SACRAMENTO RIVER FALL CHINOOK

(JULY 2019)

SALMON REBUILDING PLAN,
ENVIRONMENTAL ASSESSMENT*,
MAGNUSON-STEVENS FISHERY CONSERVATION AND MANAGEMENT ACT ANALYSIS*,
REGULATORY IMPACT REVIEW*, AND
INITIAL REGULATORY FLEXIBILITY ANALYSIS*

REGULATORY IDENTIFIER NUMBER 0648-BI04

PLEASE NOTE: THE PORTION OF THIS DOCUMENT THAT IS FOCUSED ON THE SALMON REBUILDING PLAN ARE MAINLY SECTIONS 1-5 AND ANY APPENDICES NOTED IN THOSE SECTIONS.

THIS IS AN INTEGRATED DOCUMENT AND SOME PORTIONS OF THE DOCUMENT [INDICATED BY AN ASTERISK (*)] MAY CURRENTLY BE INCOMPLETE. ANY INCOMPLETE PORTIONS WILL BE DEVELOPED BY NATIONAL MARINE FISHERIES SERVICE, AND MADE AVAILABLE FOR PUBLIC COMMENT THROUGH THE NOTICE-AND COMMENT RULEMAKING PROCESS.

Pacific Fishery Management Council
7700 NE Ambassador Place, Suite 101
Portland, OR 97220-1384
(503) 820-2280
www.pcouncil.org

National Marine Fisheries Service (NMFS)
7600 Sand Point Way, NE, BIN C15700
Seattle, WA 98115-0700
(206) 526-6150
www.noaa.gov/fisheries

This draft version of the document may be cited in the following manner:
Pacific Fishery Management Council. 2019. *Salmon Rebuilding Plan for Sacramento River Fall Chinook.* Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

A report of the Pacific Fishery Management Council pursuant to National Oceanic and Atmospheric Administration Award Number NA15NMF4410016.

ACKNOWLEDGEMENTS

The Salmon Technical Team, NMFS, and the Council staff express their thanks for the expert assistance provided by those listed here and numerous other tribal and agency personnel in completing this report.

Dr. Michael O'Farrell, STT Chair
National Marine Fisheries Service, Santa Cruz, California

Mr. Jon Carey, STT Vice-Chair
National Marine Fisheries Service, Seattle, Washington

Ms. Wendy Beeghley, STT member
Washington Department of Fish and Wildlife, Montesano, Washington

Mr. Craig Foster, STT member
Oregon Department of Fish and Wildlife, Clackamas, Oregon

Ms. Vanessa Gusman
California Department of Fish and Wildlife, Santa Rosa, California

Dr. Steve Haeseker, STT member
U.S. Fish and Wildlife Service, Vancouver, Washington

Ms. Ashton Harp, STT Member
Northwest Indian Fish Commission, Forks, Washington

Mr. Matt Johnson
California Department of Fish and Wildlife, Red Bluff, California

Dr. Robert Kope, former STT member, Vice-Chair
National Marine Fisheries Service, Seattle, Washington (retired)

Mr. Larrie Lavoy, former STT member
National Marine Fisheries Service, Seattle, Washington (retired)

Mr. Alex Letvin, STT member
California Department of Fish and Wildlife, Santa Rosa, California

Ms. Peggy Mundy
National Marine Fisheries Service, Seattle, Washington

Mr. Colin Purdy
California Department of Fish and Wildlife, Rancho Cordova, California

Ms. Mindy Rowse
National Marine Fisheries Service, Seattle, Washington

Dr. Jim Seger
Pacific Fishery Management Council, Portland, Oregon

Dr. Rob Titus
California Department of Fish and Wildlife, Sacramento, California

Dr. Ed Waters
Economist (on contract with the Pacific Fishery Management Council), Beaverton, Oregon

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS AND ABBREVIATIONS

ABC	acceptable biological catch
ACL	annual catch limit
BY	brood year
CCC	California Coastal Chinook
CDFW	California Department of Fish and Wildlife
CDWR	California Department of Water Resources
CNFH	Coleman National Fish Hatchery
Council	Pacific Fishery Management Council
CVP	Central Valley Project
CWT	coded-wire tag
EA	Environmental Assessment
EEZ	exclusive economic zone (from 3-200 miles from shore)
EIS	Environmental Impact Statement
ESA	Endangered Species Act
ESU	evolutionarily significant unit
F_{ABC}	exploitation rate associated with ABC
F_{ACL}	exploitation rate associated with ACL (= F_{ABC})
FMP	fishery management plan
F_{MSY}	maximum sustainable yield exploitation rate
F_{OFL}	exploitation rate associated with the overfishing limit (= F_{MSY}, MFMT)
FONSI	Finding of No Significant Impacts
FRAM	Fishery Regulatory Assessment Model
FRH	Feather River Hatchery
GAM	generalized additive models
ISBM	individual stock-based management
JPI	juvenile production index
KMZ	Klamath Management Zone (ocean zone between Humbug Mountain and Horse Mountain)
KOHM	Klamath Ocean Harvest Model
KRFC	Klamath River fall Chinook
LAR	Lower American River
MFMT	maximum fishing mortality threshold
MSA	Magnuson-Stevens Fishery Conservation and Management Act
MSST	minimum stock size threshold
MSY	maximum sustainable yield
NA	not available
NEPA	National Environmental Policy Act
NFH	Nimbus Fish Hatchery
NMFS	National Marine Fisheries Service
NPGO	North Pacific Gyre Oscillation
NS1G	National Standard 1 Guidelines
ODFW	Oregon Department of Fish and Wildlife
OFL	overfishing limit
OY	Optimum Yield
PDO	Pacific Decadal Oscillation
PFMC	Pacific Fishery Management Council (Council)
PSC	Pacific Salmon Commission
PST	Pacific Salmon Treaty
RBDD	Red Bluff Diversion Dam
RBFO	Red Bluff Field Office
RER	rebuilding exploitation rate

LIST OF ACRONYMS AND ABBREVIATIONS (continued)

S_{ABC}	spawning escapement associated with ABC
S_{ACL}	spawning escapement associated with ACL (= S_{ABC})
SHM	Sacramento Harvest Model
SI	Sacramento Index
S_{MSY}	MSY spawning escapement
S_{OFL}	spawning escapement associated with the overfishing limit (= S_{MSY})
SRFC	Sacramento River fall Chinook
SRWC	Sacramento River winter Chinook
STT	Salmon Technical Team
USBR	United States Bureau of Reclamation
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VSI	visual stock identification
WDFW	Washington Department of Fish and Wildlife

1.0 EXECUTIVE SUMMARY

Sacramento River fall Chinook salmon (SRFC) met the criteria for overfished status in 2018 as defined in Section 3.1 of the Pacific Coast Salmon Fishery Management Plan (FMP). In response, the Pacific Fishery Management Council (Council) directed the Salmon Technical Team (STT) and collaborators to develop a rebuilding plan for Council consideration within one year. This report represents the SRFC rebuilding plan and includes requirements described in section 3.1.4.1 of the FMP, including: (1) an evaluation of the roles of fishing, marine and freshwater survival in the overfished determination, (2) any modifications to the criteria for determining when the stock has rebuilt, (3) recommendations for actions the Council could take to rebuild the stock, and (4) specification of the rebuilding period.

Section 3 describes the evaluation of potential factors that led to the overfished status. The analysis found that below average freshwater flows and high temperatures throughout the Sacramento Basin coincided with relatively high levels of pre-spawn mortality for the critical broods (defined as brood years 2012-2014). Low flows and warm temperatures in the lower Sacramento River were likely to have affected survival of outmigrating smolts from brood years 2013 and 2014. Hatchery releases were below average levels for the critical brood years, and offsite release practices utilized during drought conditions led to increased straying and river harvest of returning adults. Large scale indices of ocean productivity indicated that warm, unproductive ocean conditions were in place during the year of ocean entry for a portion of the critical broods. However, there were indications that forage conditions and predation risk in the Gulf of the Farallons were favorable for the outmigrating critical broods. Stock assessment and fishery management errors were also found to contribute to the overfished status of SRFC.

Section 4 provides recommendations for action in this rebuilding plan, including the rebuilt criterion, fishery management strategies to be employed during the rebuilding period, a recommendation for further investigation into habitat issues, an analysis of rebuilding times, and a suite of further recommendations, some of which lie outside the jurisdiction of the Council. Estimates of rebuilding time ranged from two to three years across all three management strategy alternatives. An analysis of the socio-economic impacts of management strategy alternatives is presented in Section 5. Section 6 presents an analysis of the environmental impacts of the alternative rebuilding strategies, as required under the National Environmental Policy Act (NEPA).

This rebuilding plan was adopted as draft for public review at the April 2019 Council meeting in Rohnert Park, California. At the June 2019 meeting in San Diego, California the Council adopted the rebuilding plan as final, with the following decisions: (1) maintain the default criterion for achieving rebuilt status as defined in the FMP, (2) identification of Alternative I (status quo control rule) as the preferred management strategy alternative, (3) direct the Council's Habitat Committee to review the status of essential fish habitat as described in section 4.5, and (4) direct the STT to further assess the feasibility of implementing "Further recommendations" 1-4 found in section 4.7.

2.0 INTRODUCTION

In 2018, SRFC met the criteria for overfished status as defined in Section 3.1 of the FMP (PFMC 2016a). In response, the Pacific Fishery Management Council (Council) directed the STT to propose a rebuilding plan for Council consideration within one year. The FMP, and the Magnuson-Stevens Fishery Conservation and Management Act (MSA), requires that a rebuilding plan must be developed and implemented within two years of the formal notification from National Marine Fisheries Service (NMFS) to the Council of the overfished status. Excerpts from the FMP relevant to status determinations and rebuilding plans are provided in Appendix A.

The Council's criteria for overfished status is met if the geometric mean of escapement, computed over the most recent three years, falls below the minimum stock size threshold (MSST), which is defined for applicable stocks in Table 3-1 of the FMP. For SRFC, the maximum sustainable yield spawner escapement level (S_{MSY}) is defined as 122,000 hatchery and natural-area adult spawners. The MSST for SRFC is defined as 91,500 hatchery and natural-area adult spawners, with MSST $= 0.75 \times S_{MSY}$. The geometric mean of SRFC hatchery and natural-area adult spawners over years 2015-2017 was 76,714, and thus in 2018 the stock met the criteria for overfished status. Figure 2.0.a displays the time series of SRFC hatchery and natural-area adult escapement and the running three-year geometric mean of escapement relative to S_{MSY} and the MSST. The FMP identifies the default criterion for achieving rebuilt status as attainment of a 3-year geometric mean of spawning escapement exceeding S_{MSY}.

Overfished status is defined by recent spawner escapement for salmon stocks, which is not necessarily the result of overfishing. Overfishing occurs when in any one year the exploitation rate on a stock exceeds the maximum fishing mortality threshold (MFMT), which for SRFC is defined as the MSY fishing mortality rate (F_{MSY}) of 0.78. It is possible that overfished status could be the result of normal variation in abundance, as has been the case in the past for several salmon stocks. However, the occurrence of reduced stock size or spawner escapements, depending on the magnitude of the short-fall, could signal the beginning of a critical downward trend. Imposing fisheries on top of already low abundances could further jeopardize the capacity of the stock to produce MSY over the long term if appropriate actions are not taken to ensure that conservation objectives are achieved.

In this rebuilding plan, we begin by providing an overview of the SRFC stock, the geography of the Sacramento Basin, and fisheries management. We then review the potential factors that may have contributed to the overfished status. Recommendations regarding alternative rebuilding actions are proposed, as are recommendations for actions outside of the management of salmon fisheries. We end with a socioeconomic analysis of the impact of the recommended rebuilding alternatives. All escapement and harvest values reported herein represent the data available at the time of the overfished determination, including preliminary 2017 data, except in Section 4.6 and Appendix B which describe a prospective analysis and thus utilize the most recent data. Updates to escapement and harvest did not affect the overfished determination or potential causal factors.

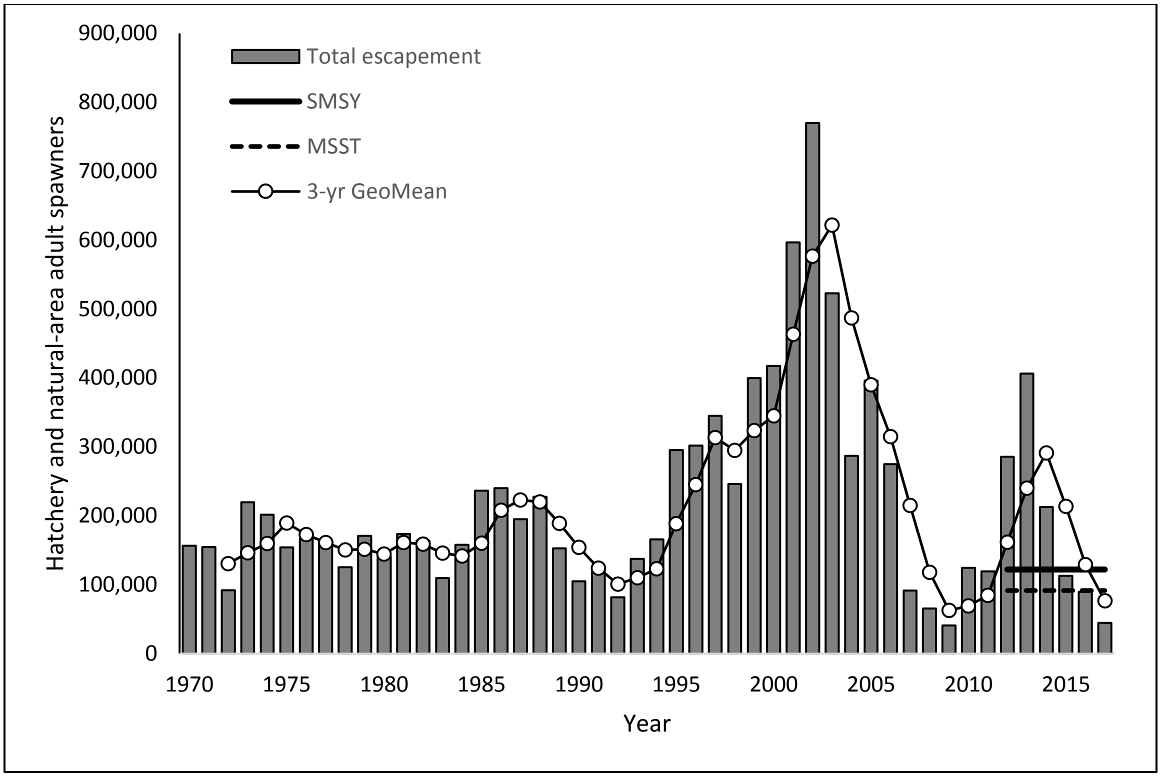

Figure 2.0.a. Sacramento River Fall Chinook spawner escapement of hatchery and natural-area adults.

2.1 National Environmental Policy Act

In addition to addressing the requirements of the FMP and MSA, this rebuilding plan document integrates the environmental assessment required under the National Environmental Policy Act (NEPA).

2.1.1 Proposed Action

The Proposed Action is for the Council to adopt and NMFS to approve a rebuilding plan for the SRFC salmon stock, which has been determined by NMFS to be overfished under the MSA. The rebuilding plan must be consistent with the MSA and the provisions of the FMP; therefore, the plan shall include a control rule and a specified rebuilding period. The specified rebuilding period shall be as short as possible, taking into consideration the needs of the commercial, recreational, and tribal fishing interests, and economic effects on coastal communities.

2.1.2 Purpose and Need

The purpose of the proposed action is to develop and implement a harvest control rule that will be applied to setting annual ocean salmon fishery management measures that impact SRFC. This harvest control rule will be designed to attain a three-year geometric mean spawning escapement that meets the S_{MSY} specified for that stock in the FMP in the least amount of time possible while taking into account the biology of the stock, international agreements, and the needs of fishing communities, but not to exceed 10 years. The need for the proposed action is to rebuild SRFC, which NMFS determined in 2018, to be overfished under the MSA.

2.2 Stock overview

2.2.1 Location and geography

The Sacramento River Basin comprises approximately 26,000 square miles between the Sierra Nevada and Cascade ranges to the east and the Coast Range to the west. The headwaters of the Sacramento River lie in the Cascade Range, near Mount Shasta. The river flows south to the Sacramento-San Joaquin River Delta, which begins just downstream of the city of Sacramento, then into San Pablo and San Francisco bays and ultimately into the Pacific Ocean (Figure 2.2.1.a). Major tributaries to the Sacramento River include the Feather River, Yuba River (which itself is a tributary of the Feather River), and the American River. Numerous smaller tributaries flow from the Sierra Nevada, and to a lesser extent, from the Coast Range into the Sacramento River. Many of these tributaries are important spawning and rearing areas for SRFC.

Four runs of Chinook salmon, named after the season in which mature fish enter the river to spawn, are present in the Sacramento River and its tributaries. These runs include SRFC, late-fall run, winter run, and spring run. Yoshiyama et al. (1998) notes that each run features a somewhat protracted run timing that can lead to substantial temporal overlap in the Sacramento Basin. As such, the Sacramento River is known to have adult Chinook salmon present in the system throughout the year. Two of the runs that utilize the Sacramento River are listed under the Endangered Species Act (ESA): spring run are listed as Threatened and winter run are listed as Endangered. These listings are in large part due to extensive loss of the cold headwater habitats that these runs require. SRFC, and to a lesser degree late-fall run, are not as dependent on high-elevation and/or spring-fed habitats as spring and winter Chinook.

The Sacramento River and its tributaries have been heavily modified over time by a variety of actions, including dam construction, flood control efforts, and water diversions for agricultural and domestic uses. Keswick Dam, near the city of Redding and approximately nine miles downstream of Shasta Dam, is the upstream terminus of anadromy for the Sacramento River. Dams are also present on the Feather, Yuba, and American rivers, as well as many of the smaller tributaries, eliminating a substantial amount of Chinook spawning habitat. Hatcheries are used to mitigate for the lost production of salmon due to impassable dams. Historical accounts of salmon abundance in the Sacramento Basin, and descriptions of the physical changes to the Sacramento River and its tributaries can be found in Fisher (1994) and Yoshiyama et al. (1998).

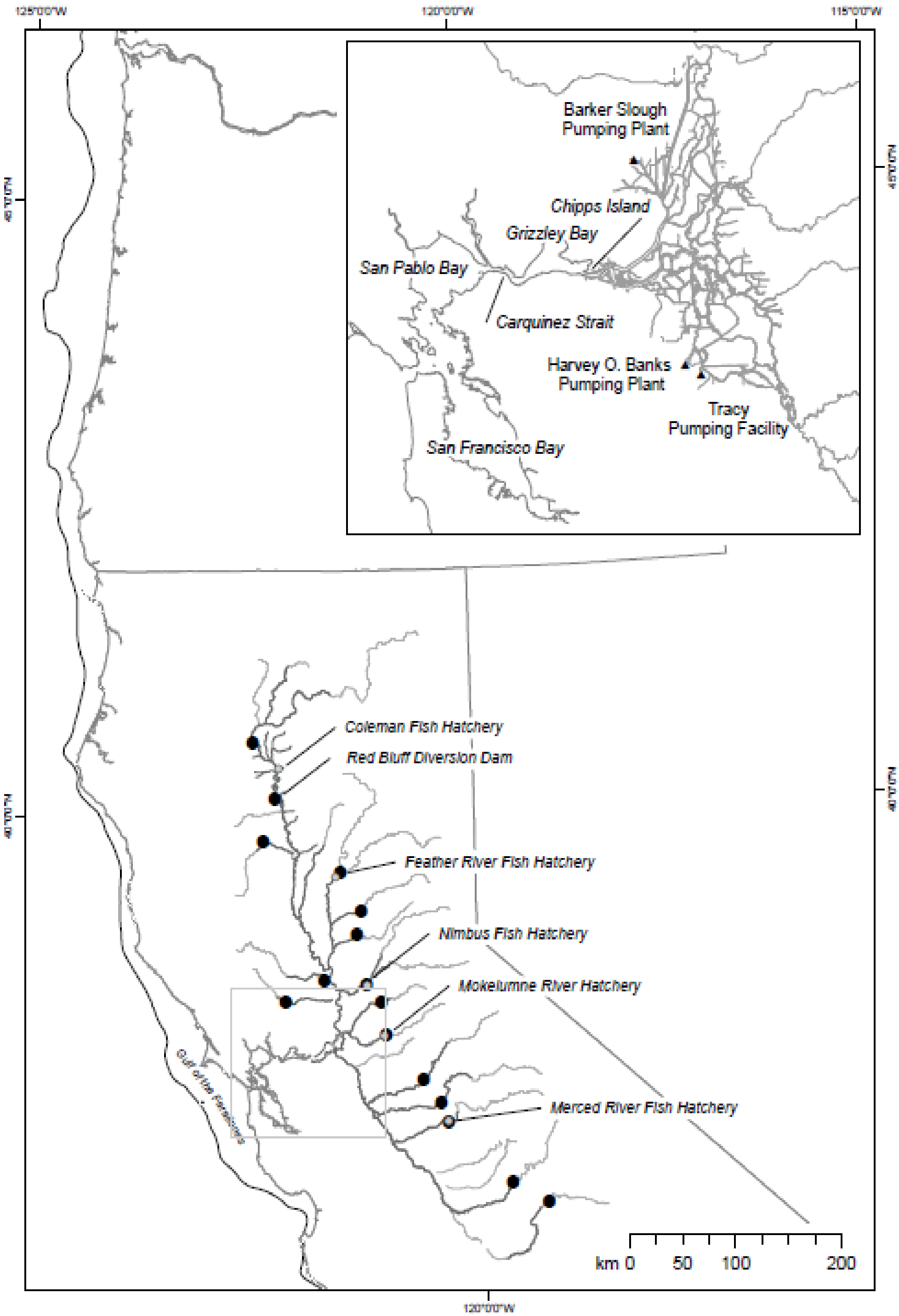

Figure 2.2.1.a. Map of the Sacramento River Basin, Delta, and coastal ocean. Black dots indicate dams, most of which are impassable. Coleman, Feather River, and Nimbus fish hatcheries produce SRFC. Figure reproduced from Lindley et al. (2009).

2.2.2 *Stock composition*

Mature SRFC return to hatcheries and natural spawning areas. Although a portion of the spawning stock every year consists of age-2 fish, primarily males referred to as "jacks," only age-3 and older fish are considered adults and thus used to assess stock status. Since 1970, and excluding the years that contributed to the current overfished status (2015-2017), natural-area escapement (which includes both natural- and hatchery-origin fish) has represented on average 81 percent of the total adult escapement in the Sacramento Basin (PFMC 2018b). However, while this percentage has greatly fluctuated over time, in general there has been a decreasing trend. Every decade, the average percentage of adult escapement occurring in natural areas has declined, beginning with 91 percent in the 1970s, 84 percent in the 1980s, 80 percent in the 1990s, 75 percent in the 2000s, and only 63 percent since 2010. During 2015-2017, the average was even lower at 55 percent, with 2017 being the lowest on record at only 39 percent of the adult return. This is 14 percent less than the next lowest percentage on record, which was 53 percent in 2005 (Figure 2.2.2.a; PFMC 2018b). Even among the natural-area spawners, recent analyses utilizing coded-wire tags (CWTs) collected during the 2010-2013 escapements indicated high levels of hatchery-origin SRFC (Kormos et al. 2012, Palmer-Zwahlen and Kormos 2013, Palmer-Zwahlen and Kormos 2015, Palmer-Zwahlen et al. 2018). This was especially true in the Feather and American rivers, where hatchery-origin SRFC composed as high as 90 percent and 73 percent, respectively, of the natural-area escapement (see Table 3.1.8.b). Preliminary analyses done for this rebuilding plan indicated similarly high levels of hatchery-origin SRFC in natural-area spawning grounds during the overfished years of 2015-2017 (see Table 3.1.8.a).

SRFC spawn in the fall and the fry emerge during winter through early spring. Juveniles enter the ocean from spring through mid-summer, spending little time in the estuary. Ocean harvest data indicates that SRFC are primarily caught from the coast of northern Oregon to southcentral California, which in terms of fishery management translates to Cape Falcon, OR to the U.S./Mexico border. Within this ocean range, SRFC generally compose larger portions of the overall harvest in areas closer to San Francisco Bay. These fish typically spend around a year and a half to three years in the ocean before returning to freshwater, although waiting four, and to a lesser extent five, years to mature is not uncommon. SRFC that spend less than two years in the ocean are considered age-2 when they return and, as mentioned above, are not considered adults.

