory studies of juvenile fall-run Chinook Salmon indicate that similar growth can occur at temperatures up to 17°C and 20°C (62.6°F and 68°F) when fed to satiation, but fish reared at these temperatures were more susceptible to predation vulnerability than fish reared at the lower temperature range (Cech and Myrick 1999; Marine and Cech 2004). When food supply is limited, juveniles may require lower water temperatures to achieve optimal growth rates (McCullough 1999).

In a comprehensive review of the available literature, the U.S. Environmental Protection Agency (USEPA; 2003) identified two juvenile-rearing conditions with different temperature recommendations that are intended to be followed during summertime maximum temperature conditions. First, core rearing is defined by moderate- to high-density juvenile rearing. In areas designated as core rearing habitat, the recommended 7-DADM is 16°C (60.8°F). This temperature is also recommended for waters with degraded habitat that is believed to be capable of supporting moderate- to high-density rearing. Second, non-core rearing is defined by moderate- to low-density juvenile rearing. In areas designated as core rearing habitat, the recommended 7-DADM is 18°C (64.4°F). The use designation of non-core incorporates the fact that juveniles will use waters with higher-than-optimal temperatures. As such, degraded habitats with high current water temperatures may be observed with very limited or no rearing during the summertime but could have the capacity to have higher rates of juvenile rearing if maximum temperatures are reduced. This would generally include any waters that are identified as rearing habitat during spring and fall. Because habitat degradation can occur at different severities and juvenile-rearing distributions may vary in time, the spatial extent of core and non-core rearing habitat must be determined with the best available scientific information. These temperature recommendations from USEPA (2003) are intended to protect against lethal conditions, provide optimal or near-optimal growth conditions when food may be limited, and reduce the risk of temperature-induced diseases. The lower temperature recommendation for core rearing habitat accounts for the higher density of juveniles in these waters.

One caveat of the USEPA (2003) temperature recommendations is that they are recommended for salmonids of the Pacific Northwest. Recent laboratory studies on hatchery-origin Chinook Salmon from along the Pacific Coast have identified population-specific thermal tolerances (Zillig 2022; Zillig et al. 2023; Zillig et al. 2025). For instance, populations adapted to warmer temperatures, such as fall-run Chinook Salmon from the Feather River and CNFH, grew faster at 20°C (68°F) than at 11°C (51.8°F; Zillig et al. 2023). Optimal temperatures, based on metabolic rates for these two populations, was 22.2°C and 19.6°C (72.0°F and 67.3°F), respectively, when juveniles were reared at 20°C (68°F; Zillig et al. 2023). This study suggests that Chinook Salmon have the capacity to adapt and acclimate to warming temperatures, to some extent. Juvenile Chinook Salmon reared at lower temperatures (11°C [51.8°F]) had less ability to recover from heat stress, as described in Zillig et al. (2025). Additionally, some populations may have maladaptive phenotypes that cause them to be less able to acclimate than other populations. For instance, winter-run Chinook Salmon exhibited reduced growth rates and thermal optima when acclimated to 20°C (68°F), compared to winter-run Chinook Salmon acclimated to 16°C (60.8°F) in laboratory conditions (Zillig 2022). As such, population-specific temperature management approaches may be more appropriate than temperature thresholds derived on a species level (Zillig et al. 2021).

6.3.2 Out-Migration

Juvenile non-core rearing and out-migration limits set by USEPA (2003) include an upper limit of 18°C (64.4°F). However, during out-migration, juveniles may be tolerable of higher water temperatures (USEPA 2003). As such, the USEPA (2003) recommends a 20°C (68°F) summertime maximum 7-DADM for juvenile out-migration, but with the caveat that waters should be restored to their natural thermal regime when possible. Extended exposure to 20°C (68°F) may lead to adverse effects such as impaired smoltification, reduced growth, and increased risk of diseases and predation. A field study on fall-run Chinook Salmon in the Snake River, Oregon, also found that out-migrating juveniles sought out water temperatures between 16°C and 20°C (60.8°F and 68°F; Tiffin et al. 2009). Additionally, they observed that a portion of these juveniles selected warmer temperatures during the nighttime when they were more actively moving downstream (Tiffin et al. 2009). As such, out-migrating juveniles are expected to tolerate a range of temperatures and seek thermal refugia as needed during migration.

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