Hatchery production of SRFC comes from Coleman National Fish Hatchery (CNFH), operated by the U.S. Fish and Wildlife Service (USFWS), and from Feather River Hatchery (FRH) and Nimbus Fish Hatchery (NFH), operated by the California Department of Fish and Wildlife (CDFW). CNFH is located on Battle Creek, a tributary near the upper limit of anadromy in the Sacramento mainstem, and smolts are typically released directly into the creek. However, in response to severe drought conditions in the Sacramento River, brood years 2013 and 2014 had 62 percent and 100 percent of their smolts, respectively, trucked to the delta and released into net pens. The Feather River is located downstream of Battle Creek, and almost all fall-run production from FRH is trucked and released into net pens in the delta and San Pablo/San Francisco Bay, as well as coastal net pens located in Half Moon Bay and Santa Cruz. The American River, where NFH is located, is even further downstream and flows through the city of Sacramento. While a portion of the production at NFH is always trucked to the delta or bay and released into net pens, brood years 2013 and 2014 were entirely trucked, again due to extreme drought conditions in-river.

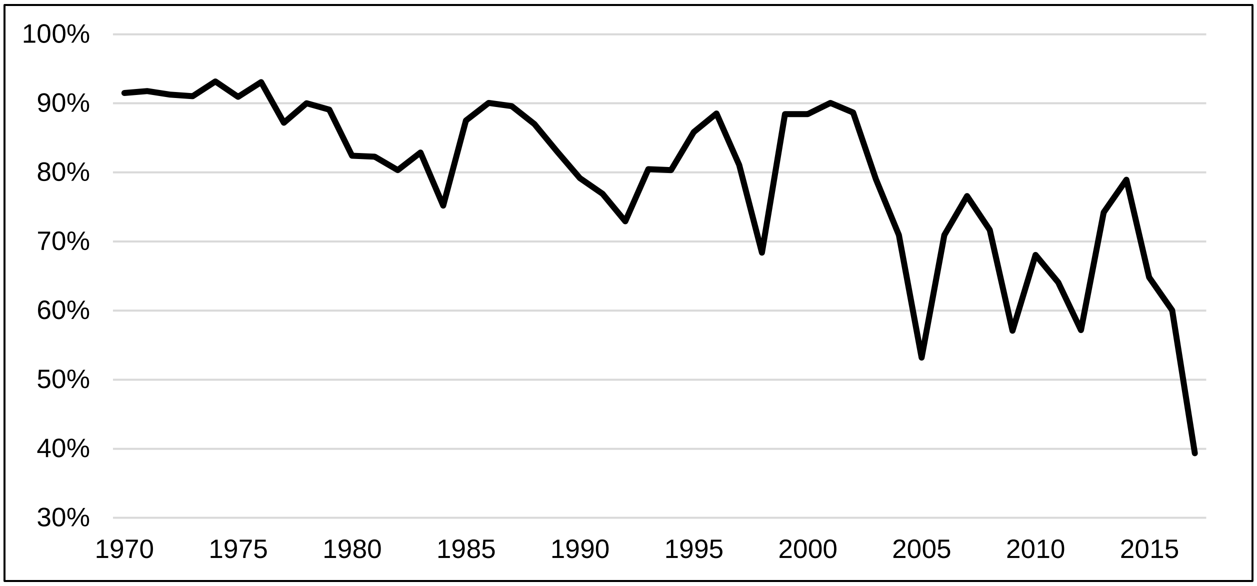

Figure 2.2.2.a. Historical percentages of the adult Sacramento River fall Chinook escapement that consisted of natural area spawners, as opposed to hatchery spawners.

2.3 Management Overview

2.3.1 Conservation objectives

Table 3-1 in the FMP (PFMC 2016a) defines the conservation objective for SRFC as: "122,000-180,000 natural and hatchery adult spawners (MSY proxy adopted 1984)". Justification for this conservation objective and citations for supporting documents are also found in Table 3-1 of the FMP (PFMC 2016a).

Prior to 2012, the conservation objective guided annual fisheries management for this stock. Fisheries were planned so as to achieve hatchery and natural-area adult escapement levels within the goal range, when possible. Upon adoption of Amendment 16 to the FMP in 2012, annual fishery management of the SRFC stock has been guided by a harvest control rule that incorporates some aspects of the conservation objective (PFMC 2016a).

2.3.2 Management strategy

Current management of SRFC is guided by a control rule that specifies the maximum allowable exploitation rate based on a forecast of potential spawner abundance, which is the hatchery and natural-area adult escapement in the absence of fisheries (Figure 2.3.2.a). The exploitation rate cap specified by the control rule includes harvest impacts of both ocean and river fisheries.

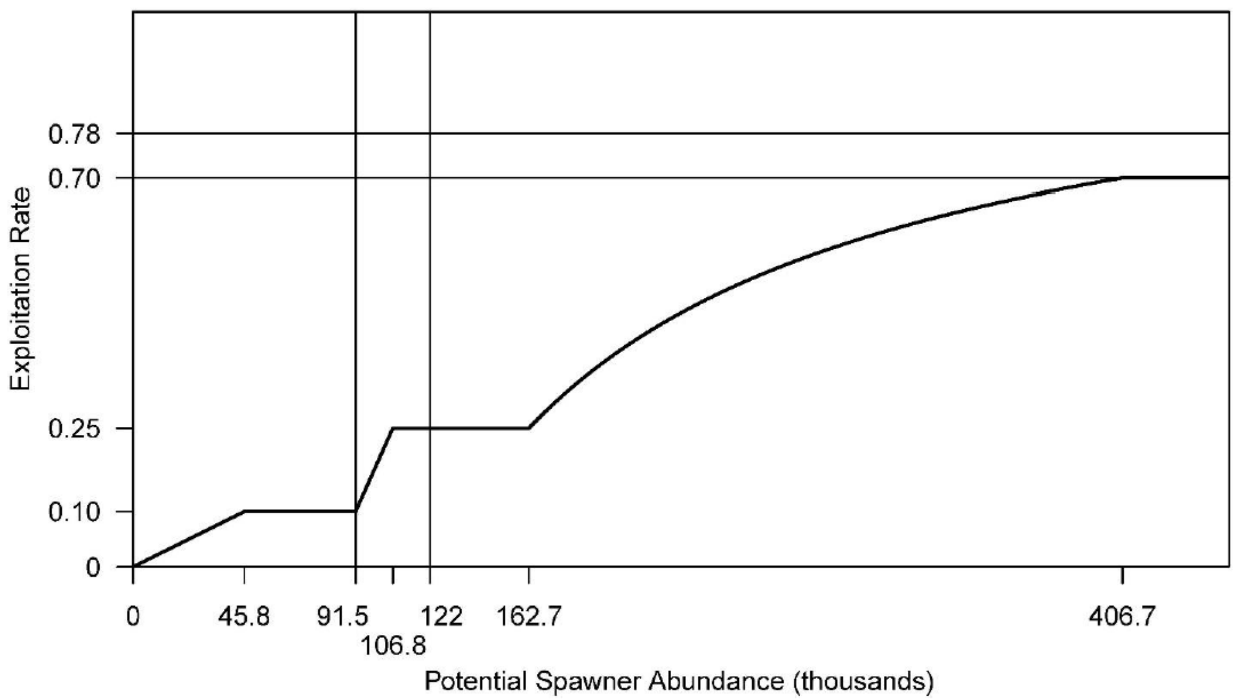

Figure 2.3.2.a. Sacramento River fall Chinook control rule. Potential spawner abundance is the predicted hatchery and natural area adult spawners in the absence of fisheries, which is equivalent to the Sacramento Index. See the salmon FMP, Section 3.3.6, for control rule details.

For SRFC, potential spawner abundance is represented by the forecast of the Sacramento Index (SI), the aggregate-age (> age-2) abundance index for this stock. The SI in year *t* is the sum of (1) adult SRFC ocean fishery harvest south of Cape Falcon, OR between September 1 (*t* – 1) and August 31 (*t*), (2) adult SRFC impacts from non-retention ocean fisheries when they occur, (3) the year *t* recreational harvest of adult SRFC in the Sacramento River Basin, and (4) the year *t* SRFC adult spawner escapement. A detailed description of the SI and the estimation of its components can be found in O'Farrell et al. (2013). A forecast of the SI is made annually, and the methods used to forecast this index have changed over time. Since 2014, the SI has been forecast using a log-log model relating jacks (t-1) to the SI (t) with lag-1 autoregressive errors fitted to SI data from 1983-forward. A description of this approach can be found in PFMC (2014), Appendix E, and in annual versions of Preseason Report I (Stock Abundance Analysis and Environmental Assessment Part 1 for Ocean Salmon Fishery Regulations) since 2014.

At high levels of potential spawner abundance, the control rule specifies a maximum allowable exploitation rate of 0.70, the fishing mortality rate associated with the acceptable biological catch (F_{ABC}). At moderate abundance, the control rule specifies an allowable exploitation rate that results in an expected escapement of S_{MSY} = 122,000 hatchery and natural-area adults (the curved portion of the control rule). At low levels of abundance the control rule specifies *de minimis* exploitation rates that allow for some fishing opportunity but result in the expected escapement falling below 122,000 adults.

3.0 REVIEW OF POTENTIAL FACTORS LEADING TO OVERFISHED STATUS

3.1 Freshwater survival

3.1.1 Review of freshwater conditions

3.1.1.1 Sacramento River mainstem

Temperature impacts on salmon can take the form of lethal and sub-lethal effects including adult pre-spawn mortality, reduced fecundity, egg and embryo mortality, and increased susceptibility to disease. Data from the U.S. Geological Survey (USGS) gauge located downstream of Keswick Dam on the Sacramento River was used to characterize water temperatures and flows during spawning (Figures 3.1.1.1.a and 3.1.1.1.b). In terms of incubation temperatures, Martin et al. (2017) identified 54° F (12° C) as the temperature below which there is no longer any temperature-induced mortality. Mortality rates are nearly 100 percent at temperatures of 62° F (16.7° C) or greater (Myrick and Cech 2001).

Water temperatures measured immediately downstream of Keswick Dam were above 54° F during the spawning period in 12 of 18 brood years from 1997 through 2014. Of note are the 'critical' broods of 2012-2014, which are the brood years that primarily contributed to escapement in 2015-2017. While water temperatures recorded below Keswick are reflective of habitat conditions in the immediate area, SRFC regularly utilize the mainstem Sacramento River for spawning from Keswick Dam downstream to Princeton Ferry (river mile 165) (Killam 2018).

In 2014 CDFW installed fifty water temperature loggers in the uppermost anadromous portion of the Sacramento River downstream of Keswick Dam to monitor drought-related water quality impacts (Killam and Thompson 2015). Water temperatures coming out of Keswick during 2014 approached the 62° F lethal limit and were the highest observed across brood years 1997-2014. Killam and Thompson (2015) recorded increasing water temperatures in SRFC spawning areas downstream of Keswick Dam. Water temperature monitoring in 2014 showed that water temperatures in the uppermost 83 river miles were above 56° F for a majority of the SRFC spawning period from late September to mid-November with temperatures peaking at 61° F in early October (the beginning of peak spawning for SRFC) (Killam and Thompson 2015). It was likely that nearly all SRFC in the Sacramento River deposited eggs in water temperatures considered to be lethal to all, or portions of, incubating eggs or pre-emergent fry in 2014. An estimated 15,923 female SRFC used the river in 2014. However, it was not possible to use rotary screw trap data to evaluate mainstem Sacramento River juvenile SRFC production in 2014 because SRFC juveniles captured in the traps could be from any number of tributaries upstream of trapping locations (Killam and Thompson 2015).

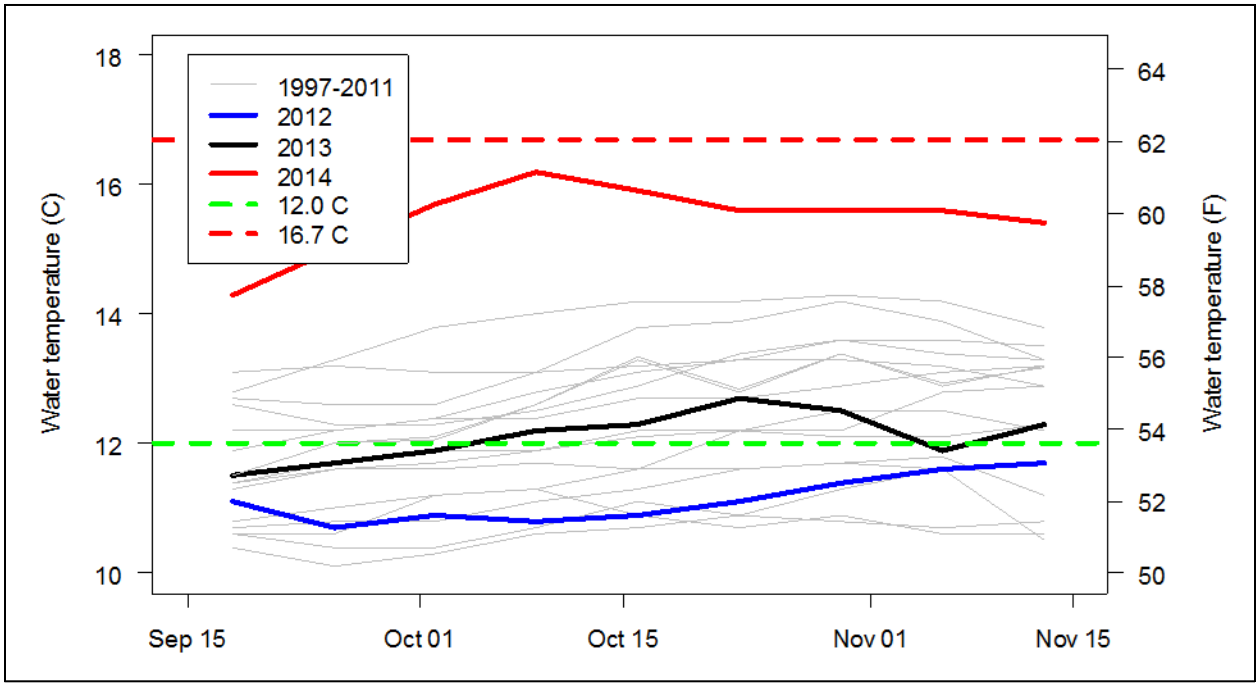

Figure 3.1.1.1.a. Water temperatures (°C on the left axis, °F on the right axis) in the Sacramento River below Keswick Dam during the spawning period for fall Chinook salmon across brood years 1997-2014 (data from Killam and Thompson 2015). The lower dashed line represents the temperature below which there is no mortality due to temperature (12˚°C/54°F) and the upper dashed line represents the temperature associated with nearly 100 percent temperature-induced mortality (16.7˚°C/62°F).

Flow levels influence the quantity and quality of spawning habitat. Sacramento River flow levels during the spawning period were relatively low during brood years 2012 and 2013 compared to previous years (Figure 3.1.1.1.b). Brood year 2014 experienced the lowest prolonged flow levels in the time series shown.

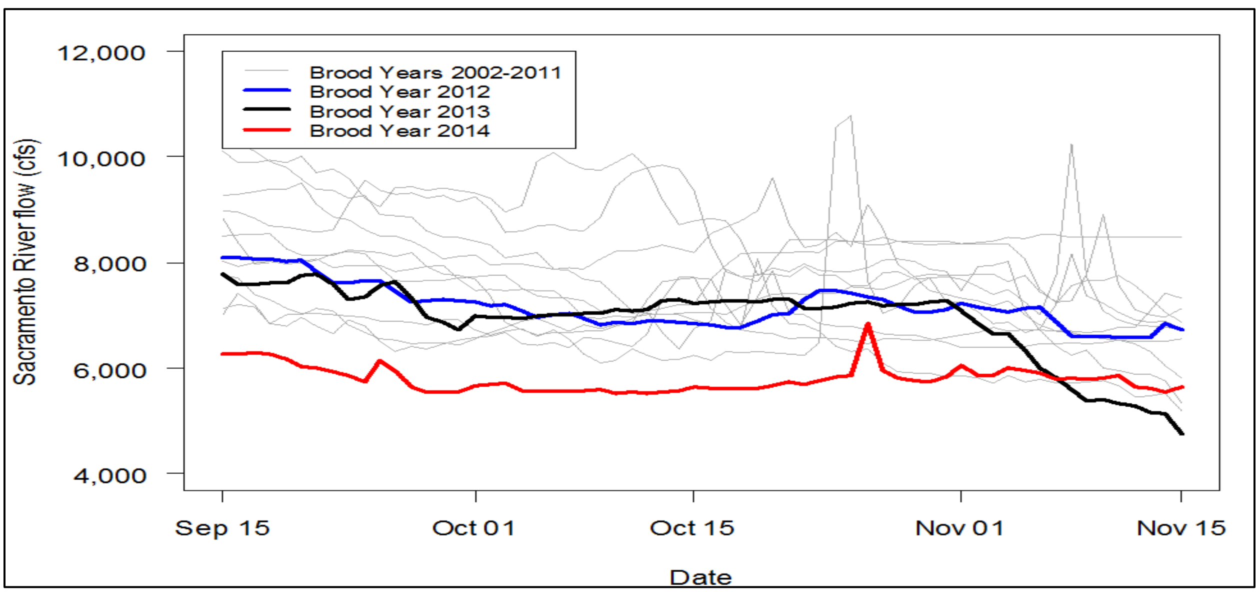

Figure 3.1.1.1.b. Sacramento River flow levels below Keswick Dam during the spawning period for brood years 2002-2014.

Water temperatures and flows experienced by juvenile SRFC were also indexed at the USGS gauge at Freeport, downstream of the city of Sacramento. Water temperatures were highest for brood year 2014 outmigrants (Figure 3.1.1.1.c). Flows were low for the 2012, 2013, and 2014 outmigrants (Figure 3.1.1.1.d).

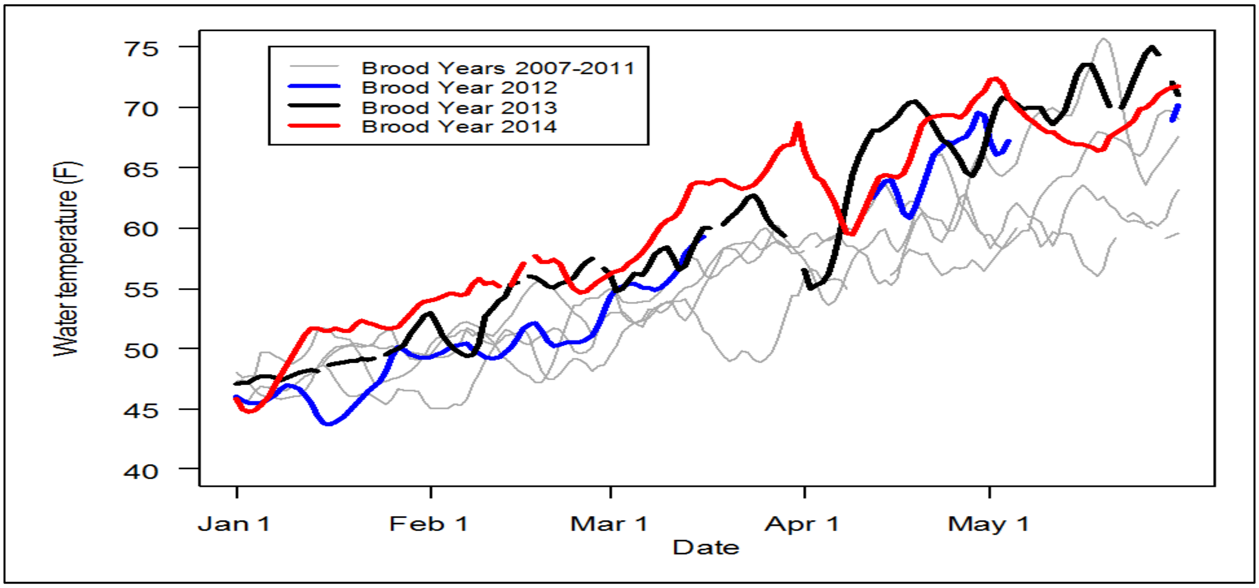

Figure 3.1.1.1.c. Sacramento River water temperature (°F) at Freeport (downstream of Sacramento) encountered by outmigrating fall Chinook juveniles from brood years 2007-2014.

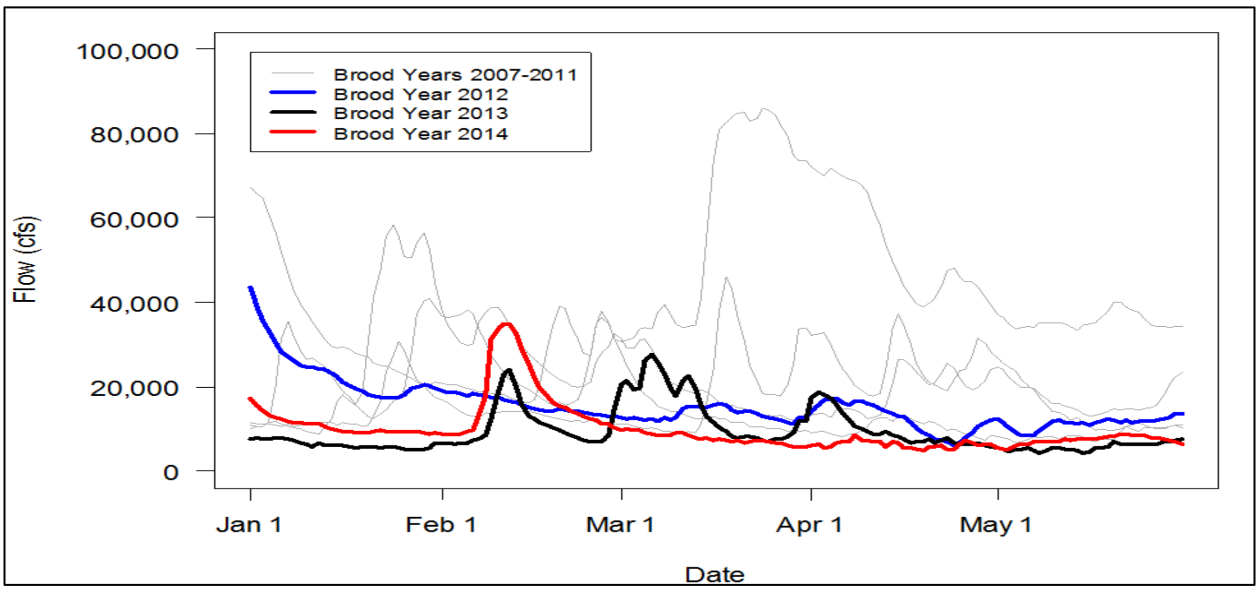

Figure 3.1.1.1.d. Sacramento River flow (cfs) at Freeport (downstream of Sacramento) encountered by outmigrating fall Chinook juveniles from brood years 2007-2014.

As previously mentioned, SRFC typically spawn from late September through mid-November, with the peak spawning occurring in October. Table 3.1.1.1.a presents the observed timing of

SRFC spawning by week, for the period September 3 through December 10. Data are based on observations of fresh female carcasses encountered during spawning seasons 2003 through 2017.

Table 3.1.1.1.a. Timing of Sacramento River fall-run Chinook spawning by week, for spawning seasons 2003 through 2017.

Week Beginning	Average Percent of Total Redds	Cumulative Percent of Total Redds
Sep 3	0.1%	0.1%
Sep 10	0.2%	0.3%
Sep 17	1.4%	1.7%
Sep 24	5.0%	6.7%
Oct 1	7.8%	14.5%
Oct 8	11.3%	25.8%
Oct 15	19.4%	45.2%
Oct 22	18.0%	63.3%
Oct 29	12.2%	75.5%
Nov 5	7.7%	83.2%
Nov 12	5.5%	88.7%
Nov 19	5.1%	93.7%
Nov 26	2.9%	96.7%
Dec 3	2.2%	98.9%
Dec 10	1.1%	100.0%

Reductions in flow during the spawning and egg incubation period can lead to redd dewatering. Since fall of 2013, the CDFW Red Bluff Field Office has actively monitored the fate of SRFC redds constructed in shallow water spawning habitat in the mainstem Sacramento River using funding through the Anadromous Fish Restoration Program. Newly constructed redds are marked with a unique marker and given a GPS waypoint, depth measurements are recorded, and current flow releases from Keswick Dam are noted. Field crews then return to these redds following scheduled flow reductions from Keswick Dam. The shallow water redd survey is conducted from Tehama Bridge at river mile (RM) 237 to Keswick Dam at RM 302. Table 3.1.1.b details the number of shallow redds identified and marked, and the number of those redds de-watered following flow reductions. While data do not exist for brood year 2012, there were generally low percentages of redds de-watered for brood years 2013 and 2014. It should be noted that these data only quantify redds that have been completely de-watered. It does not quantify redds partially de-watered nor changes in habitat associated with flow reductions, including velocity of water and dissolved oxygen in the egg pocket of shallow water redds.

Table 3.1.1.1.b. The number of shallow fall-run Chinook redds identified and marked, and the number of those redds de-watered following flow reductions on the main-stem Sacramento 2013 through 2017.

Year	Total Shallow Redds Identified	Percent De-watered
2013	515	2.7%
2014	43	0.3%
2015	291	2.1%
2016	0	NA
2017	15	1.5%

High river temperatures may contribute to pre-spawn mortality. As noted in Figure 3.1.1.1.a, temperatures during the spawning period were well above average for brood year 2014. CDFW provided estimates of pre-spawn mortality for brood years 2003-2017 based on sampling conducted in the Sacramento River mainstem (Figure 3.1.1.1.e). The average rate of pre-spawn mortality was 2.1 percent and in most years the rate was less than 4 percent. The notable exception was brood year 2014 where pre-spawn mortality was estimated to be 8.9 percent.

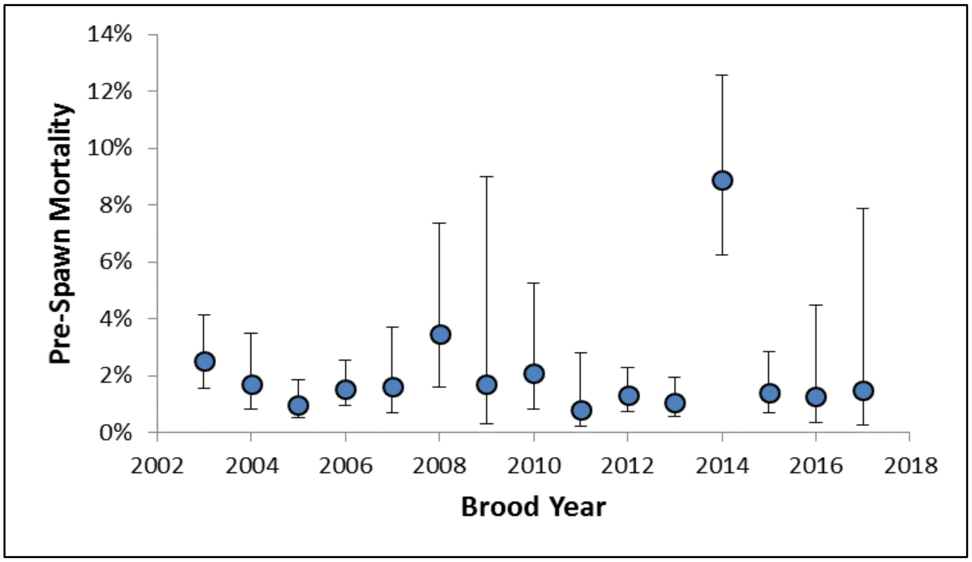

Figure 3.1.1.1.e. Estimates of pre-spawn mortality for Sacramento River fall Chinook (circles) along with 95 percent confidence intervals (whiskers) across brood years 2003-2017. Data source: CDFW.

Low flows and elevated water temperatures associated with exceptional drought conditions in the Sacramento River Basin were experienced by outmigrating juvenile SRFC beginning in spring 2013 and these conditions persisted through spring outmigration periods in 2014 and 2015. Acoustic telemetry studies in the Sacramento River have revealed low and variable survival during outmigration, suggesting marine mortality may not be the primary source of variability in cohort size as previously believed (Michel 2018). Recent investigations of juvenile Chinook survival in the Sacramento River mainstem using acoustic telemetry have shown that flow is strongly coupled with outmigration survival (Henderson 2018, Michel 2015, 2018, Notch 2017). Beginning in 2013, an investigation of juvenile survival of natural-origin Chinook emigrating from Mill Creek was initiated (Notch 2017). While this study focused on spring-run juveniles specifically, the location of the rotary screw trap (river mile 5) utilized to obtain juveniles was downstream of SRFC spawning habitat, and extensive Mill Creek juvenile Chinook life history investigations by CDFW show that young of the year spring-run closely mimic SRFC juveniles in emigration timing and length-at-date (Johnson and Merrick 2012). In this study juvenile Chinook smolts were captured in Mill Creek in April and May and implanted with miniaturized acoustic tags. The survival of tagged fish was then evaluated using over 140 acoustic receivers deployed each spring throughout the migration pathway of juvenile Chinook salmon from Mill Creek to the Pacific Ocean. In 2013, a total of 59 fish were tagged, and a single fish was detected surviving to the Golden Gate (Notch 2017). In 2014 and 2015, 36 and 186 fish were tagged, respectively, with zero fish either year surviving to the ocean (Notch 2017). The hydrograph of the Sacramento River is mostly unnatural and managed to store water in Shasta Reservoir for summer agricultural deliveries, maintaining delta water quality, and Sacramento River temperature management.

Generally, after April 15 water deliveries for agriculture increase and flows from Keswick Reservoir increase as a result. However, while the upper Sacramento River sees increasing flows, river levels downstream of Glenn Colusa Irrigation District and the numerous other large diversions along the Sacramento River are greatly reduced. This reduction in flow increases progressively downstream, and the Sacramento River reaches its lowest flows downstream of Tisdale in the vicinity of the Wilkins Slough USGS gauge. For brood year 2013, 38 percent of the CNFH-origin SRFC juveniles were released onsite, and these juveniles faced identical environmental conditions in the Sacramento River as the Mill Creek study fish. While all SRFC hatchery production was trucked for the 2014 brood, natural-origin SRFC juveniles were faced with extremely challenging conditions for survival in the Sacramento River mainstem.

3.1.1.2 Feather River

The Feather River is 67 miles long from the fish barrier dam (anadromous fish barrier) down to the confluence with the Sacramento River (Figure 2.2.1.a), and is the largest tributary to the Sacramento River. Although the Yuba and Bear rivers are considered major tributaries to the Feather River, under most conditions, Oroville Reservoir releases dictate the vast majority of the river flows. SRFC spawning activity in the Feather River primarily occurs upstream of RM 53 to RM 67 (Figure 3.1.1.2.a).

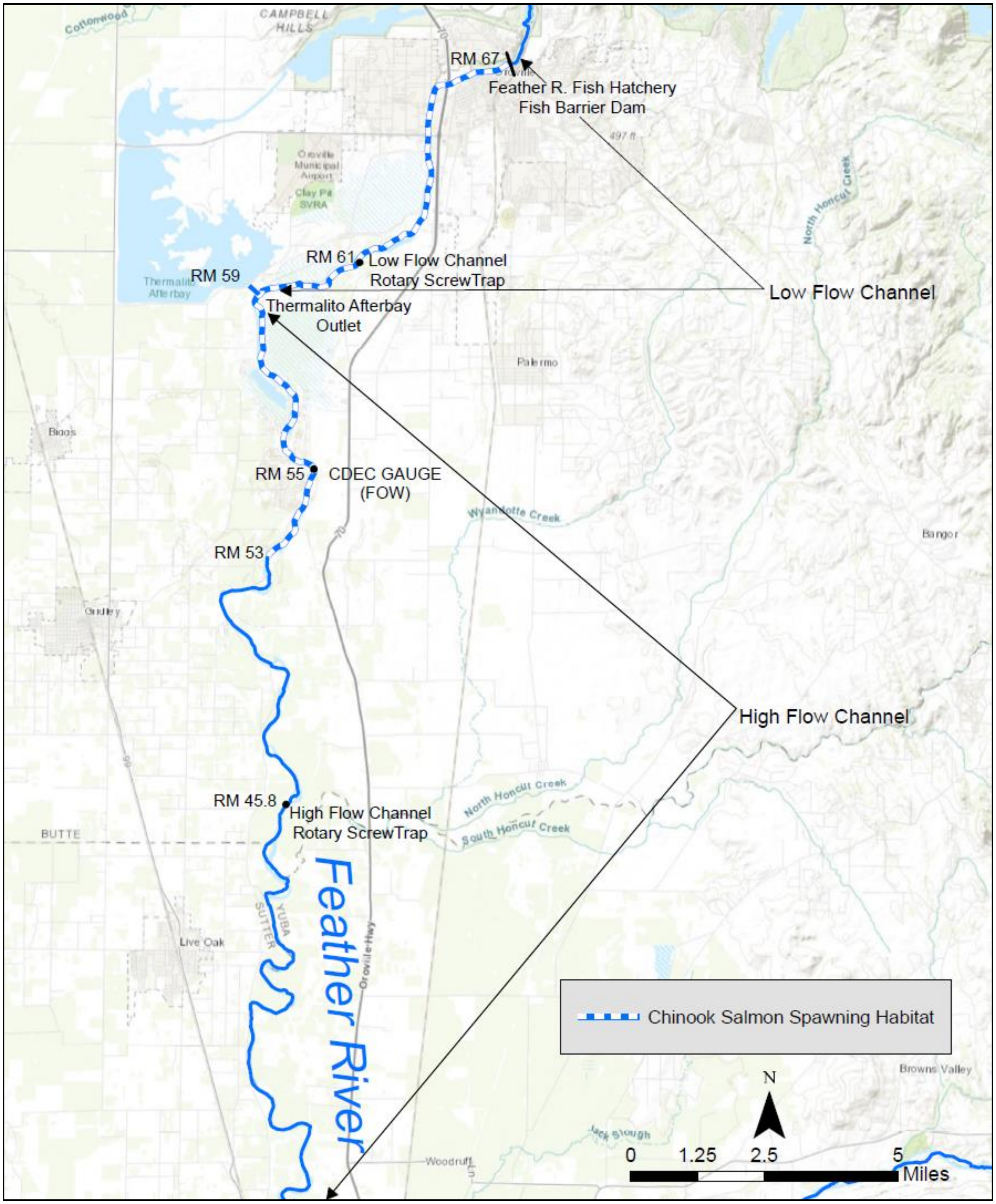

Figure 3.1.1.2.a. Map of the Feather River, including the fish barrier dam and the Thermalito Afterbay river outlet at RM 59.

Currently, an agreement between the California Department of Water Resources (CDWR) and CDFW (CDWR and CDFG 1983) regulates water temperature at FRH, located just below the barrier dam (see Figure 3.1.1.2.a). As a result, water temperatures in the low flow channel (between the fish barrier dam and the Thermalito Afterbay river outlet at RM 59) are often within a few degrees of required temperatures at the hatchery. In contrast, warm water releases from the Thermalito Afterbay river outlet (RM 59) frequently result in the exceedance of optimal spawning temperatures for SRFC during October downstream of RM 59. Temperature data in this portion of the Feather River were not available for 2012. In 2013, daily high temperatures were consistently over 56° F during October 1-28, with a high of 61° F on October 2. In 2014, daily high temperatures were consistently over 56° F during October 1-November 14, with a high of 64° F on October 2. (Figure 3.1.1.2.b). Water temperature data were collected by the CDWR at RM 55 using the Feather River Oroville Wildlife Area South Boundary Near Gridley gauge.

As referenced above, temperature impacts on salmon can take the form of lethal and sub-lethal effects including adult pre-spawn mortality, reduced fecundity, egg and embryo mortality, and include increased transmission or susceptibility to disease. It is likely that temperatures exceeding suitable spawning temperatures limited available spawning habitat for adult SRFC returning to the Feather River in the high flow channel over much of their spawning period between 2011 and 2017 resulting in direct and indirect effects including pre-spawn mortality. To evaluate pre-spawn mortality, female SRFC carcasses encountered during the escapement survey were qualitatively checked for the presence of eggs. Between 2011 and 2017, adult pre-spawn mortality ranged from a high of 30.3 percent in fall of 2013 to a low 1.2 percent in fall of 2017, with a mean of 17.2 percent (Table 3.1.1.2.a). High levels of pre-spawn mortality were observed for the critical broods and regardless of cause resulted in a reduction in potential juvenile production.

As population density, temperatures, habitat availability, and other factors can influence pre-spawn mortality, it is difficult to directly correlate observed pre-spawn mortality with water temperatures alone. Although density dependent and other factors may be influencing observed rates in pre-spawn mortality, these data suggest that adult pre-spawn mortality frequently decreases potential juvenile production in the Feather River. It is likely that reduction of temperature-suitable spawning habitat, and a consolidation of spawners returning to habitat in close proximity to the hatchery, contributed to the observed elevated annual pre-spawn mortality during the 2012-2014 spawning seasons.

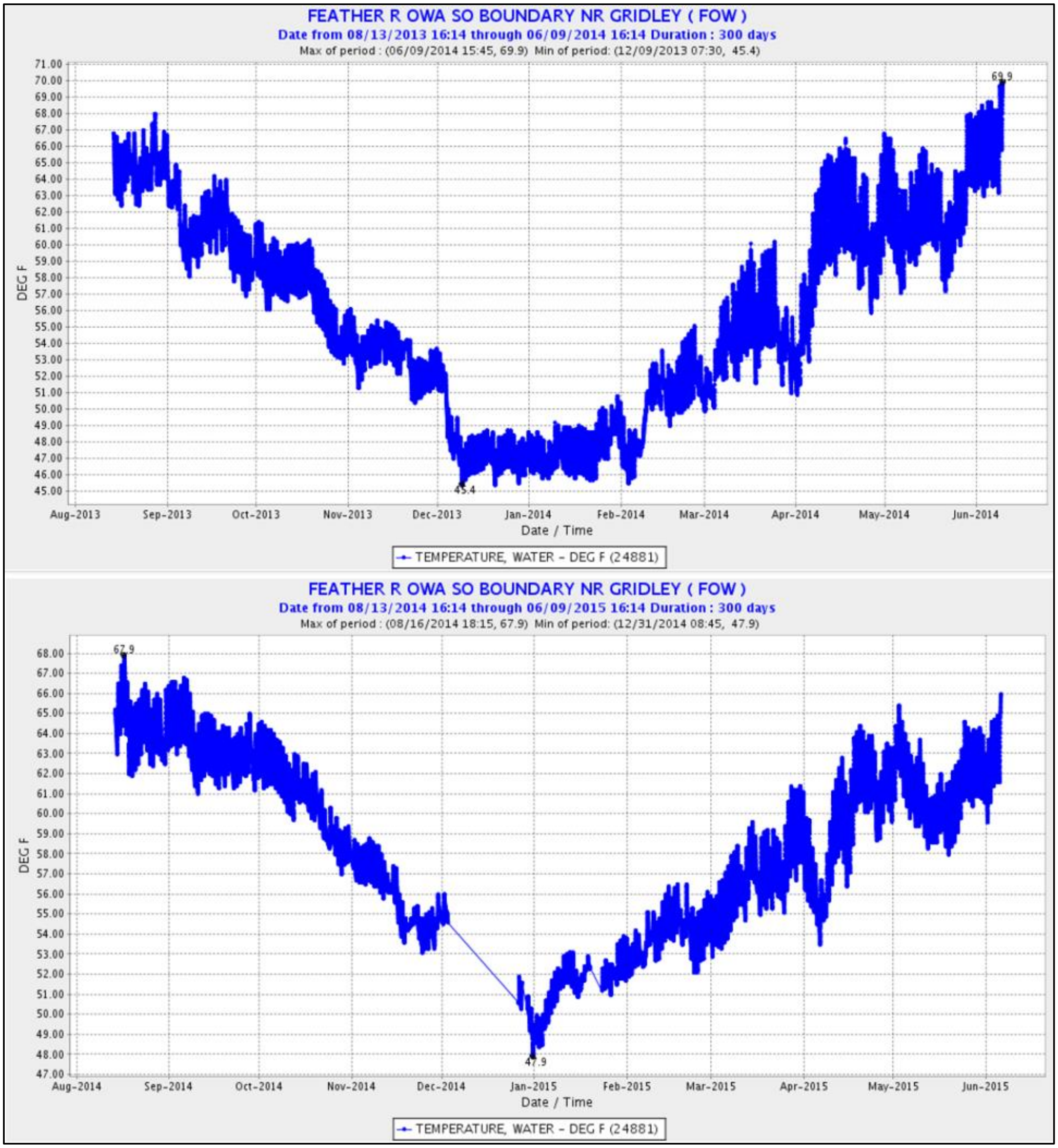

Figure 3.1.1.2.b. Feather River water temperatures (°F) downstream of the Thermalito Afterbay river outlet during the incubation, rearing, and outmigration periods for brood years 2013 and 2014. Temperatures affecting brood year 2012 were unavailable. Data was obtained from the CDWR gauge at the southern boundary of the Oroville Wildlife Area near Gridley, California.

Table 3.1.1.2.a. Total natural area escapement in the Feather River (including jacks) during 2011-2017, and the percentage of which that were estimated to have died prior to spawning.

Year	Feather River Natural Area Escapement[a/]	Percent Pre-spawn Mortality
2011	47,289	25.3%
2012	63,649	22.1%
2013	151,209	30.3%
2014	60,721	29.4%
2015	20,566	2.7%
2016	38,742	9.4%
2017	10,564	1.2%

a/ Spring-run Chinook are not distinguished from fall-run in the Feather River natural area spawning surveys, and thus are included in the escapement numbers reported here.

3.1.1.3 American River

The American River is the second largest tributary to the Sacramento River, a critical component of the San Francisco Bay/Sacramento-San Joaquin Delta ecosystem, and has historically contributed substantially to the overall SRFC stock. Folsom Reservoir on the American River is part of the Central Valley Project (CVP) and along with upstream diversions has altered flow and temperature regimes in the lower American River (LAR) from historical patterns and reduced available habitat (NMFS 2009a). During summer months, LAR water temperatures are controlled by blending warmer surface water in the reservoir with the reservoir's cold-water pool, utilizing temperature shutters at Folsom Dam. The timing and magnitude of reservoir releases affects how much cold-water pool is utilized to achieve LAR temperature targets throughout summer months. The disproportionate volume of reservoir cold-water pool needed to achieve summer temperature targets while releasing large volumes of stored water for CVP exports frequently exhausts cold-water pool storage prior to SRFC spawning, making it difficult to achieve suitable SRFC spawning temperatures. Over time, elevated water temperatures during the SRFC spawning period may be influencing spawn timing for American River-origin SRFC due to differential reproductive success of early versus late spawners.

As previously discussed, the effects of elevated water temperatures on Chinook salmon can be expressed in a variety of ways and direct measures of temperature impacts are often difficult to quantitatively assess. Bowerman et al. (2017) found that pre-spawn mortality increases with prolonged exposure to elevated water temperatures particularly in systems with high hatchery influence. Water temperatures in late October and early November are frequently over 60° F in the LAR and likely increase adult pre-spawn mortality. It is likely that adult pre-spawn mortality and direct egg and embryo mortality substantially decreased juvenile production in the LAR during 2012 through 2015. Additional flow-related impacts likely exacerbated temperature-related reductions in juvenile production (see section 3.1.9).

To evaluate pre-spawn mortality on the American River, female SRFC carcasses encountered during the escapement survey were qualitatively checked for the presence of eggs. The level of egg retention was determined by inspecting the abdominal cavity. Females are assumed to be unspawned if >70% of eggs are present, partially spawned if 30-70% of eggs are present, or spawned if <30% of eggs are present. Figure 3.1.1.3.a shows a trend from 2013 through 2015 where the majority of female carcasses encountered during the first 2-3 weeks of the survey (last two weeks of October and first week of November) were unspawned transitioning to fully spawned as the season progressed. As population density, temperatures, habitat availability, and other factors can influence pre-spawn mortality, it is difficult to correlate observed pre-spawn mortality with water temperatures alone. Regardless of cause, however, all years evaluated show a reduction in potential juvenile production due to pre-spawn mortality. As 2013 had the largest adult escapement to the LAR and 2014 had the warmest water temperatures during the time period in question (2013-2015), it is likely that these were contributing factors to the observed pre-spawn mortality during those years.

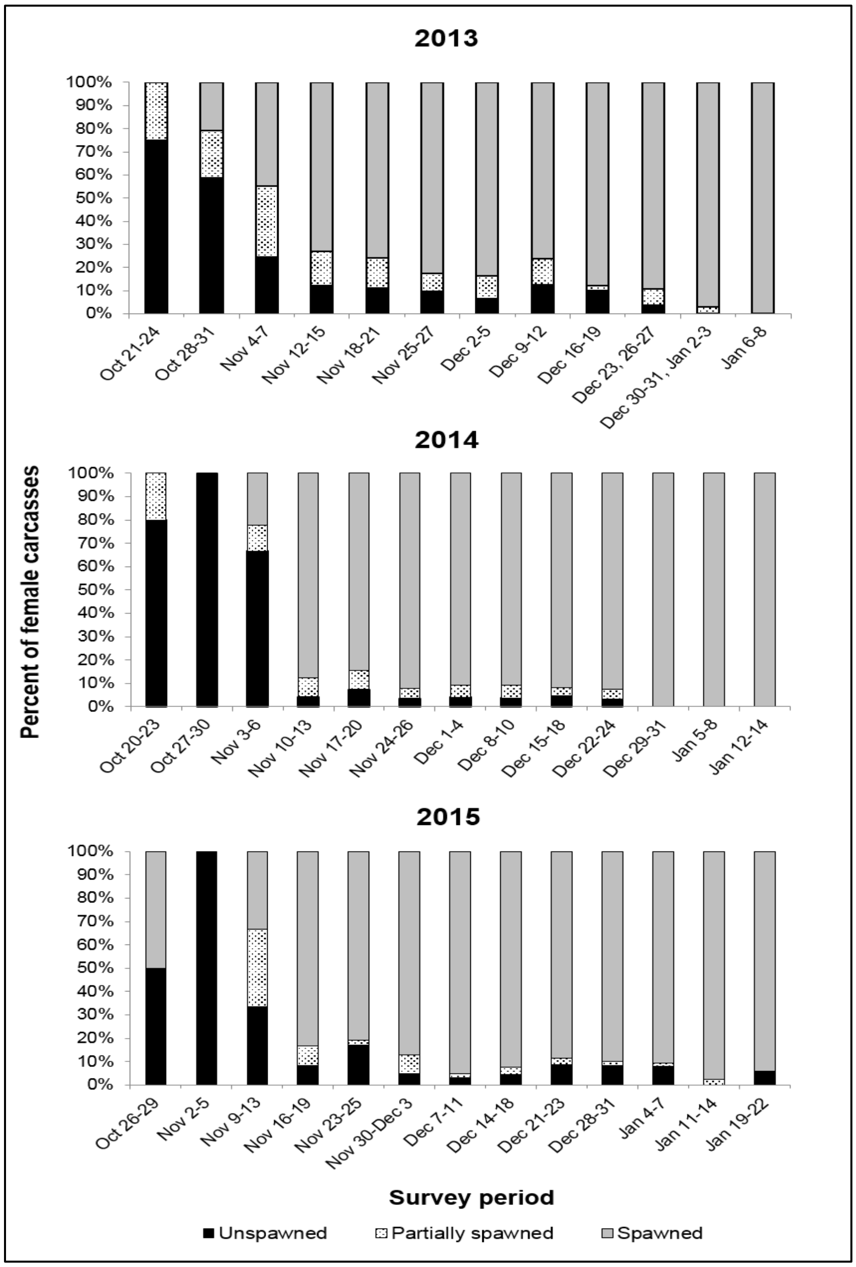

Figure 3.1.1.3.a. Estimated proportions of unspawned (>70% of eggs present), partially spawned (30-70% of eggs present), and spawned (<30% of eggs present) female SRFC carcasses in the American River natural area surveys during the 2013-2015 spawning seasons.

The American River has a long history of elevated water temperatures and from 2012 to 2016, water temperatures in excess of 56° F occurred during the SRFC spawning period (Figure 3.1.1.3.b), likely resulting in egg and embryo mortality. Chinook salmon spawning at 60° F is often associated with loss of eggs during these periods, caused by mortality in eggs and developing embryos (Snider and Vyverberg 1995). In the LAR, Chinook salmon eggs incubated in water temperatures above 62° F resulted in 100 percent mortality, eggs incubated in water at 60-62° F had 50 percent mortality to the eyed stage, and eggs incubated in 55-59° F experienced 20 percent mortality (Hinze 1959). When eggs were taken at water temperatures of 60-62° F and incubated at cooler temperatures of 55-56° F there was still a 30 percent loss by the eyed egg stage of development. In the Sacramento River, Chinook salmon eggs and fry exposed to water temperatures ranging from 43.5-63.0° F showed similar results. Mortalities of 80 percent or more were observed when fingerlings were incubated in water temperatures of 60-61° F (Healey 1979). Martin et al. (2017) showed that egg size in fish strongly influences oxygen uptake. As a consequence, lab-based assessments can underestimate temperature-related egg mortality, and salmon egg mortality in the natural environment may be occurring at temperatures as low as 53.6° F. Brood year 2014 experienced especially poor conditions as water temperatures were not consistently below 60° F until December 6. Temperatures in 2015 and 2016 did not contribute to the current overfished status since the progeny of those broods did not return as adults until 2018 and later, but high temperatures are likely to hinder rebuilding in the short term. Similar examples of poor freshwater conditions outside of the critical years are provided in other sections of this plan, and while they cannot be considered causative factors for the current status, they are still noteworthy and critical to rebuilding. Water temperature data were collected by the USGS at the William B. Pond gauging station.

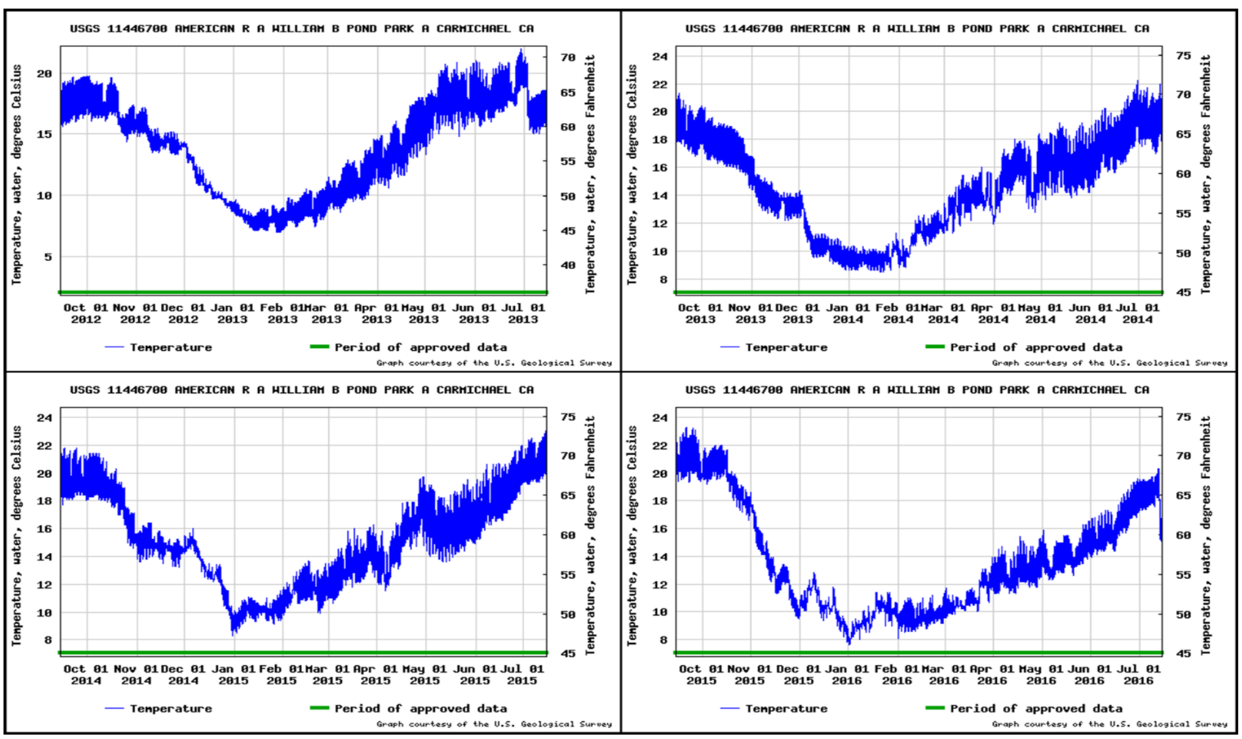

Figure 3.1.1.3.b. American River water temperatures (°C on the left axis, °F on the right axis) during the incubation, rearing, and outmigration periods for brood years 2012-2015. Data was obtained from the USGS gauge at William B. Pond Park near Carmichael, California.

Estimates of egg-to-fry survival in the LAR highlight how poor natural production has been. From 2012 through 2016, egg-to-fry survival estimates in the LAR have ranged from 1.3 to 7.3 percent (PSMFC 2014a, 2014b, Silva and Bouton 2015) (Table 3.1.1.3.a). Based on scientific literature review, at least 10 percent freshwater survival was needed to stabilize or recover Chinook salmon to viable population levels in North American west coast rivers (Anchor QEA 2016, BDCP 2012, Quinn 2005).

Table 3.1.1.3.a. Lower American River SRFC egg-to-fry survival estimates from rotary screw traps for brood years 2012-2016.

Brood Year	Survival Rate	Number of Female Spawners
2012	6.8%	23,383
2013	1.3%	28,215
2014	2.2%	12,429
2015	7.3%	6,153
2016	4.4%	3,580

Adult SRFC returns to LAR natural areas have dropped precipitously between 2013 and 2017 from a high of 52,631 in 2013 to a low of 5,742 in 2017. This concerning trend is likely a response to pre-spawn mortality and poor egg-to-fry survival. When returns of hatchery-produced SRFC and stray salmon from other tributaries are factored in using CWT recovery data, it becomes quite clear that poor natural production in the LAR is dramatically affecting adult returns and is decreasing LAR contributions to the ocean sport and commercial fisheries, a considerable economic impact to the fishing industry. Low adult returns to the LAR and few naturally-produced fish are also influencing the ability of Nimbus Fish Hatchery to produce SRFC associated with mitigation for Folsom Dam. As an integrated hatchery, naturally-produced fish must be incorporated into broodstock at acceptable levels to prevent hatchery operations from genetically influencing the natural population and allow for local area adaptation (CA HSRG 2012).

3.1.2 Parental spawner abundance

For the 2012-2014 critical broods, parental spawner escapement to hatcheries and natural areas was near or above the average over years 1970-2017 and well above the S_{MSY} of 122,000 adults (see Table B-1 in PFMC 2018b).

Estimates of the number of female spawners above Red Bluff Diversion Dam (RBDD) are reported in Voss and Poytress (2017). Excluding the 2002 and 2003 high escapement years, the average number of female spawners above RBDD has been 24,400 fish (Figure 3.1.2.a). The number of female spawners in brood years 2012-2014 were above this average, ranging from 32,600 to 39,400 across these brood years.

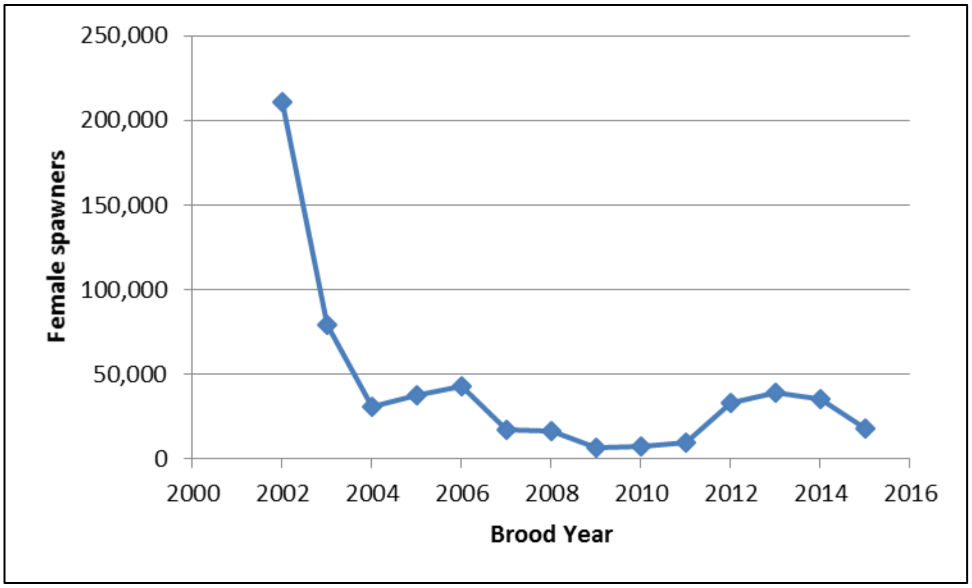

Figure 3.1.2.a. Estimates of the number of female spawners above Red Bluff Diversion Dam (from Voss and Poytress 2017).

3.1.3 Juvenile Production Estimates

Since 2002, USFWS has used screw traps attached to RBDD to estimate juvenile SRFC passage (Voss and Poytress 2017). These estimates represent a fry-equivalent juvenile production index (JPI) that provides a useful measure of juvenile productivity above RBDD (Figure 3.1.3.a). Across brood years 2002-2015, the average JPI has been 18.5 million fry. Brood years 2012 and 2013 were well-above average, but brood year 2014 was the lowest value recorded for the JPI.

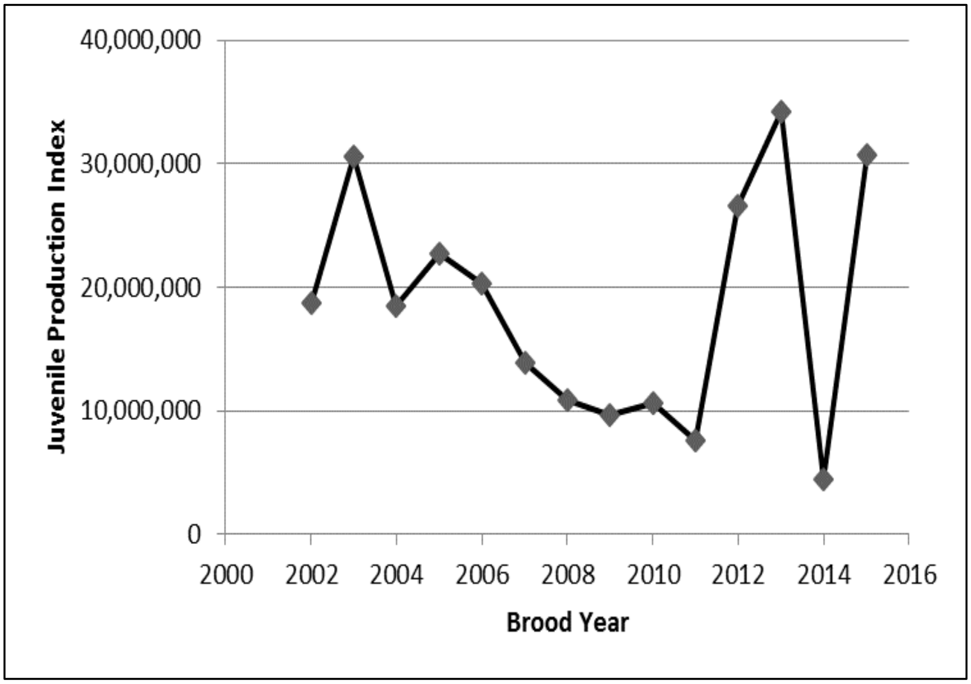

Figure 3.1.3.a. Fry-equivalent Juvenile Production Index estimates of SRFC production above RBDD across brood years 2002-2015 (Voss and Poytress 2017).

Since 1995, CDFW has used rotary screw traps at Knights Landing to track emigrating juvenile SRFC passage into the Sacramento-San Joaquin Delta. Passage estimates for the Knights Landing screw traps followed similar trends to those observed at RBDD for brood year 2013 through 2016 outmigrants, with a substantial reduction in passage observed for brood year 2014 (Table 3.1.3.a). Data for brood year 2012 were not available.

Table 3.1.3.a. Juvenile SRFC passage estimates at Knights Landing for brood years 2013 -2016.

Brood Year	Smolts (in millions)
2013	25.8
2014	3.2
2015	19.7
2016	11.4

3.1.4 Disease

In addition to influencing pre-spawn mortality and available suitable spawning habitat, elevated temperatures and stable low reservoir releases in the Feather River have likely contributed to disease infectivity and disease contraction in juvenile SRFC. Since 2012, pathogens *Ceratonova shasta* (*C. shasta*) and *Parvicapsula minibicornis* (*P. minibicornis*) have been monitored by USFWS in collaboration with CDWR and CDFW. Between 2012 and 2016 (January-May), a pattern of *C. shasta* and *P. minibicornis* infectivity was observed and likely affected a large proportion of the emigrating population. *C. shasta* was detected in 35 percent, 58 percent, and 46 percent of the juveniles collected in spring of 2014, 2015, and 2016, respectively (Foott 2014, Foott et el. 2016, Foott and Imrie 2016). Pathogen monitoring was also conducted on the Sacramento River in spring of 2013 and 2014 (Foott 2013, 2014). In 2013, asymptomatic infections of *C. shasta* and *P. minibicornis* were observed in 62 natural Sacramento River Chinook juveniles collected from Red Bluff to Tisdale (Foott 2013). In 2014, *C. shasta* infection was detected in juvenile Chinook salmon collected from the lower Sacramento River at a rate of 74 percent (Foott 2014). It is therefore likely that infectivity in the Sacramento River was high for natural-origin SRFC juveniles during drought conditions in 2013, 2014, and likely 2015, leading to reduced fitness and outmigration success for juvenile SRFC.

As referenced above, warm water releases from the Thermalito Afterbay river outlet (RM 59) on the Feather River frequently result in temperatures that exceed optimal spawning temperatures for SRFC in October downstream of the outlet. This likely compresses adult spawners into available temperature suitable spawning habitat upstream of the outlet at least for a portion of the spawning window. Pathology data suggested a zone of high infectivity was likely present in the high flow channel downstream of the Afterbay river outlet (Foott 2014). In both 2015 and 2016 a zone of high *C. shasta* infectivity was present beginning near the confluence of RM 59 and extended downstream to at least RM 45, according to reports provided by the USFWS California-Nevada Fish Health Center (Foott et al. 2016, Foott and Imrie 2016).

It is reasonable to assume that if a majority of adults spawn in the low flow channel (upstream of RM 59), and their progeny must emigrate through a zone of high *C. shasta* infectivity, then in-river juvenile production would be severely reduced. For brood years 2012 through 2015, passage estimates within the high flow channel (RM 45.8) were substantially lower than estimates of passage at the low flow channel rotary screw trap at RM 61 (Table 3.1.4.a). These data suggest that the emigrating juvenile populations of brood years 2012-2015 were reduced by an average of 48 percent in only 15 miles of habitat. While some loss due to predation and other causes would be expected between the two sampling locations, the magnitude of loss suggests that disease severely reduced in-river production in the Feather River and that there was no appreciable spawning downstream of RM 61. If successful spawning occurred downstream of RM 61 during 2012 through 2015, it did not occur in sufficient magnitude to offset the observed losses. It is worthwhile noting that in spring of 2018 (brood year 2017), only 1.9 million juveniles were estimated to have passed the low flow channel rotary screw trap (RM 61). This is the lowest passage estimate during the 2012-2018 period and suggests that short-term stock rebuilding may need to rely more heavily on hatchery production than natural production from the Feather River.

It is generally accepted that in order to develop an infectious zone the following factors need to coincide: low velocity, unvaried flows in close proximity to spawning areas (myxospore input), and temperatures above 54-59° F (12-15° C). It is also worth noting that due to reoccurring pathogen issues documented on the Feather River, pulse flows similar to those mandated on the Klamath River (*HVT v. NMFS* 2017) may be prudent to help with stock rebuilding and maintenance.

Table 3.1.4.a. Sacramento River fall Chinook juvenile passage estimates in the Feather River and the estimated mortality during downstream migration, brood years 2011-2015.

Brood Year	Juvenile Passage Estimate at River Mile 61.0	Juvenile Passage Estimate at River Mile 45.8	Percent Reduction
2011	9,902,393	9,271,622	6%
2012	26,254,553	13,871,128	47%
2013	27,645,796	23,888,112	14%
2014	19,087,391	7,516,495	61%
2015	10,025,589	2,994,935	70%

3.1.5 Stock and recruitment

Stock-recruitment relationships are used to characterize the relationship between the number of parental spawners and their progeny. The number of progeny produced per spawner is typically highest at low spawner abundances and declines with increasing spawner abundance due to density-dependent effects (e.g., redd superimposition at high spawner densities). In addition to quantifying density-dependent effects, stock-recruitment relationships are also useful for quantifying density-independent effects (e.g., water temperature during egg incubation). Density-independent effects can be indexed by examining the residuals[1] from a stock-recruitment relationship, with negative residuals representing lower than expected recruitment given the number of parental spawners, and positive residuals representing higher than expected recruitment given the number of parental spawners. For these reasons, stock-recruitment relationships provide a useful framework for characterizing the levels of density-dependence alongside density-independent effects in a population.

[1] Residuals are the differences between the observed $\log_e$ (recruits/spawners) and the predicted $\log_e$ (recruits/spawners) from the stock-recruitment relationship. In this application, recruits are the Juvenile Production Index and spawners are the number of female spawners.

The estimated number of spawners upstream of RBDD and the JPI estimates calculated from RBDD passage provide the necessary components for examining the stock-recruitment relationship for the Sacramento River and its tributaries upstream of RBDD (Figure 3.1.5.a). The Ricker stock-recruitment function that was fit to these data indicated that the juvenile production index increases with increased spawner abundance with maximum average juvenile production at approximately 80,000 female spawners, that there was a moderate amount of density-dependence at higher spawner abundances, and that there was a relatively low amount of density-independent variation.

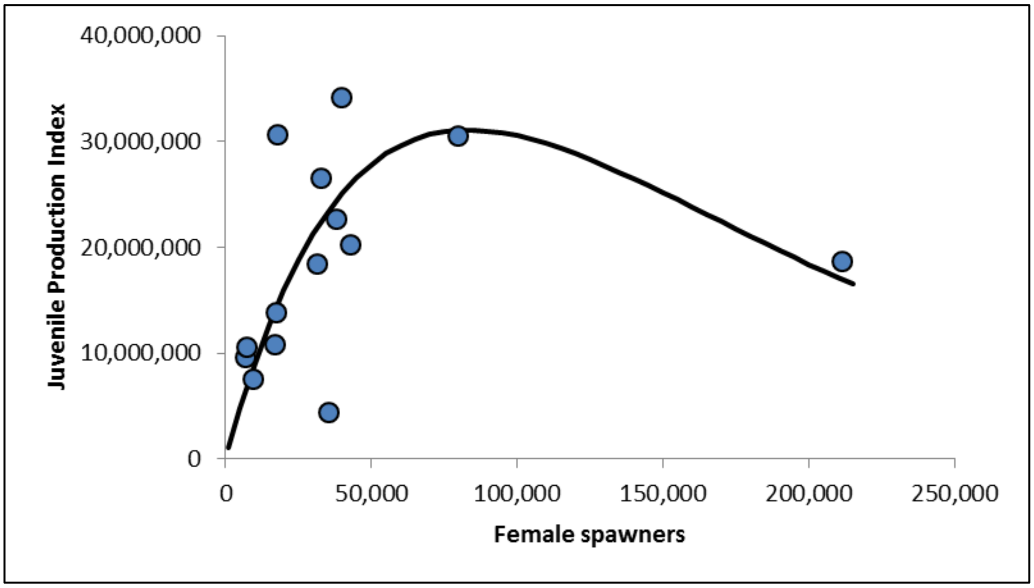

Figure 3.1.5.a. Estimates of the number of the total number of female spawners above RBDD and the fry-equivalent juvenile production index for brood years 2002-2015. The line represents the Ricker stock-recruitment function that was fit to the data.

As mentioned above, the residuals from the fitted stock-recruitment relationship characterize the density-independent factors influencing productivity, with negative residuals indicating lower-than-expected recruitment given spawner abundance and positive residuals indicating higher-than-expected recruitment given spawner abundance. Examining the residuals for the fitted stock-recruitment function for SRFC data indicated that brood years 2012 and 2013 had slightly higher-than-expected recruitment given female spawner abundance, but brood year 2014 had dramatically lower-than-expected recruitment given the number of female spawners that year (Figure 3.1.5.b).

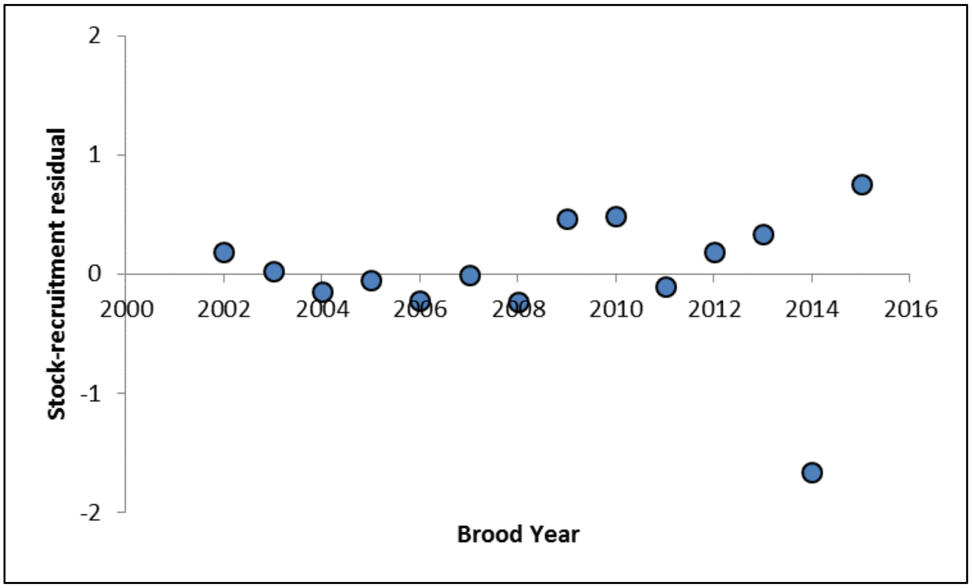

Figure 3.1.5.b Residuals from the fitted stock-recruitment relationship by brood year for the Sacramento River above RBDD.

3.1.6 Hatchery production

As described earlier, hatchery production of SRFC comes from Coleman National Fish Hatchery (CNFH), operated by USFWS, and from Feather River Hatchery (FRH) and Nimbus Fish Hatchery (NFH), operated by CDFW. CNFH is located on Battle Creek, a tributary near the upper limit of anadromy in the mainstem, and smolts are typically released directly into the creek. However, in response to severe drought conditions in the Sacramento River, brood years 2013 and 2014 had 62 percent and 100 percent of their smolts, respectively, trucked to the delta and released into net pens. At FRH, all of the fall-run production is trucked (or sometimes barged) and released into net pens in the delta and San Pablo/San Francisco Bay, as well as coastal net pens located in Half Moon Bay and Santa Cruz. NFH is located on the American River, upstream of the city of Sacramento. A portion of the production at NFH is always trucked to the delta or bay and released into net pens, although in most of the recent years the majority of smolts have been released into the American River. However, the 2013 and 2014 broods were entirely trucked to San Pablo Bay for release, again due to extreme drought conditions in-river. Figure 3.1.6.a shows the percentages of the total annual SRFC hatchery releases (all three hatcheries combined) that were trucked offsite prior to release for the 2006-2014 broods. Offsite releases have returned to more standard levels since the 2014 brood. The effects of these offsite releases for CNFH and NFH are discussed in Section 3.1.7.

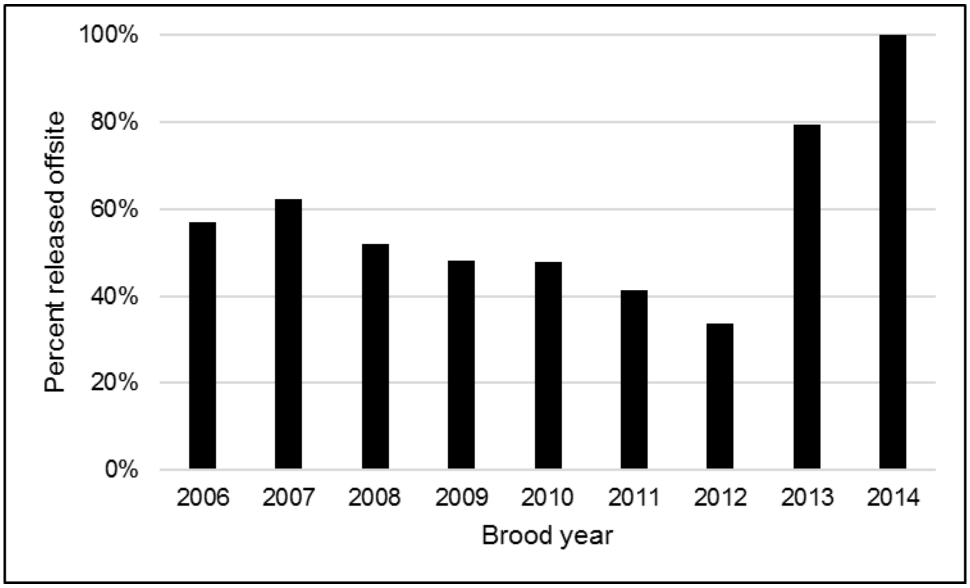

Figure 3.1.6.a. Percentages of the total annual SRFC hatchery releases that were transported offsite via truck prior to release, brood years 2006-2014.

Table 3.1.6.a shows the total number of SRFC smolts released annually from each hatchery for brood years 2000-2014. For all three facilities, annual release numbers during the brood years that contributed to the overfished status were lower than the 2000-2011 averages. While CNFH and NFH released on average 800-900 thousand fewer smolts during the critical years, the difference was even greater at FRH with an average of 2.8 million fewer smolts released. There was increased mortality at FRH for the 2013 and 2014 broods due to an egg fungus, and this reduced production during those years, especially for the 2014 brood. Variability in enhancement releases, which are separate from mitigation release targets, also factored into the reduced production at FRH as compared to earlier broods. Across years, enhancement release targets have shifted between FRH and the Mokelumne River Hatchery, which is outside of the Sacramento Basin and thus not included as a component of the SRFC stock. FRH enhancement releases have been as high as 4 million SRFC smolts, but the release target at FRH was only 2 million during the critical years. Additionally, FRH did not come close to meeting that target for any of those broods, especially 2013 and 2014 due to the egg fungus issue previously mentioned. Across the three hatcheries in Table 3.1.6.a, the combined reduction in SRFC production during the critical years was substantial. On average, approximately 4.5 million fewer smolts were released annually for the 2012-2014 broods as compared to the 2000-2011 broods, which is a 17 percent reduction.

Table 3.1.6.a. Numbers of SRFC smolts released from Coleman National Fish Hatchery (on Battle Creek), Feather River Hatchery, and Nimbus Fish Hatchery (on the American River) for the 2000-2014 broods.

Brood Year	Coleman National Fish Hatchery	Feather River Hatchery	Nimbus Fish Hatchery	Total SRFC Smolts Released
2000	12,664,580	5,036,622	4,375,806	22,077,008
2001	11,318,028	6,743,911	4,222,082	22,284,021
2002	14,018,806	8,137,445	4,361,300	26,517,551
2003	13,101,565	8,549,876	4,578,400	26,229,841
2004	11,854,153	8,996,680	4,570,000	25,420,833
2005	13,355,345	10,347,148	3,002,600	26,705,093
2006	12,316,193	9,785,968	6,130,383	28,232,544
2007	12,699,100	10,148,313	6,931,264	29,778,677
2008	14,021,126	8,351,309	4,194,887	26,567,322
2009	11,569,461	9,719,123	4,612,769	25,901,353
2010	12,709,391	10,552,142	4,855,599	28,117,132
2011	12,508,161	10,012,097	4,805,043	27,325,301
2012	**11,875,014**	**6,952,929**	**4,012,500**	**22,840,443**
2013	**11,780,007**	**6,632,534**	**3,587,565**	**22,000,106**
2014	**11,846,951**	**4,578,358**	**3,932,549**	**20,357,858**
2000-2011 avg.	12,677,992	8,865,053	4,720,011	26,263,056
2012-2014 avg.	11,833,991	6,054,607	3,844,205	21,732,802

3.1.7 Effects of offsite hatchery releases on straying and in-river harvest

As discussed in the previous section, all SRFC hatchery production for brood year 2014, and most of the brood year 2013 production, was trucked offsite and released into delta, bay, or coastal net pens. For CNFH specifically, there was much concern over the decision to truck their smolts to the delta during those years. Returning spawners from offsite CNFH releases have been shown to stray at high rates, more so than the other two Sacramento Basin hatcheries. SRFC released onsite at CNFH have a high tendency to return to the upper Sacramento Basin, where they originated, with minimal straying (estimated between 0 and 6 percent). In contrast, SRFC produced at CNFH but trucked to downstream release sites have been found spawning in every accessible sub-basin within the Central Valley, with observed stray rates ranging from 73 to 98 percent. Trucked releases from FRH and NFH have not been observed straying nearly to the extent of trucked CNFH releases, with stray rates typically in the vicinity of 5-25 percent (Kormos et al. 2012, Palmer-Zwahlen and Kormos 2013, Palmer-Zwahlen and Kormos 2015, Palmer-Zwahlen et al. 2018). Still, even with the substantial straying risk, particularly for CNFH releases, trucking smolts was deemed necessary during those drought years due to the highly degraded in-river conditions.

Straying has traditionally been defined for SRFC as fish spawning outside of their respective hatchery's sub-basin (i.e., outside of the upper Sacramento, Feather, and American basins for CNFH, FRH, and NFH, respectively), and the stray rates reported above were calculated in this manner (Kormos et al. 2012, Palmer-Zwahlen and Kormos 2013, Palmer-Zwahlen and Kormos 2015, Palmer-Zwahlen et al. 2018). However, MSST for SRFC is based on the pooled adult escapement to the entire Sacramento Basin. Therefore, straying spawners do not necessarily contribute to an overfished status unless they stray to the San Joaquin Basin or outside of the Central Valley altogether. For example, SRFC produced at CNFH that spawn in the Feather or American basins, while technically straying, are still counted toward total SRFC escapement.

However, if straying affects their migratory behavior and increases their susceptibility to in-river harvest, it could affect overall escapement and thus contribute to an overfished status. Table 3.1.7.a presents preliminary estimates for numbers of adult SRFC from each hatchery (with CNFH and NFH broken out into onsite and offsite releases) that returned to the Central Valley, strayed into the San Joaquin Basin, were harvested in-river, and ultimately escaped to Sacramento Basin spawning areas (hatchery and natural) during 2015-2017. Brood year 2014, which was entirely released offsite for all three hatcheries, contributed to adult escapement in 2017 as age-3 spawners. Brood year 2013, which was mostly released offsite (38 percent of the CNFH production was still released at the hatchery), contributed to adult escapement in 2016 (age-3) and 2017 (age-4). Neither of these broods were old enough to be considered adults in 2015.

Table 3.1.7.a. Preliminary estimates for numbers of hatchery-origin adult SRFC from Coleman National Fish Hatchery, Nimbus Fish Hatchery, and Feather River Hatchery that returned to the Central Valley, strayed into the San Joaquin Basin, were harvested in-river, and escaped to Sacramento Basin spawning areas (hatchery and natural) during 2015-2017. Estimates for Coleman and Nimbus are further broken out into onsite and offsite releases.

2015	Total Central Valley Run	Strays into San Joaquin Basin	*% of total Central Valley run that strayed into San Joaquin Basin*	Total Sacramento Basin Run	Sacramento Basin In-river Harvest	*% of total Sacramento Basin run that was harvested in-river*	Sacramento Basin Escapement
Coleman - onsite	16,890	0	*0%*	16,890	2,806	*17%*	14,084
Coleman - offsite[a/]	38	0	*0%*	38	0	*0%*	38
Nimbus - onsite	6,957	0	*0%*	6,957	796	*11%*	6,161
Nimbus - offsite	4,423	420	*9%*	4,003	1,082	*27%*	2,921
Feather River[b/]	53,012	514	*1%*	52,498	5,683	*11%*	46,815
2016							
Coleman - onsite	9,815	0	*0%*	9,815	1,931	*20%*	7,884
Coleman - offsite	19,879	767	*4%*	19,112	8,513	*45%*	10,599
Nimbus - onsite	1,031	0	*0%*	1,031	127	*12%*	904
Nimbus - offsite	11,411	1,442	*13%*	9,969	3,065	*31%*	6,904
Feather River[b/]	39,598	110	*0%*	39,488	5,012	*13%*	34,476
2017							
Coleman - onsite	434	0	*0%*	434	43	*10%*	391
Coleman - offsite	16,263	2,832	*17%*	13,431	5,954	*44%*	7,477
Nimbus - onsite[c/]	14	0	*0%*	14	0	*0%*	14
Nimbus - offsite	12,830	4,350	*34%*	8,480	2,838	*33%*	5,642
Feather River[b/]	29,780	912	*3%*	28,868	8,827	*31%*	20,041

a/ Brood year 2010 (age-5) was the only brood with offsite Coleman releases that contributed to adult escapement in 2015.

b/ All Feather River Hatchery releases were conducted offsite.

c/ Brood year 2012 (age-5) was the only brood with onsite Nimbus releases that contributed to adult escapement in 2017.

During the three years that contributed to the overfished status, no adults from onsite-releases were estimated to have strayed into the San Joaquin Basin. It was markedly different for offsite releases, however, and adults returning from offsite NFH releases actually strayed into the San Joaquin Basin at higher rates than those returning from offsite CNFH releases. Stray rates generally increased each year during 2015-2017, and they were particularly high in 2017. That year, approximately one third of the adults returning from offsite NFH releases strayed into the San Joaquin Basin. It was also high for offsite CNFH releases at 17 percent, and between all three hatcheries in 2017, over 8,000 adults strayed into the San Joaquin Basin and were lost from SRFC escapement. In 2016, 13 percent and 4 percent of the adult spawners returning from offsite NFH and CNFH releases, respectively, strayed into the San Joaquin Basin. Adults returning from FRH, where all releases were offsite, did not stray into the San Joaquin Basin at particularly high rates during any of the critical years.

Offsite-released fish were noticeably more prone to harvest once inside the Sacramento Basin. Adults returning from offsite CNFH releases were harvested at especially high rates in 2016 and 2017, at slightly less than half. During those same years, approximately one third of the adults returning from offsite NFH releases were harvested in-river, and FRH-origin adults had a similarly high harvest rate in 2017. Prior to 2016, the basin-wide harvest rate in the river sport fishery averaged 14 percent annually. Although the high harvest rates in Table 3.1.7.a only pertain to hatchery-origin SRFC, they are symptomatic of a larger problem as the entire SRFC stock experienced elevated in-river harvest rates during 2016 and 2017, largely due to the migratory behavior of spawners returning from offsite hatchery releases. While the salmon being discussed here did return to the greater Sacramento Basin, and thus had the possibility of contributing to SRFC escapement, there was a great deal of sub-basin straying, particularly with CNFH-origin salmon straying into the Feather and American basins. The data aren't presented here, but preliminary results indicate that straying outside of the upper Sacramento Basin was greater than 90 percent for offsite-released CNFH adults returning in 2016 and 2017, in line with the rates reported for earlier return years (Kormos et al. 2012, Palmer-Zwahlen and Kormos 2013, Palmer-Zwahlen and Kormos 2015, Palmer-Zwahlen et al. 2018). Since the majority of CNFH-origin SRFC returning during those two years were from offsite releases, this created a large shift in sport fishing effort away from the upper Sacramento Basin and into the Feather and American basins, due to a severe lack of fish returning to upper Sacramento areas. Focusing fishing pressure in the areas where most of the fish were returning likely resulted in increased harvest rates on all SRFC regardless of origin, and basin-wide harvest rates did exceed historical rates in 2016 (21 percent), and even more so in 2017 (36 percent). SRFC adult escapement was sharply reduced during those two years as a result of these increased harvest rates. Section 3.3.2 provides more details on in-river harvest, and specifically the shift in fishing effort during 2016 and 2017.

3.1.8 Hatchery-origin contributions to natural area escapement and inland harvest

Since hatchery production of SRFC has remained relatively constant, comparing the annual proportions of hatchery-origin fish in natural spawning areas and inland harvest can help elucidate the relative strength of the natural component of the stock. For example, if a particular sub-basin's natural area escapement is almost entirely comprised of hatchery-origin fish, it may indicate very low survival among the natural component of those broods due to conditions that the hatchery component was able to avoid. Table 3.1.8.a provides preliminary estimates of hatchery-origin contributions to SRFC natural area escapement and harvest in the upper Sacramento River mainstem, Feather River, and American River, as well as harvest in the lower Sacramento River mainstem (no escapement data available for this sector) during 2015-2017. Tributary data is not included in this analysis due to inconsistences in available data between years. CDFW has been analyzing hatchery-origin contributions to Central Valley escapement and harvest since return year 2010, and reports are currently available for 2010-2013 which offer a means of comparison (see

Kormos et al. 2012, Palmer-Zwahlen and Kormos 2013, Palmer-Zwahlen and Kormos 2015, Palmer-Zwahlen et al. 2018). Table 3.1.8.b summarizes the hatchery- and natural-origin contributions from those reports, for the same sectors that were analyzed for 2015-2017. A common result across the CDFW reports is that hatchery-origin fish routinely make up the majority of natural area escapement and harvest, and at various levels of escapement. SRFC escapement was higher during 2010-2013 than during the years that contributed to the overfished status, although it was not incredibly high during 2010 and 2011 when 124,270 and 119,342 adults, respectively, returned to Sacramento Basin hatcheries and natural areas. Escapement increased significantly in 2012 and even more so in 2013 when 285,429 and 406,200 adults returned, respectively (PFMC 2018b). It is important to note that adults were not analyzed separately in the CDFW reports, so the hatchery-origin proportions reported in Table 3.1.8.b include age-2 fish unlike the values presented below for 2015-2017.

Table 3.1.8.a. Preliminary estimates of natural- and hatchery-origin adults that contributed to natural area escapement and harvest in the upper Sacramento River mainstem, Feather River, and American River, and harvest in the lower Sacramento River mainstem (no escapement data available for this sector) during 2015-2017.

	Natural-origin Adults	Hatchery-origin Adults	Total Adults	Percent Hatchery-origin
Upper Sacramento River				
Natural Area Escapement				
2015	8,629	18,246	26,875	68%
2016	2,652	1,709	4,361	39%
2017	444	381	825	46%
In-river Harvest				
2015	1,807	5,258	7,065	74%
2016	1,091	1,696	2,787	61%
2017	1,496	97	1,593	6%
Feather River				
Natural Area Escapement				
2015	2,786	15,283	18,069	85%
2016	5,578	28,476	34,054	84%
2017	754	7,366	8,120	91%
In-river Harvest				
2015	0	1,839	1,839	100%
2016	763	3,456	4,219	82%
2017	93	6,673	6,766	99%
American River				
Natural Area Escapement				
2015	4,084	7,364	11,448	64%
2016	1,735	5,394	7,129	76%
2017	1,336	4,406	5,742	77%
In-river Harvest				
2015	657	3,573	4,230	84%
2016	2,413	10,101	12,514	81%
2017	0	8,166	8,166	100%
Lower Sacramento River				
In-river Harvest				
2015	1,302	2,432	3,734	65%
2016	92	4,243	4,335	98%
2017	2,083	3,458	5,541	62%

Table 3.1.8.b. Estimates of natural- and hatchery-origin SRFC that contributed to natural area escapement and harvest in the upper Sacramento River mainstem, Feather River, and American River, and harvest in the lower Sacramento River mainstem (no escapement data available for this sector) during 2010-2013. Values reported here are total numbers, not just adults, so they include age-2 SRFC. Data was obtained from Kormos et al. 2012, Palmer-Zwahlen and Kormos 2013, Palmer-Zwahlen and Kormos 2015, and Palmer-Zwahlen et al. 2018.

	Natural-origin Adults	Hatchery-origin Adults	Total Adults	Percent Hatchery-origin
Upper Sacramento River				
Natural Area Escapement				
2010	13,146	3,226	16,372	20%
2011	7,735	2,848	10,583	27%
2012	7,314	15,121	22,435	67%
2013	21,375	11,140	32,515	34%
In-river Harvest				
2010	1,310	770	2,080	37%
2011	5,059	14,912	19,971	75%
2012	7,883	17,642	25,525	69%
2013	7,018	13,929	20,947	66%
Feather River				
Natural Area Escapement				
2010	9,933	34,981	44,914	78%
2011	4,883	42,406	47,289	90%
2012	6,530	57,119	63,649	90%
2013	23,603	127,606	151,209	84%
In-river Harvest				
2010	326	868	1,194	73%
2011	703	3,515	4,218	83%
2012	2,551	9,760	12,311	79%
2013	3,591	9,058	12,649	72%
American River				
Natural Area Escapement				
2010	5,134	2,439	7,573	32%
2011	7,150	14,170	21,320	66%
2012	9,347	25,553	34,900	73%
2013	19,096	35,163	54,259	65%
In-river Harvest				
2010	0	375	375	100%
2011	1,118	20,293	21,411	95%
2012	5,128	18,435	23,563	78%
2013	3,663	6,304	9,967	63%
Lower Sacramento River				
In-river Harvest				
2010	61	1,947	2,008	97%
2011	2,806	12,094	14,900	81%
2012	3,142	16,674	19,816	84%
2013	7,615	12,874	20,489	63%

During 2015-2017, hatchery-origin fish contributed to natural area escapement in these sectors in proportions that were generally in line with what was presented in the CDFW reports (see Kormos et al. 2012, Palmer-Zwahlen and Kormos 2013, Palmer-Zwahlen and Kormos 2015, Palmer-Zwahlen et al. 2018). In the upper Sacramento River, hatchery-origin contributions to natural area escapement ranged from 20 to 67 percent during 2010-2013, and the percentages during the overfished years were mostly within this range (2015 was just outside at 68 percent). Given that offsite-released CNFH-origin SRFC are estimated to have strayed outside of the upper Sacramento Basin at greater than 90 percent during 2016 and 2017 as described in the previous section, it is not surprising that hatchery-origin fish composed much lower proportions of the natural area escapement in this sector during those two years as compared to 2015. Natural area spawners in the Feather River contained the highest proportions of hatchery-origin fish among the three sectors in each year, and this is also what was reported in the CDFW reports. During 2010-2013, hatchery-origin spawners composed between 78 and 90 percent of the Feather River's natural area escapement, and the percentages during 2015-2017 were mostly within this range (2017 was just outside at 91 percent). Natural area spawners in the American River displayed the largest deviation from the hatchery-origin contributions reported for 2010-2013, although the differences were still minimal. In the CDFW reports, hatchery-origin fish were present in American River natural spawning areas at rates between 32 and 73 percent. The hatchery-origin contribution in 2015 was within this range, but it was slightly higher during 2016 and 2017 at 76 and 77 percent, respectively.

Hatchery-origin contributions to inland harvest are more variable between years and sectors. The upper Sacramento River sport fishery adult harvest was comprised of relatively lower proportions of hatchery-origin fish as compared to the other sectors, and this was also observed during 2010-2013 (Kormos et al. 2012, Palmer-Zwahlen and Kormos 2013, Palmer-Zwahlen and Kormos 2015, Palmer-Zwahlen et al. 2018). During those years, hatchery-origin fish composed between 37 and 75 percent of the upper Sacramento River harvest, and the proportions during 2015 and 2016 were within this range. In 2017, however, the proportion decreased precipitously to 6 percent. This was, again, likely due to the extensive straying outside of the upper Sacramento Basin estimated for offsite-released CNFH-origin SRFC as described above. The primary brood contributing to the 2017 run was brood year 2014, which was the year CNFH trucked 100 percent of their production to the delta for release. In the Feather River, hatchery-origin contributions to inland adult harvest were at or near 100 percent during 2015 and 2017. This is well above the 2010-2013 range reported by CDFW of 72 to 83 percent, however the 2016 proportion was within this range. The 2017 American River adult sport harvest was also estimated to be comprised entirely of hatchery-origin fish, although this has been observed in the past as CDFW reported a range of 63 to 100 percent during 2010-2013. The hatchery-origin contributions to the 2015 and 2016 American River adult sport harvests were much lower and within the range observed by CDFW. The influx of offsite-released CNFH-origin SRFC into the Feather and American rivers, combined with the large shift in fishing effort to these sub-basins, likely contributed to the considerably high hatchery-origin contributions to sport harvest in these sectors during 2017. Section 3.3.2 provides more background on the effort shift observed in the Central Valley sport fishery during the overfished years. In the lower Sacramento River sport fishery, hatchery-origin fish composed only 65 and 62 percent of the adult harvest, respectively, in 2015 and 2017, near the bottom of the 2010-2013 range reported by CDFW of 63 to 97 percent. The 2016 sport harvest, however, was just above this range as 98 percent of the adults harvested were estimated to be of hatchery-origin. An important feature of the lower Sacramento River sport fishery is that anglers intercept SRFC returning to all three of the other sub-basins, since all fish entering the Sacramento Basin have to traverse through the lower Sacramento River. Thus, harvest and hatchery-origin contributions in this sector are highly influenced by the relative strengths of these different sub-stocks, making it difficult to interpret differences observed between years.

Although hatchery-origin contributions to adult harvest were elevated over previously reported proportions in select years and sectors, the same was not observed to any great extent among natural area spawners. While production as a whole was clearly weak for the broods that contributed to the overfished status, there is insufficient evidence to suggest that the relative contribution of natural production was any weaker than for the broods that contributed to the 2010-2013 escapements. However, what occurred during 2010-2013 may not be representative of other years, so this analysis could be strengthened in the future once additional years of data are available for comparison.

3.1.9 Other relevant factors

Drought actions and regulatory oversight of state and federal water project operations
On January 17, 2014, California Governor Jerry Brown issued a Drought Emergency Proclamation that directed the State Water Resources Control Board (Water Board) to consider petitions to modify established requirements for diversion and water quality including requirements relating to water quality objectives for the San Francisco Bay/Sacramento-San Joaquin Delta Estuary as was establish by Water Rights Decision-1641 for the State and Central Valley Water Projects. As a result, Temporary Urgency Change Petitions (TUCPs) and other associated actions were filed by CDWR and the U.S. Bureau of Reclamation (USBR) in 2014, 2015, and 2016 (see https://www.waterboards.ca.gov/waterrights/water_issues/programs/drought/tucp/).

CDWR and USBR requested that the Water Board consider modifying requirements of USBR's and CDWR's water right permits to enable changes in operations, and requested concurrence under federal biological opinions for the state and federal water projects. Petitions requested reduced delta outflow requirements to increase reservoir storage, along with associated modifications to delta water quality standards. In addition, TUCPs requested greater flexibility in CDWR and USBR operations of the Delta Cross Channel (DCC) gates to ensure freshwater supplies were maintained and to minimize salinity intrusion from San Francisco Bay. It was widely recognized that some of the requested modifications to standards and requirements could pose risks to fisheries resources. In response to these concerns, a drought operations plan was developed in 2014 to maximize regulatory flexibility to allow for swift adjustments in response to changes in the weather and environment to help bolster water supplies when possible while minimizing impacts to fish and wildlife (USBR and CDWR 2014). The 2014 plan called for increased monitoring in order to respond to the needs of state and federally listed fish species, and included a matrix of triggers for DCC gate operations to prevent entrainment of ESA-listed Sacramento River winter Chinook (SRWC) and Central Valley spring Chinook into the interior delta. Entrainment into the interior delta has been shown to slow emigration and increase loss rates of salmonids (USBR and CDWR 2014).

SRFC have evolved with and are adapted to high spring flows associated with snow melt. Drought conditions in 2013 through 2015 resulted in reduced reservoir releases affecting fall temperatures and spawning habitat availability, and also influenced conditions during juvenile outmigration. Reduced winter and spring flows resulted in elevated temperatures within emigration corridors, decreased food availability, increased energetic expenditure during emigration associated with slow water velocities, and increased risk of predation and disease contraction. The 2013-2015 drought likely impacted juvenile SRFC in several ways resulting in decreased recruitment to ocean fisheries and subsequent adult escapement. As SRFC are not state or federally listed, drought operations plans and triggers were not designed to be particularly protective of this stock. This extended to SRFC hatchery production and resulted in altered release strategies. For example, USFWS developed an alternate release plan for CNFH fall-run production which modified standard release strategies if downstream temperatures exceed certain thresholds and the DCC gates are open (USFWS 2014). Similar drought release strategies were developed for NFH. In both cases, thresholds were met in 2014 and all fall-run production was released into net pens in the delta or San Francisco Bay. While these actions may have improved survival of juveniles to ocean entry and increased recruitment to the ocean fisheries, they also drastically increased straying of returning adults. In the case of CNFH fall-run production, the rate of adult straying in fall of 2017 was high and the hatchery was unable to meet its production goal. This will likely influence the SRFC stock rebuilding timeline.

3.2 Marine survival

3.2.1 Review of ocean conditions

The California Current Large Marine Ecosystem, in which SRFC spend the majority of their ocean life history, spans nearly 3,000 km from southern British Columbia to Baja California. The California Current underwent an extreme warming event beginning in late 2014 with record high temperatures observed in 2015. During 2014-2015, an anomalously warm pool of water in the Gulf of Alaska, referred to as the “warm blob”, began affecting temperatures in more southerly areas inhabited by SRFC. An intense El Niño event in 2015 and 2016 also contributed to the record high sea surface temperatures (SSTs) observed in the California Current (Figure 3.2.1.a).

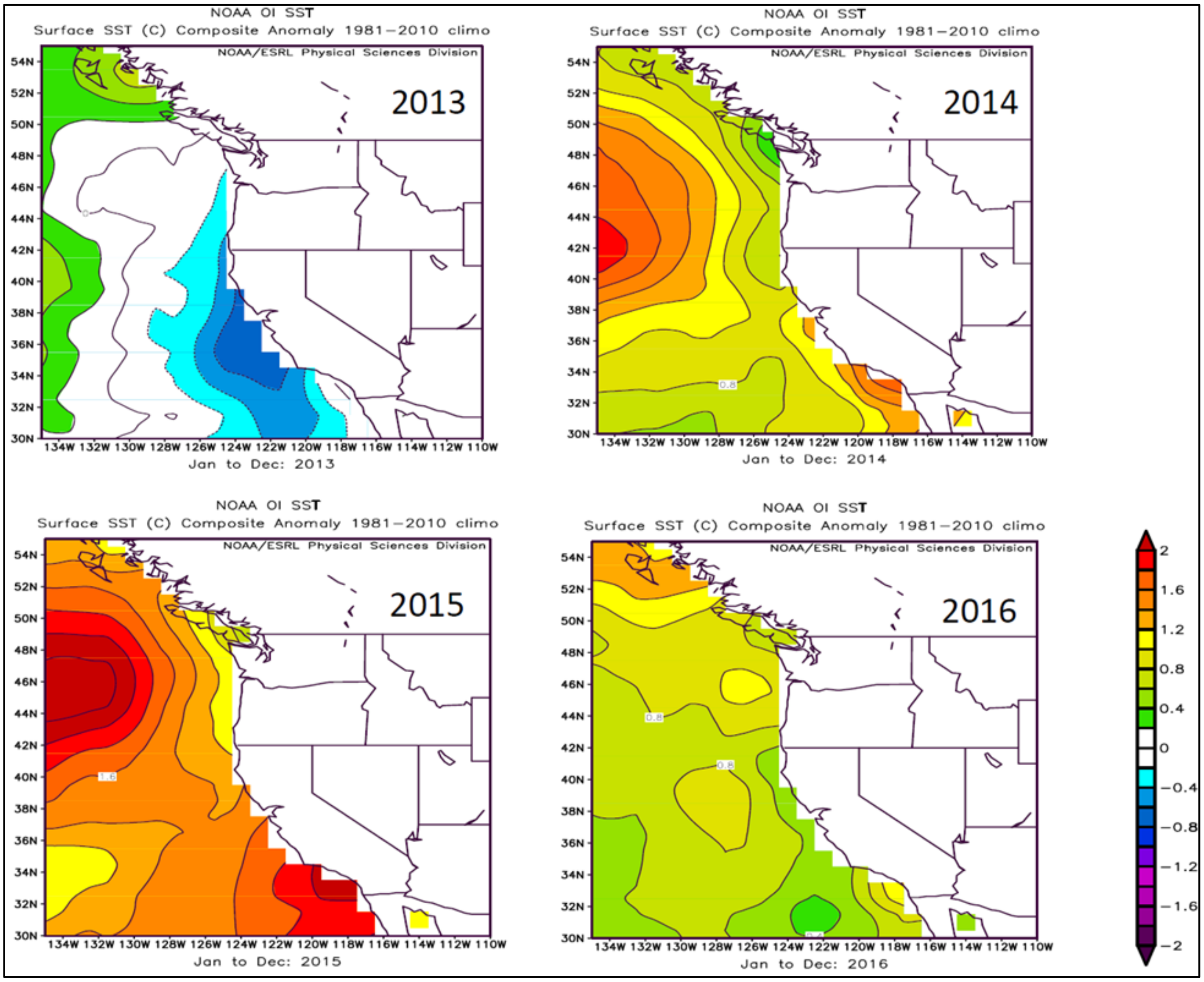

Figure 3.2.1.a. Annual sea surface temperature anomalies for years 2013-2016 (Nathan Mantua, NMFS, personal communication).

Large scale indices of ocean climate suggested generally unproductive conditions in the California Current beginning in 2014 and lasting through at least 2016. Figure 3.2.1.b displays time series for three relevant North Pacific climate indices.

The Oceanic Niño Index (ONI) is a three-month running mean of SST anomalies averaged over the eastern Pacific equatorial region that is used to gauge the state of the El Niño/Southern Oscillation (ENSO). The period from 2010 through late 2014 was generally neutral or cool. However, the period from late 2014 through mid-2016 was characterized by strongly positive (warm) SST anomalies that were similar to or surpassed the warm anomalies from the strong ENSO events of the early 1980s and late 1990s.

The Pacific Decadal Oscillation (PDO) is an index that describes the temporal evolution of the dominant spatial pattern of sea-surface temperature anomalies over the North Pacific (Mantua et al. 1997), and is often closely correlated with the ONI. Positive values of the PDO are generally associated with warm conditions along the U.S. West Coast. The PDO switched from a negative to positive phase beginning in 2014, with very high values observed in 2015 and 2016.

The North Pacific Gyre Oscillation (NPGO) is well correlated with salinity, nutrients, and chlorophyll-a in the California Current (Di Lorenzo et al. 2008). Negative NPGO values are associated with decreased equatorward flow in the California Current and thus less subarctic source waters, lower nutrients, reduced upwelling, and reduced chlorophyll-a. Since 2014, the NPGO has primarily been in a negative phase, suggesting lower productivity in the central and southern California Current.

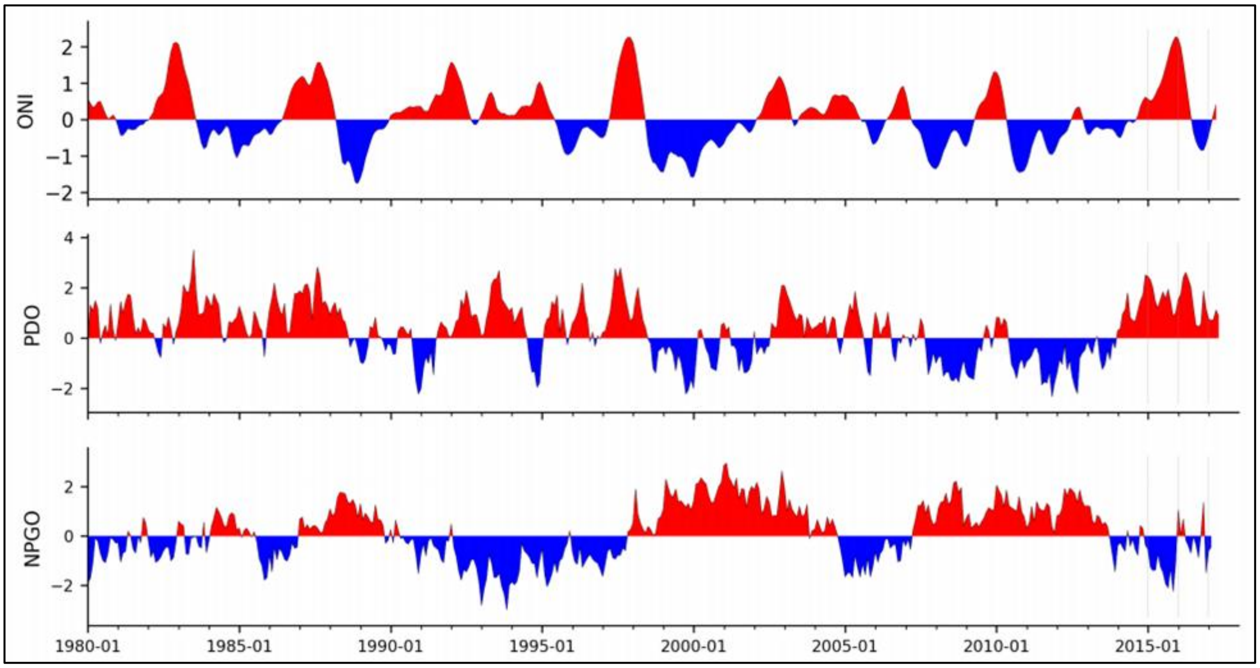

Figure 3.2.1.b. Time series for three ocean climate indices relevant to productivity of the California Current: the Oceanic Niño Index (ONI), the Pacific Decadal Oscillation (PDO), and the North Pacific Gyre Oscillation (NPGO). Tick marks represent January values (Figure reproduced from Wells et al. 2017).

Local-scale ocean conditions relevant to SRFC also demonstrate relatively warm, unproductive conditions present for juvenile salmon entering the ocean from 2014 through 2016, corresponding to brood years 2013-2015, with better conditions encountered by brood year 2012. McClatchie et al. (2016) compared SST anomalies from the 1997-1998 El Niño and the period from 2014-2016 for the region from Trinidad Head (just south of the Klamath River mouth) to Point Conception, California (Figure 3.2.1.c). In both coastal and more offshore areas in this region there were substantial positive SST anomalies from 2014-16, similar to or greater than those anomalies during the 1997-1998 El Niño event.

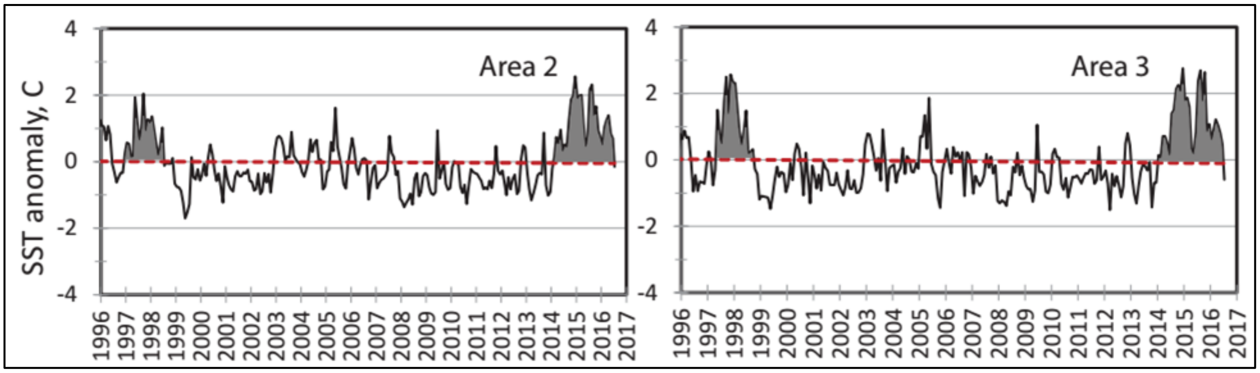

Figure 3.2.1.c. Anomalies of monthly mean sea-surface temperature in offshore (Area 2) and coastal (Area 3) areas off central California between Trinidad and Pt. Conception. Anomalies were calculated relative to the long-term (1981-2016) mean monthly values. The shaded areas correspond to the anomalies of 1997-1998 and 2014-2016. (Figure adapted from McClatchie et al. 2016).

The Cumulative Upwelling Index (CUI) provides another indicator of productivity in the California Current. It is defined as the cumulative sum of daily upwelling index (Bakun 1973; Schwing et al. 1996) values for the calendar year. Figure 3.2.1.d displays the CUI from 1967 through the middle of 2015, with years 2013-2015 highlighted. Of particular relevance for SRFC are the CUI values for 36° N (just south of Monterey Bay) and 39° N (just north of Point Arena). In the region of interest during 2013-2015, the CUI was either close to or greater than the 1967-2011 average, with 2013 having among the highest level of CUI over the time series (Leising et al. 2015).

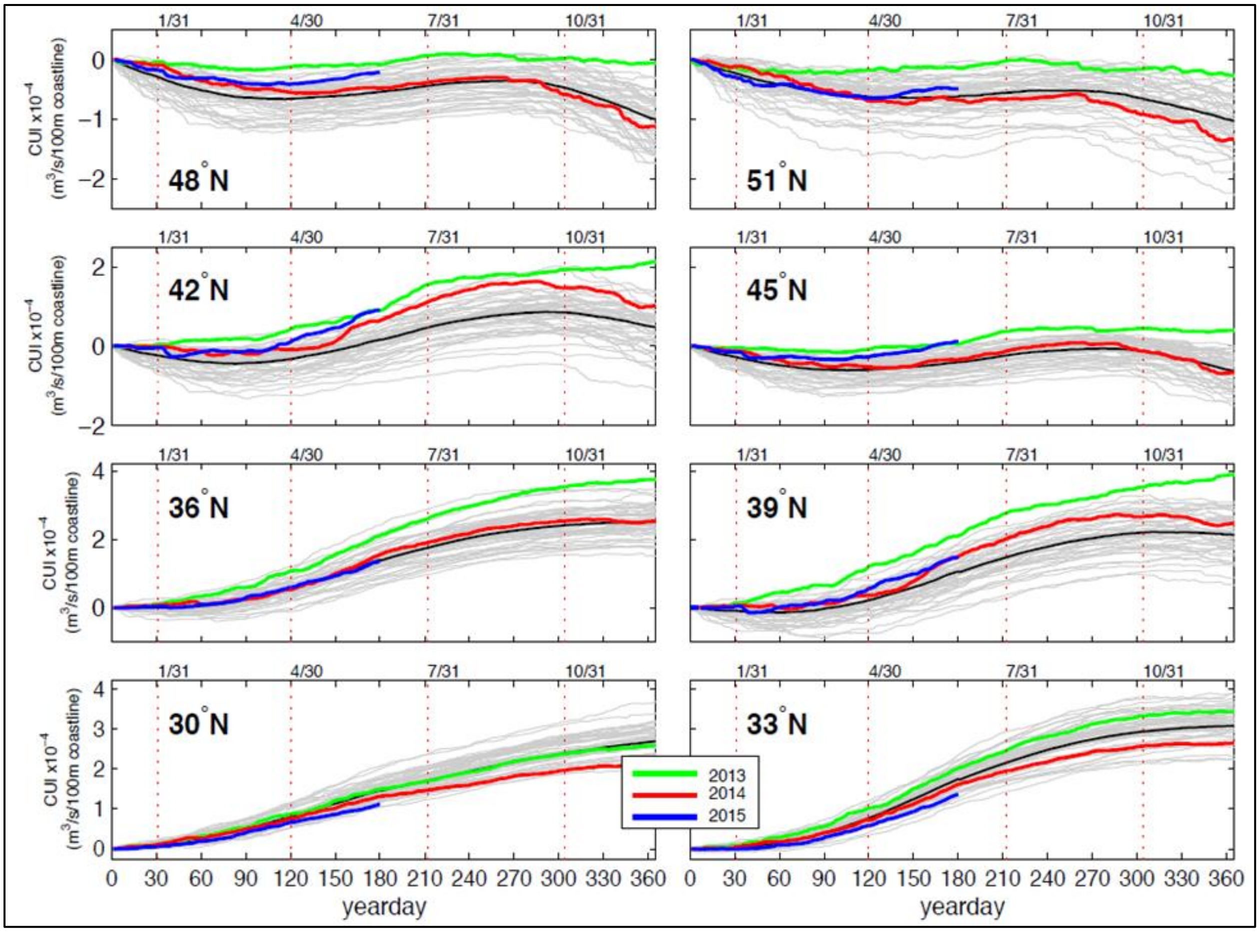

Figure 3.2.1.d. Plots of the Cumulative Upwelling Index (CUI) by latitude. The black line is the mean from 1967-2011 and grey lines are years 1967-2013. Years 2013-2015 are represented by the colored lines defined in the legend. Figure reproduced from Leising et al. (2015).

Zooplankton biomass has been used as an indicator of feeding conditions for juvenile salmon and the forage fishes that are important salmon prey. A change in the copepod community in central Oregon was associated with the record high SSTs in 2014-2016. From approximately 2011 through the summer of 2014, the biomass of lipid-rich, cold water, northern copepods was generally high off Newport, OR. As waters warmed in the area, the copepod community switched to one dominated by a lipid-poor, warm water, southern copepod assembly (Leising et al. 2015). The dominance of the warm water copepod assemblage continued into 2017, and the biomass of the lipid-rich northern copepods declined to the lowest levels observed (Figure 3.2.1.e; Wells et al. 2017). Off Trinidad Head, CA, a decline in northern copepods and increase in southern copepods was also noted, with general correspondence to the observations at Newport. A similar pattern was seen for krill populations at Trinidad, where northern species were supplanted by a krill assemblage dominated by southern and offshore species (Leising et al. 2015, McClatchie et al. 2016, Wells et al. 2017).

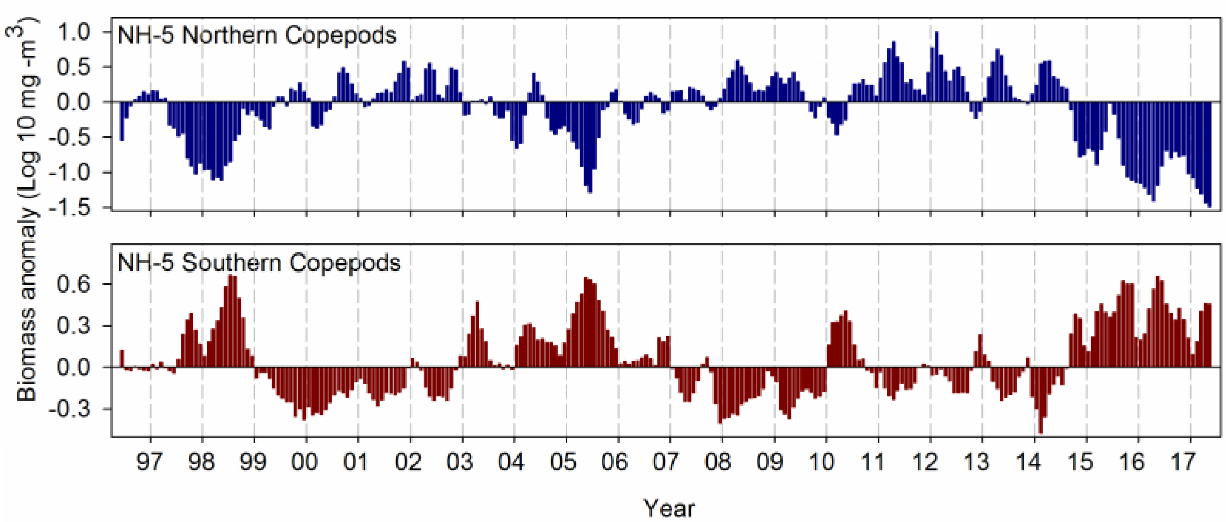

Figure 3.2.1.e. Time series plots of northern and southern copepod biomass anomalies in coastal Oregon waters, measured along the Newport Hydrographic Line. Figure reproduced from Wells et al. (2017).

Ichthyoplankton biomass can also be indicative of foraging conditions for juvenile salmon. Off Newport, OR, moderate to low biomass levels of ichthyoplankton considered to be important prey for salmon were observed in 2013-2014, which would correspond to the outmigration years for brood year 2012-2013 SRFC. The biomass of salmon-favored ichthyoplankton increased substantially in 2015, with major contributions from rockfish and anchovy (Figure 3.2.1.f). While ichthyoplankton surveys do occur off the coast of California, there are currently no winter surveys, which is the period of time most relevant to juvenile Chinook entering the ocean. While SRFC adults are caught in ocean fisheries up to and north of Newport, OR, it is unclear how relevant the zooplankton results for Newport and Trinidad, and the ichthyoplankton results for Newport, might be for juvenile SRFC entering the ocean in the Gulf of the Farallons.

Forage conditions for juvenile SRFC first entering the Gulf of the Farallons can be assessed by examining catches of salmon prey from the Rockfish Recruitment and Ecosystem Assessment Survey conducted in May and June by the NMFS Southwest Fisheries Science Center. This midwater trawl survey has been conducted in the core region, spanning approximately from Bodega Bay to Monterey Bay, since 1983 (Ralston et al. 2013, Sakuma et al. 2016). Ralston et al. (2015) found that catches of young-of-the-year groundfish, krill, and market squid tended to be higher when cooler conditions prevailed in the California Current. In 2013-2015, corresponding to the outmigration years for the critical broods, there were large catches of these taxa (Sakuma et al. 2016). While large scale and some local-scale indices of ocean productivity suggested warm and unproductive conditions in 2015, the core area in central California experienced substantial nearshore upwelling and the presence of relatively cool subarctic water at depth (Santora et al. 2017). Wells et al. (2012) found that body condition of juvenile Chinook salmon was positively related to the abundance of adult krill of the species *Thysanoessa spinifera*, and that the abundance of returning Chinook was positively associated with body condition as juveniles. Catches of *T. spinifera* were large from 2012-2014, but declined from those high levels in 2015 (Sakuma et al. 2016). Given current understanding of the interaction between krill abundance and salmon condition (Wells et al. 2016), results from the midwater trawl survey in central California suggest better foraging conditions for juvenile SRFC from the critical broods than was indicated by the larger-scale indices of productivity and more northern zooplankton and ichthyoplankton biomass estimates.

Predation is likely to be a substantial source of mortality for juvenile salmon. Wells et al. (2017) examined the relationship between foraging dynamics and prey abundance for common murre, a piscivorous seabird with a large nesting colony on Southeast Farallon Island. The primary prey of common murre is young-of-the-year rockfish, and when this prey type is plentiful it makes up a large proportion of murre diet. However, when young-of-the-year rockfish are at low abundance, murre diet shifts to anchovy, which can co-occur with juvenile Chinook, and are generally distributed more inshore than young-of-the-year rockfish. This inshore shift in murre foraging behavior to target anchovy could lead to higher levels of predation on co-occurring juvenile Chinook. As previously noted, young-of-the-year rockfish were very abundant in central California during 2013-2015 and murre diet, in terms of biomass, was dominated by this prey source in those years (Warzybok et al. 2018). Consistent with the pattern identified by Wells et al. (2017), the low levels of anchovy consumption by murre suggests that in 2013-2015, there were likely low levels of predation on outmigrating Chinook salmon.

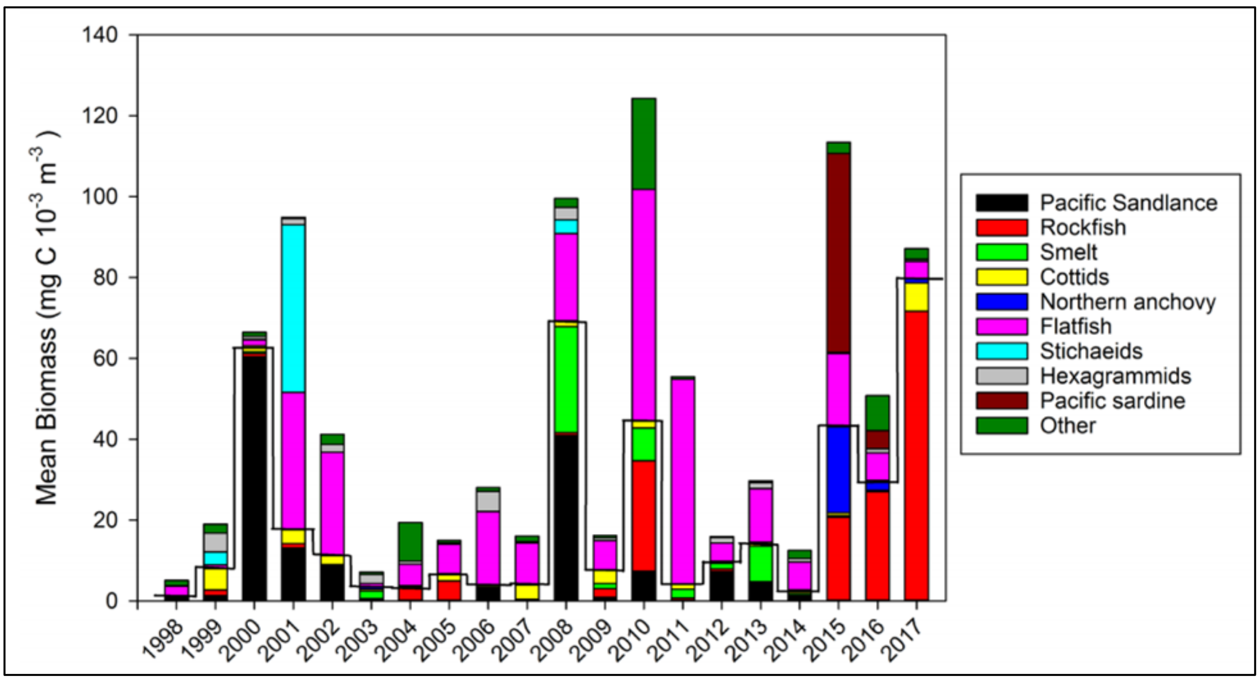

Figure 3.2.1.f. Annual mean biomass of five important juvenile salmon prey taxa (below solid line) and five other larval fish taxa (above solid line) collected during winter (January-March) along the Newport Hydrographic Line, 9-46 km off the coast of Oregon. Figure reproduced from Wells et al. (2017).

Seabird nest success and productivity over the critical period of 2012-2015 was mixed. At Castle Rock National Wildlife Refuge near Crescent City, CA, reproductive success of common murre was near average in 2013-2015, with no data reported for 2012 (McClatchie et al. 2016). Productivity of a variety of seabird species nesting at Southeast Farallon Island differed by species. McClatchie et al. (2016) observed that standardized productivity of several species was down in 2015 relative to 2014, but remained near or above long term averages. It was also noted that the 2015-2016 ENSO event did not appear to have as large an impact on seabird productivity at

Southeast Farallon Island relative to previous strong ENSO events. While results for seabird nest success and productivity were mixed over the period of interest, there were indications that the warming that began in 2014 contributed to seabird mortality. Jones et al. (2018) describe a mass mortality event for Cassin's auklets from California to British Columbia that occurred in 2014-2015. To the north, the biomass of lipid-poor, southern copepods was identified as the most supported predictor of this event. In central California, mortalities were dominated by young-of-the-year birds, which were surmised to be from the breeding colonies on the Farallon Islands.

For the years of primary interest with regard to the SRFC overfished status (outmigration years 2013-2015), indicators of ocean productivity and feeding conditions for salmon were highly dynamic over time and space. Outmigration year 2013 was characterized by generally cool SSTs in the California Current, relatively high biomass of northern copepods at off Newport, OR, and moderate levels of ichthyoplankton biomass for species known to be important prey for juvenile salmon. Upwelling indices were above average, which indicated relatively high overall productivity in the California Current (IEA 2014). In 2014 the California Current began to shift to a less productive system (IEA 2015). Basin-scale indices such as the PDO and NPGO switched phases from a generally high productivity phase to low productivity phase for the California Current. Upwelling was reduced relative to the very strong indices in 2013, though from latitude 36^o N to latitude 48^o N, upwelling generally remained at average or above average levels. Late in 2014, SSTs warmed and the copepod assemblage off Newport, OR transitioned from an assemblage dominated by northern copepods to one dominated by southern copepods. A similar shift in the zooplankton assemblage was observed further south at Trinidad Head. Winter ichthyoplankton biomass for important salmon prey species was very low off Newport in 2014. A mass mortality event of a planktivorous seabird, Cassin's auklet, began in 2014 from British Columbia to central California. A strong ENSO event developed in 2015 and basin-scale indices (PDO and NPGO) strongly suggested low productivity conditions in the California Current (IEA 2016). Positive upwelling anomalies were observed in the spring and summer of 2015 between latitude 36^o N to latitude 48^o N, yet record high SSTs were observed off California and Oregon. The zooplankton community off Newport and Trinidad Head remained dominated by lipid-poor southern and offshore species yet a relatively high salmon-favorable ichthyoplankton biomass was observed in 2015 at Newport. Despite these observations further north, in central California, there were indications of a productive nearshore ecosystem in 2013-2015 with relatively high krill abundance. Furthermore, there were indications that predation on outmigrating SRFC by common murre was likely to be low, given the high contribution of young-of-the-year rockfish to murre diets.

In summary, for the critical brood years of 2012-2014, outmigrating juvenile SRFC encountered a wide range of ocean conditions. The earliest brood encountered generally cool, productive conditions in the California Current that could be characterized as favorable for salmon survival. An abrupt transition occurred in 2014; however, with rapid warming that resulted in record high SSTs in 2015, the development of a very strong ENSO event in 2015, and most large-scale indicators pointing toward low productivity in the California Current from mid-2014 through 2016. However, in central California there was substantial localized upwelling, high levels of forage available to juvenile Chinook, and an ecosystem state that potentially resulted in low levels of predation at the time around ocean entry.

3.2.2 Early marine survival index

During the critically low escapement years of 2007-2009, Lindley et al. (2009) developed a survival index based on ocean sport CWT recoveries from age-2 FRH-origin SRFC in the San Francisco management area (between Pt. Arena and Pigeon Pt.). A modified version has been applied here that only utilizes a specific type of hatchery release, but also includes NFH-origin SRFC. In every year since brood year 2006, there have been releases of FRH- and NFH-origin SRFC that were trucked to San Pablo Bay and acclimated in net pens before release. Since these fish bypassed the majority of their freshwater downstream migration, and many of the hazards associated with it, they provide a means of assessing early marine survival and thus are the sole hatchery release groups used here. Similar to Lindley et al. (2009), the index is based on sample-expanded age-2 CWT recoveries in the San Francisco management area sport fishery. Stock concentration and fishing effort are highest here, and the season structure is very similar across years. One exception is the minimum size limit, which has been either 20 or 24 inches and can have a significant effect on the retention of age-2 fish. For this reason, CWT recoveries were further limited to occurring in July or later, since in most of the seasons analyzed here the size limit was 20 inches during those months. To standardize the recoveries across varying degrees of angler effort, they were divided by the effort values reported in Table A-4 of PFMC (2018b) and converted to CPUE values. The survival rate index is then defined as the CPUE per 1,000,000 tagged smolts released.

Figure 3.2.2.a displays the early marine survival index for brood years 2008-2015. The 2012-2014 broods, which were the primary contributors to the overfished status, had generally higher survival rates than the four broods that preceded them, with a couple important exceptions. The survival rate for brood year 2012 NFH-origin salmon was very low, just barely above the lowest in the time series, however this was not the case for FRH-origin fish from that brood. Also, the survival rate for brood year 2009 FRH-origin salmon was slightly higher than the 2012 and 2013 broods. Looking forward, the survival rate for brood year 2015 was substantially higher than any of the other broods, which could benefit rebuilding of the stock. Despite the poor marine conditions faced by the 2013 and 2014 broods, this survival index does not provide any conclusive evidence that they experienced elevated mortality during their early marine residency. However, as previously described in section 3.2.1, there is evidence that marine conditions off central California were not as poor as they were throughout other areas of the California Current. Since SRFC enter the ocean as juveniles in central California, they likely benefitted from these localized favorable conditions even if they later migrated to less favorable ocean areas. Lastly, it is unclear whether SRFC released directly into San Pablo Bay undergo similar marine migrations as those that are reared in-river, and thus whether they are an appropriate indicator for the SRFC stock as a whole.

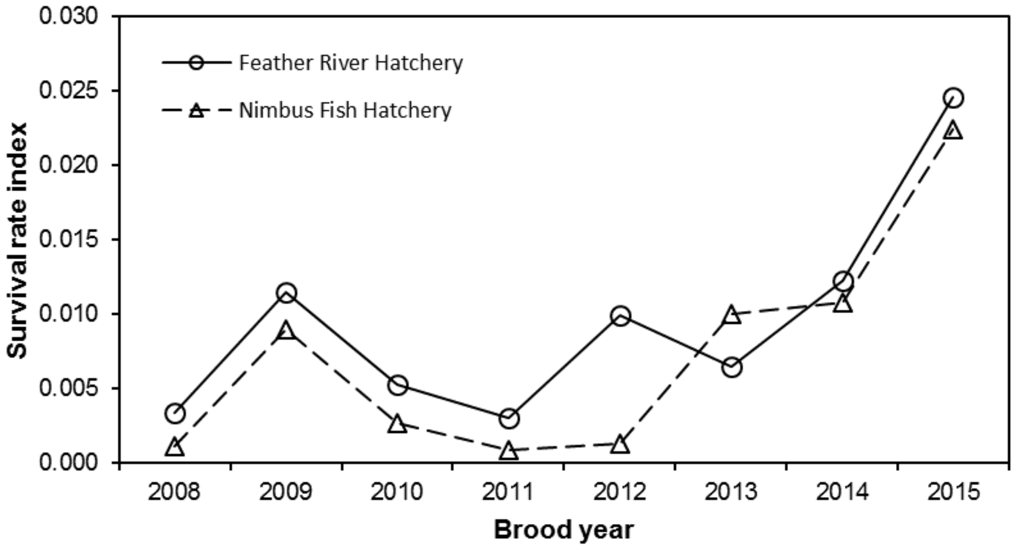

Figure 3.2.2.a. Early marine survival index for fall Chinook raised at Feather River Hatchery and Nimbus Fish Hatchery and released directly into San Pablo Bay net pens. The index is defined as the age-2 CPUE of CWT salmon in the San Francisco ocean sport fishery, July and later, per 1,000,000 smolts released.

Since brood year 2009, in addition to San Pablo Bay net pen releases, there have been smaller numbers of hatchery-raised Central Valley fall Chinook that were released directly into net pens on the coast of Central California. Since these fish completely bypassed their freshwater downstream migration, unlike San Pablo Bay releases which still had to navigate a considerable distance out of the bay, they could potentially serve as an even better indicator of early marine survival. However, due to small sample size and even greater uncertainty surrounding their marine migratory behavior, San Pablo Bay releases are currently thought to be better for assessing early marine survival. Analyzing recoveries from coastal net pen releases may still be informative.

Many of the coastal releases occur in Princeton which is within the San Francisco management area. Unfortunately, the dataset of these recoveries is already small, and further restricting them to only Princeton releases severely limits the number of years available for comparison. So to bolster sample size, the survival index also utilizes fish that were released into coastal net pens in Santa Cruz, the next port south of the San Francisco management area. While most coastal net pen releases have been SRFC produced at FRH, some have been fall Chinook from Mokelumne River Hatchery, which is in the Central Valley but is not included in the SRFC stock. However, since fish from both hatcheries completely bypassed their freshwater downstream migration and likely experienced similar marine conditions, both were utilized here. Figure 3.2.2.b displays the early marine survival index utilizing coastal net pen releases for the 2009-2015 broods. Recovery rates are greater for these releases as compared to San Pablo Bay net pens, and this is evident when comparing the scale of the survival rate (y-axis) between the two release types. The survival rate index across those broods followed a very similar pattern as the San Pablo Bay releases. The 2012-2014 broods had higher survival rates than all three of the broods that preceded them. Like the San Pablo Bay releases, the survival index calculated from coastal releases does not provide any conclusive evidence that the 2012-2014 broods experienced increased mortality during their early marine residency. Again, this may be due to regional differences in marine productivity as described above. Also, similar to San Pablo Bay releases but to an even greater extent, there is a high degree of uncertainty regarding the marine migratory behavior of coastal net pen releases.

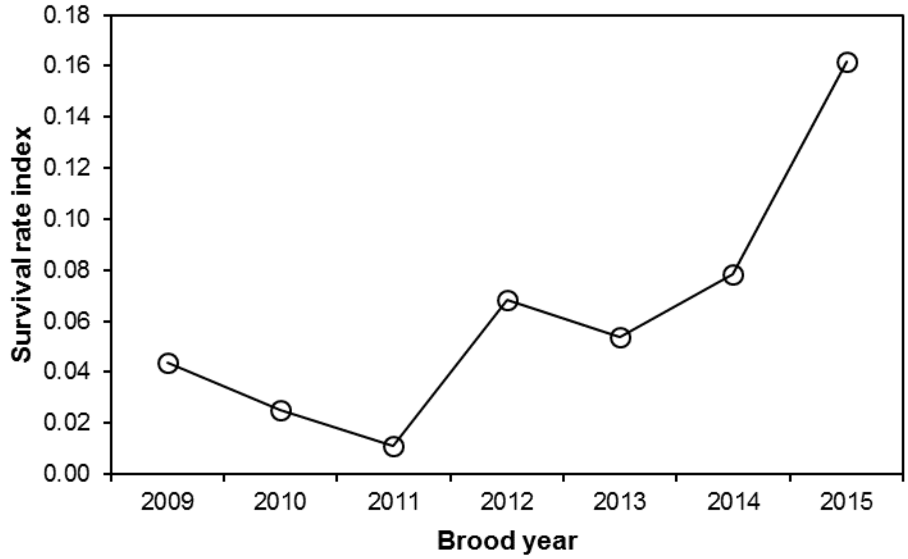

Figure 3.2.2.b. Early marine survival index for hatchery-raised Central Valley fall Chinook released directly into net pens on the coast of Central California. The index is defined as the age-2 CPUE of CWT salmon in the San Francisco ocean sport fishery, July and later, per 1,000,000 smolts released.

3.3 Harvest impacts

3.3.1 Ocean fisheries

SRFC are the largest contributing stock in California and Oregon ocean salmon fisheries (O'Farrell et al. 2013). SRFC are primarily contacted between Cape Falcon, OR and Pt. Conception, CA, with contact rates generally higher closer to San Francisco Bay, which connects the Sacramento River to the ocean. This includes the major management areas of Northern Oregon (Cape Falcon to Florence south jetty[2]), Central Oregon (Florence south jetty to Humbug Mt.), the Oregon Klamath Management Zone (KMZ) (Humbug Mt. to the OR/CA border), the California KMZ (OR/CA border to Horse Mt.), Fort Bragg (Horse Mt. to Pt. Arena), San Francisco (Pt. Arena to Pigeon Pt.), Monterey North (Pigeon Pt. to Pt. Sur), and Monterey South (Pt. Sur to the U.S./Mexico border). Both commercial and recreational ocean salmon fisheries typically occur in all of these areas. The commercial fishery generally receives a larger share of the projected ocean harvest, but their seasons are usually shorter due to the greater fishing power of the commercial fleet and the high social value placed on recreational fishing. When SRFC abundance is projected to be low and it is a constraining stock, fisheries in areas closer to San Francisco Bay (i.e., San Francisco, Fort Bragg, and both Monterey areas) are the most affected. However, SRFC was not a constraining stock in any season during 2015-2017. Rather, ocean fisheries south of Cape Falcon

[2] While the line separating the Northern and Central Oregon management areas is now the southern end of Heceta Bank, Florence south jetty was used through the 2017 season.

were primarily constrained by Klamath River fall Chinook (KRFC), and areas south of Pt. Arena were also constrained by endangered SRWC.

Commercial ocean seasons

Figure 3.3.1.a illustrates the general season structures of the 2015-2017 commercial ocean salmon fisheries between Cape Falcon and the U.S./Mexico border. In general, seasons progressively became more restrictive between 2015 and 2017, largely due to a steep downward trajectory in preseason KRFC abundances, but also to protect SRWC south of Pt. Arena.

In the Northern and Central Oregon areas, the season is typically open from mid-March/early-April through October, with various mid-season closures to reduce impacts on limiting stocks. There is also usually a November state-water-only fishery centered around the Elk River mouth in the Central Oregon area. Both areas had fairly typical seasons in 2015 and 2016, but Northern Oregon was slightly more constrained in 2017 and Central Oregon was closed to commercial fishing except for the late-season Elk River fishery. The Oregon KMZ typically opens in mid-March/early-April, with monthly quotas beginning in June. These quotas may run through September in years when KRFC is not constraining, but often some of the late-summer/fall quotas are eliminated. There is also usually an October state-water-only quota fishery centered around the Chetco River mouth. 2015 was a relatively typical season in the Oregon KMZ, but 2016 was more constrained, and in 2017 the commercial fishery was closed except for the late-season Chetco River fishery.

In the California KMZ, it is rare to have commercial fisheries outside of a September quota, although in years when KRFC is not limiting there have been quota fisheries in earlier months as well. Also, the southern end of this area has been closed to commercial salmon fishing since 1989. Punta Gorda was the original northern boundary of this closed subarea, but it has been the south jetty of Humboldt Bay since 1996. The seasons in the California KMZ consisted of the standard September quota fisheries in 2015 and 2016, but was completely closed to salmon fishing in 2017. Commercial fisheries in the Fort Bragg area tend to vary from year to year considerably more than other management areas, and are highly influenced by preseason KRFC abundances. This results in seasons comprised of various blocks of open time between May and September. In 2015, this area had a relatively wide open season, but it was curtailed back sharply in 2016, and was severely reduced further in 2017 to a September-only quota fishery. The San Francisco area is typically open May through September, with various mid-season closures to reduce impacts on limiting stocks, and also includes a small fishery centered around the entrance to San Francisco Bay during the first half of October. 2015 was a fairly typical season in the San Francisco area, but the number of open days decreased considerably in 2016, and then decreased even further in 2017 with the season being closed through July. In both Monterey areas, seasons are highly influenced by allowable impacts on SRWC, but can run anytime May through September. Due to concerns over SRWC abundances during those three years, the 2015 season was restricted to approximately three months of open time in Monterey North and slightly less in Monterey South, and the 2016 and 2017 seasons were limited to two months in both areas.

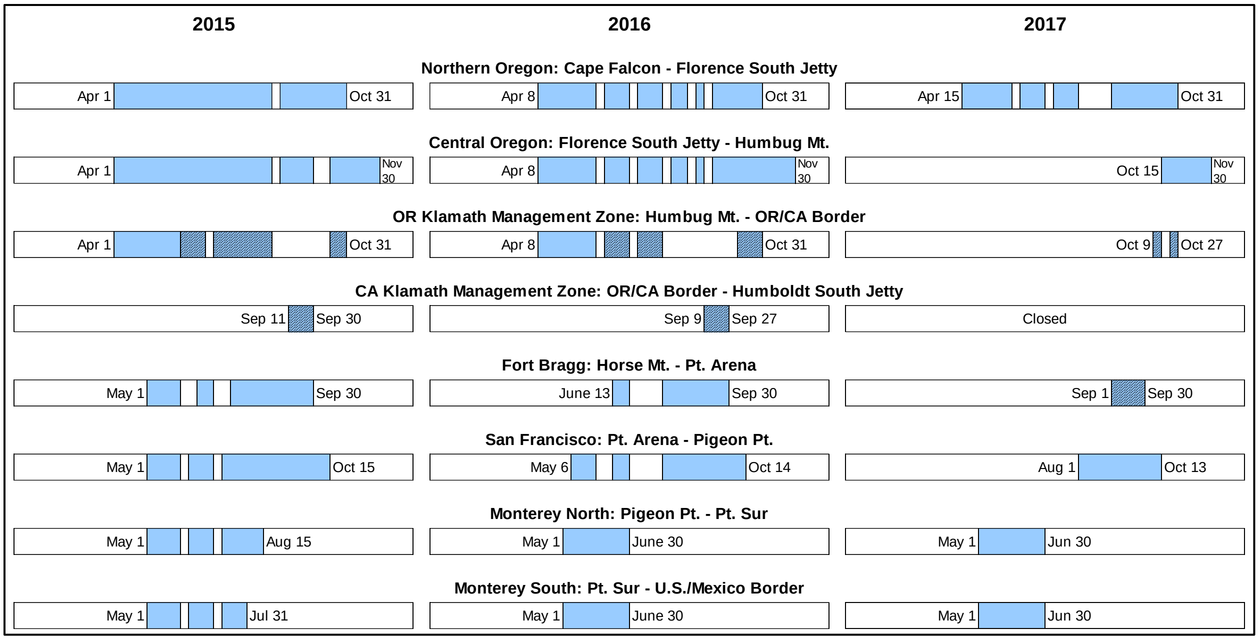

Figure 3.3.1.a. The general commercial ocean season structure for all management areas between Cape Falcon and the U.S./Mexico border during 2015-2017, with the first and last open days of the season displayed. Open periods shown with a diagonal pattern were operated under quota systems.

Recreational ocean seasons

Figure 3.3.1.b illustrates the general season structures of the 2015-2017 recreational ocean salmon fisheries between Cape Falcon and the U.S./Mexico border. As mentioned above, KRFC was the primary constraining stock during those years. The recreational fishery has relatively lower impacts on KRFC, so season reductions when KRFC is limiting are mostly confined to the KMZ, although Fort Bragg was majorly impacted in 2017 as well. In the Northern and Central Oregon areas, the season is typically open from mid-March through October, often with various coho quota fisheries occurring concurrently with portions of the Chinook season. There is also usually a November state-water-only fishery centered around the Elk River mouth in the Central Oregon area. These areas had typical seasons during all three years. Both portions of the KMZ are usually open early-May through early-September, although mid-season closures to limit KRFC impacts are common. There is also usually a state-water-only fishery centered around the Chetco River mouth in the Oregon KMZ during early-October. Both KMZ areas had full recreational seasons in 2015, but the number of open days decreased considerably in 2016, and in 2017 the entire KMZ was closed to salmon fishing except for the late-season Chetco River fishery. Recreational fisheries in the Fort Bragg and San Francisco areas are typically open from early-April through early-November, although during those three years the fishery in San Francisco only continued through October to reduce impacts on SRWC. With that exception, these areas had full seasons in 2015 and 2016. In 2017, the Fort Bragg area had a two and a half month closure in the middle of the season to limit KRFC impacts, and the San Francisco area had a two-week closure in early-May. In both Monterey areas, seasons are highly influenced by allowable impacts on SRWC, and typically run early-April through early-October. Due to concerns over SRWC abundances during those three years, the 2015 season in Monterey North ended in early-September, and the 2016 and 2017 seasons only continued through mid-July. In Monterey South, the 2015 season ended in mid-July, and the 2016 and 2017 seasons only continued through May.

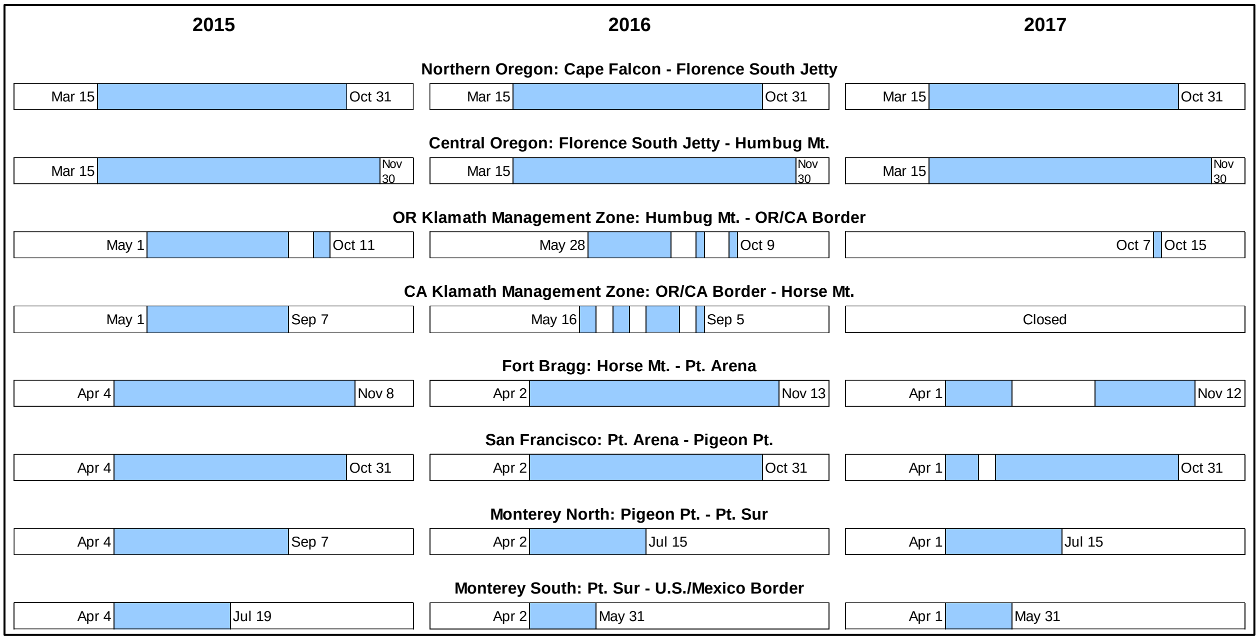

Figure 3.3.1.b. The general recreational ocean season structure for all management areas between Cape Falcon and the U.S./Mexico border during 2015-2017, with the first and last open days of the season displayed.

Adult harvest

Table 3.3.1.a displays historical adult SRFC harvest levels. For ocean harvest, the year (t) represents September 1 in the prior year (t-1) through August 31 (t). The commercial fleet harvested approximately 100,000 adult SRFC during the 2015 season, a relatively low number, and only about two-thirds and one-third that amount in 2016 and 2017, respectively. The average commercial harvest of adult SRFC during 2015-2017 was only 20 percent of the long-term average. In the recreational ocean fishery, harvest of adult SRFC increased each season during those three years, but even in 2017 the harvest was less than one-third of the long-term average. The average number of adult SRFC harvested by recreational ocean anglers during 2015-2017 was only 25 percent of the long-term average. At no point during 2015-2017 did ocean harvest of adult SRFC approach the long-term average.

Table 3.3.1.a. Harvest and abundance indices for adult Sacramento River fall Chinook in thousands of fish. Bold values indicate years which resulted in the overfished status. Table modified from Table II-1 in PFMC (2018c).

Year (t)	SRFC Ocean Harvest South of Cape Falcon[a/] Troll	Sport	Non-Ret[b/]	Total	River Harvest		Sacramento Index (SI)[c/]	Exploitation Rate (%)[d/]
1983	246.6	86.3	0.0	332.9	18.0		461.1	76
1984	266.2	87.0	0.0	353.1	25.9		538.1	70
1985	355.5	158.9	0.0	514.4	39.1		792.8	70
1986	619.0	137.5	0.0	756.4	39.2		1,035.7	77
1987	686.1	173.1	0.0	859.2	31.8		1,086.1	82
1988	1,163.2	188.3	0.0	1,351.5	37.1		1,616.1	86
1989	602.8	157.1	0.0	759.9	24.9		937.3	84
1990	507.3	150.4	0.0	657.8	17.2		780.0	87
1991	300.1	89.6	0.0	389.7	26.0	e/	534.6	78
1992	233.3	69.4	0.0	302.8	13.3	e/	397.6	79
1993	342.8	115.3	0.0	458.1	27.7	e/	623.2	78
1994	303.5	168.8	0.0	472.3	28.9	e/	666.7	75
1995	730.7	390.4	0.0	1,121.0	48.2		1,464.6	80
1996	426.8	157.0	0.0	583.8	49.2		934.7	68
1997	579.7	210.3	0.0	790.0	56.3		1,191.1	71
1998	292.3	114.0	0.0	406.3	69.8	e/	722.1	66
1999	289.1	76.2	0.0	365.3	68.9	e/	834.0	52
2000	421.8	152.8	0.0	574.6	59.5	e/	1,051.6	60
2001	284.4	93.4	0.0	377.9	97.4		1,072.0	44
2002	447.7	184.0	0.0	631.7	89.2	e/	1,490.8	48
2003	501.6	106.4	0.0	608.0	85.4		1,216.3	57
2004	621.8	212.6	0.0	834.5	46.8		1,168.2	75
2005	367.9	127.0	0.0	494.9	64.6		955.5	59
2006	149.9	107.7	0.0	257.7	44.9		577.6	52
2007	120.0	32.0	0.0	152.0	14.3	e/	257.7	65
2008	3.2	0.9	0.0	4.1	0.1	e/	69.6	6
2009	0.0	0.2	0.1	0.3	0.0	e/	41.1	1
2010	11.2	11.4	0.3	22.8	2.5	e/	149.6	17
2011	46.6	22.8	0.0	69.4	17.4	e/	206.1	42
2012	182.9	93.3	0.3	276.5	62.2	e/	624.2	54
2013	290.7	114.4	0.0	405.1	55.5	e/	866.8	53
2014	240.5	62.4	0.0	302.9	35.7	e/	551.1	61
2015	**100.0**	**24.4**	**0.0**	**124.4**	**16.9**	**e/**	**254.2**	**56**
2016	**62.9**	**28.9**	**0.0**	**91.8**	**23.9**	**e/**	**205.3**	**56**
2017[f/]	**38.8**	**31.7**	**0.0**	**70.5**	**25.0**	**e/**	**140.0**	**68**
1983-2017 avg.	338.2	112.5	0.0	450.7	38.9		729.0	62
2015-2017 avg.	67.2	28.3	0.0	95.5	21.9		199.8	60

a/ Ocean harvest for the period September 1 (t-1) through August 31 (t).

b/ Mortalities estimated from non-retention ocean fisheries (e.g., coho-only fisheries, non-retention GSI sampling). In 2008, there w ere 37 estimated mortalities as a result of non-retention fisheries that have been rounded to 0 in this table.

c/ The SI is the sum of (1) SRFC ocean fishery harvest south of Cape Falcon betw een September 1 and August 31, (2) SRFC impacts from non-retention ocean fisheries w hen they occur, (3) the recreational harvest of SRFC in the Sacramento River Basin, and (4) the SRFC spaw ner escapement.

d/ Total ocean harvest, non-retention ocean fishery mortalities, and river harvest of SRFC as a percentage of the SI.

e/ Estimates derived from CDFW Sacramento River Basin angler survey. Estimates not marked w ith a footnote are inferred from escapement data and the mean river harvest rate estimate.

f/ Preliminary.

3.3.2 In-river fisheries

Fishery area and seasons

Sport fishing for SRFC in the Sacramento Basin occurs on the Sacramento River from the Carquinez Strait near Vallejo, CA upstream to the Deschutes Road Bridge, just downstream from Redding, CA (Table 3.3.2.a). The lowermost fishing area includes Suisun Bay and adjacent channels representing portions of the western Sacramento-San Joaquin Delta, and the North and South forks of the Mokelumne River and adjacent sloughs, which represent portions of the central Delta. Fishing also occurs on the American and Feather rivers, the largest tributaries to the Sacramento River. Currently, over 400 miles of river and delta channels are available for the inland sport fishery. It is important to note that the Mokelumne River is not a tributary of the Sacramento River, and thus harvest in this river is not included when calculating the SI.

The open season for salmon fishing is designed to focus harvest on SRFC and Sacramento River late-fall Chinook, including production from both natural spawning areas and hatcheries. The general season is five months long and runs from July 16 through December 16. Minor exceptions to this season occur in select areas of the system, to avoid contact with listed Central Valley spring Chinook and SRWC in some areas, and to provide additional fishing opportunity for late-arriving SRFC in other areas.

Daily bag and possession limits

The daily bag limit for Chinook salmon in the Sacramento Basin has been two salmon per day for most of at least the last 70 years of the management history of this stock. Exceptions included a liberalization to three salmon per day on the Feather and American rivers during the mid-2000s in response to exceptionally high escapements on those rivers during 2001-2003. No harvest was allowed during the complete fishery closure on SRFC during 2008 and 2009. There was a bag limit of one salmon per day in 2010 as the stock recovered, followed by a return to the two salmon per day bag limit in 2011, which continued, along with a possession limit of four salmon, through the 2017 season. In response to the overfished status of the stock, the daily bag and possession limits for the 2018 season were one and two salmon, respectively.

Sampling design

The Chinook salmon sport fishery in the Sacramento Basin is monitored by CDFW's Central Valley Angler Survey (Survey). Currently, the Chinook salmon fishing area described above is divided into 25 survey sections (Table 3.3.2.a). A stratified, random sampling design, based on Smith (1950) and Wixom et al. (1995), is used to estimate salmon angling effort, catch, and harvest in each survey section. Each survey section is sampled four weekdays and four weekend days per month, each day selected randomly. Weekdays and weekend days constitute separate temporal strata given that angling effort is generally much higher on weekend days than on weekdays.

Table 3.3.2.a. Survey section codes and descriptions for river and delta sections surveyed by the Central Valley Angler Survey during the 2017 Chinook salmon sport fishery season in the Central Valley.

Section No.	Section Description
Sacramento River and Western Delta	
1	Carquinez Bridge to Rio Vista Bridge
1.1	Suisun Bay, Suisun Cutoff to Middle Grounds
1.2	Southhampton Bay from Benicia State Recreation Area to First Street Pier
2	Rio Vista Bridge to mouth of American River
3	American River to Knights Landing (Hwy. 113 Bridge)
4	Knights Landing to Colusa State Park
5	Colusa to Hamilton City (Hwy. 32 Bridge)
6	Hamilton City to Red Bluff Diversion Dam
7	Red Bluff Diversion Dam to Balls Ferry Boat Ramp
7.1	Barge Hole at the confluence of Battle Creek and Sacramento River
8	Balls Ferry Boat Ramp to Deschutes Road Bridge
American River	
9	Discovery Park to the interstate 80 Bridge
10	Interstate 80 Bridge to lower point of Sailor Bar peninsula
10.1	Hazel Avenue Bridge to Nimbus Dam (aka: Nimbus Basin)[a/]
10.2	Lower point of Sailor Bar peninsula to USGS cable lines adjacent to Nimbus Hatchery
Feather River	
11.1	Verona to Shanghai Rapids
11.2	Shanghai Rapids to Sunset Pumps
12	Palm Avenue Riffle to Thermalito Afterbay Outlet
12.1	Thermalito Afterbay Outlet
12.2	Sunset Pumps to Palm Avenue Riffle
Mokelumne River (Central Delta)	
16	South Fork, from the confluence with the San Joaquin to the confluence with the Cosumnes River
16.1	Beaver Slough (tributary to the South Fork Mokelumne River)
16.2	Hog Slough (tributary to the South Fork Mokelumne River)
16.3	Sycamore Slough (tributary to the South Fork Mokelumne River)
17	North Fork, from the confluence with the South Fork to the point of divergence from the mainstem

[a/] Nimbus Basin is closed to all fishing, effective March 1, 2018.

Survey components include roving counts, roving interviews, and access point interviews, as described below. Roving counts and access point interviews are used to estimate total fishing effort, while roving interviews are used to estimate catch per unit effort (CPUE) as catch/hour. Access point interviews are used to collect data for construction of effort distribution models, comparatively evaluate catch rates as derived from roving and access point interviews, and to gather completed angler trip data. Effort distribution models provide the proportion of whole-day fishing effort that is represented by an angler count made during two single hours of the fishing day.

The sampling design for the Survey underwent a critical review by Griswold and Nielson (2011). The current angler survey design is consistent with the results of the review, including the addition of a second roving count, as described below, to enhance the statistical robustness of the Survey.

Data collection

Primary data collection occurs from propeller-driven boats, jet-powered boats, drift boats, and kayaks, depending upon the physical characteristics of a given survey section. On each survey day in a given section, a high-speed pass is made through the section, during which all anglers are counted, thus comprising a roving count. Data collected during the roving count include time of observation, location by river mile, number of boats, number of boat anglers, and the number of shore anglers.

With completion of the first roving count of anglers, a second pass is made traveling back through the section to conduct roving interviews and a second roving count of anglers. Data collected during each interview include location by river mile, time of interview, fishing method, number of hours fished, number of anglers in the group, target species, zip code, whether the trip was completed, and the number of fish kept and released by species, including the time salmon were caught, as applicable.

Access point interviews are conducted at heavily used launch and shore fishing locations and are scheduled to encompass all hours of a virtual day to be used in the effort distribution model for that survey section, month, and day-type stratum (weekday or weekend day). Data collection from angler interviews occurs as described above for roving interviews.

The number of Chinook salmon caught, kept, and released is recorded for each fishing party interviewed. Harvested Chinook salmon are measured for fork length, weighed to the nearest 0.25 kg (if not gutted), sexed, and examined for the presence/absence of the adipose fin (for CWT retrieval) and any other external marks and tags. The head is collected from adipose fin-clipped Chinook salmon for CWT recovery in the lab.

SRFC harvest over the period of record

CDFW has estimated harvest of Chinook salmon in the Sacramento River sport fishery in 17 years since 1991, and continuously since 2010 (Figure 3.3.2.a). Harvest estimates of SRFC have ranged 21-fold from a low of 5,050 in 2010 to a high of 105,952 in 2002, and averaged 47,838 (SD = 28,874). Note that harvest in 2010 was exceptionally low due, in part, to a restricted fishing season following the complete SRFC fishery closure in 2008 and 2009. These estimates are for total harvest, which includes both grilse (age-2) and adult (age-3 and older) SRFC.

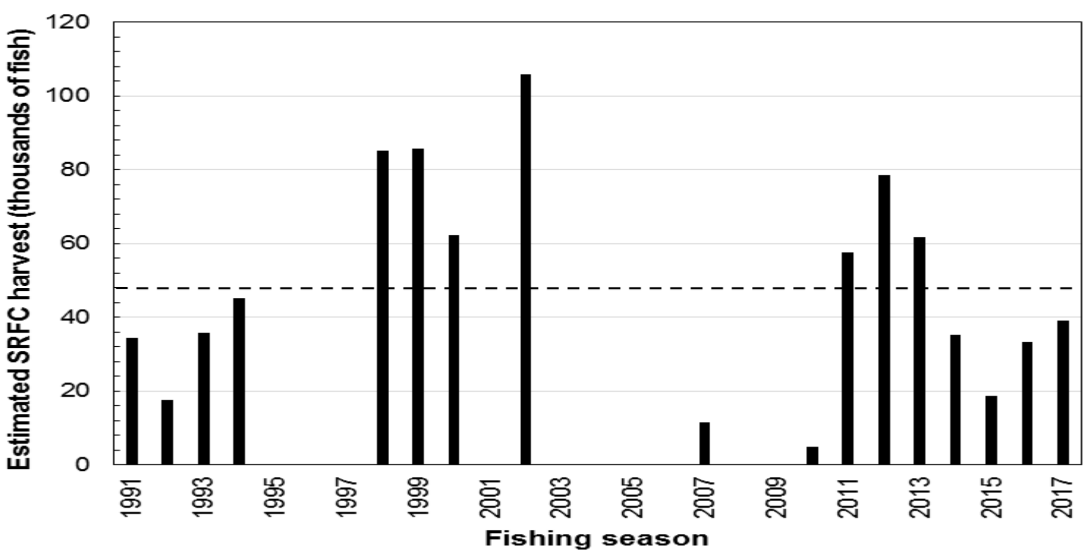

Figure 3.3.2.a. Estimated sport harvest of SRFC in the Sacramento Basin in 17 years from 1991 through 2017. Estimates are of total harvest, including both grilse (age-2) and adult (age-3 and older) SRFC. Mean harvest (dashed line) over the period of record is 47,838 salmon.

Generally, harvest of SRFC in the Sacramento River sport fishery varies predictably with overall abundance, as indexed by estimated SRFC spawner escapement in the Sacramento Basin (Figure 3.3.2.b). Using 13 years of data from 1991 through 2014, the model provides evidence that, under the prevailing regulatory structure for the river sport fishery, annual harvest is largely controlled by overall abundance of SRFC in the system. In addition, the shape of the model suggests that, at escapement levels greater than 200,000 spawners, the rate of harvest decreases relative to the increase in escapement. Estimated river harvest in 2016, and especially 2017, was much higher than what the model would have predicted based on observed escapement in those years (Figure 3.3.2.b).

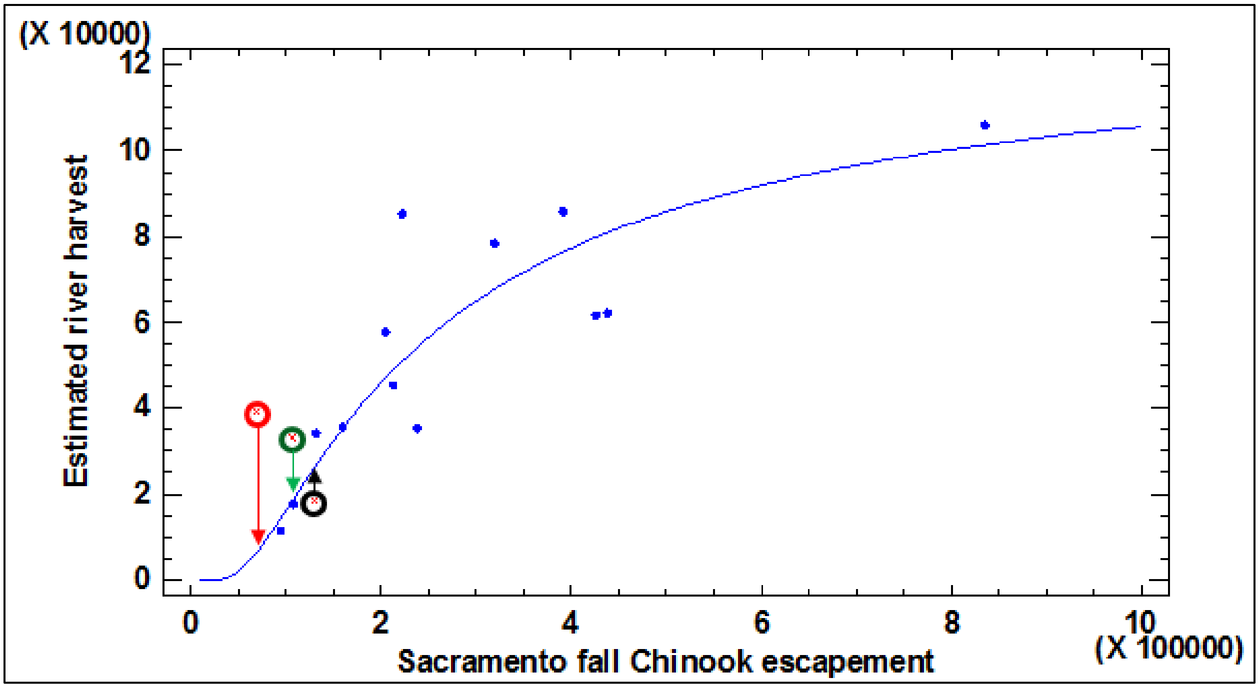

Figure 3.3.2.b. Estimated harvest of SRFC in the Sacramento River sport fishery as a function of SRFC spawner abundance (escapement) in the Sacramento Basin, based on data from 1991 – 2014 (not inclusive of all years). The data are fitted with an S-curve model, where sport harvest = exp(11.7755 – 208,203/SRFC escapement), $r^2 = 0.84$, $p<0.0001$. Data points for 2015, 2016, and 2017 are circled in black, green, and red, respectively. Harvest estimates are from CDFW, Central Valley Angler Survey, and escapement data are from CDFW, GrandTab database for Central Valley, California Chinook salmon escapement. These data include both grilse and adults combined.

Fishery performance, 2010-2017

Fishery performance for adult SRFC since the complete fishery closure in 2008 and 2009 has mostly fallen below expected levels, averaging -34 percent of forecasted harvest from 2010 through 2017 (Table 3.3.2.b). Of those eight years, realized adult harvest fell far short by 70 percent or more in three of them. In contrast, realized harvest exceeded the forecast only once since the complete fishery closure.

Table 3.3.2.b. Percent difference between the inland harvest forecast and realized harvest estimate for adult SRFC in the Sacramento Basin sport fishery, 2010-2017. Harvest forecasts are from PFMC Pre-Season III reports, and realized harvest estimates are from CDFW, Central Valley Angler Survey.

Year	PFMC adult harvest forecast	Realized adult harvest estimate	Percent difference
2010	8,200	2,469	-70%
2011	61,365	17,362	-72%
2012	74,207	62,189	-16%
2013	75,301	55,477	-26%
2014	51,233	35,725	-30%
2015	55,514	16,868	-70%
2016	24,602	23,855	-3%
2017	21,690	24,969	+15%

When considered as a percentage of total returns to the Sacramento Basin, the exploitation rate of adult SRFC in the Sacramento Basin ranged from two percent in 2010 to 36 percent in 2017 (Table 3.3.2.c), and averaged 16 percent over those eight years. As will be discussed below, the relatively high exploitation rates in 2016 and 2017 were coincident with unusual patterns in distribution of the salmon fishery resource in the Sacramento Basin, and consequently of fishing effort and harvest.

Table 3.3.2.c. Exploitation rates of total SRFC returns (adult harvest + adult escapement) to the Sacramento Basin during 2010-2017.

Year	Adult harvest estimate	Adult escapement estimate	Exploitation rate
2010	2,469	124,270	2%
2011	17,362	119,342	13%
2012	62,189	285,429	18%
2013	55,477	406,200	12%
2014	35,725	212,468	14%
2015	16,868	112,947	13%
2016	23,855	89,674	21%
2017	24,969	44,574	36%

2015 river sport fishery

Harvest of SRFC in the 2015 river sport fishery reflected the relatively low abundance of SRFC returning to the Sacramento Basin that year. The estimated harvest of 18,619 (grilse + adults) was 30 percent lower than what the river harvest model (Figure 3.3.2.b) predicted based on observed SRFC escapement.

The adult SRFC harvest fell well below the PFMC forecast in 2015, but remained within an expected range when considered as a percentage of adult SRFC returns to the Sacramento Basin. An estimated 733,921 angler hours yielded an adult SRFC harvest of 16,868. This estimate was 70 percent less than the PFMC harvest forecast of 55,514 adults (Table 3.3.2.b), but represented a relatively normal 13 percent exploitation rate of total adult returns (Table 3.3.2.c).

Distribution of SRFC harvest in 2015 reflected a relatively high level of fishing effort and success in the upper Sacramento River (survey sections 4-8 in Table 3.3.2.a), American River, and lower Sacramento River (survey sections 1-3 in Table 3.3.2.a, Figure 3.3.2.c). The percentage of harvest in the Feather River was relatively low (<10 percent). Typical concentrations of fishing effort were observed, mainly at the Barge Hole on the upper Sacramento River, at the Thermalito Afterbay Outfall on the Feather River, and at Nimbus Basin on the American River.

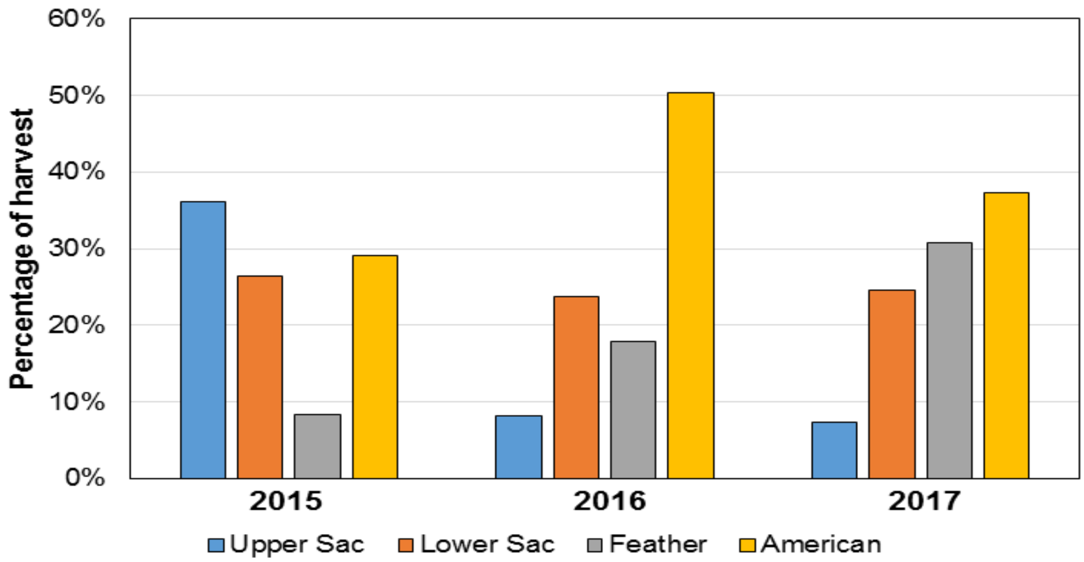

Figure 3.3.2.c. Estimated percentage of SRFC harvest in the upper Sacramento River, lower Sacramento River, Feather River, and American River during 2015-2017. Estimated harvest is of grilse and adults combined.

2016 river sport fishery

The American River received a very high level of fishing effort during the 2016 Chinook salmon sport fishery, which yielded a harvest estimate that exceeded the other Sacramento Basin management zones by factors of two to six. The fishery stock on the American River was very mixed and was boosted by a high contribution of out-of-basin SRFC of hatchery origin. Among known-origin SRFC harvested (based on 137 CWTs recovered in the fishery), 76 percent were from hatcheries outside the American River, with CNFH contributing 51 percent, followed by a 20 percent contribution from FRH (Table 3.3.2.d). While a mixed-stock composition of known hatchery-origin SRFC is expected in the lower Sacramento fishery given that this area is the primary migratory portal to upstream spawning grounds in the Sacramento Basin, harvest of hatchery-origin SRFC in the American River fishery was expected to be dominated by fish from NFH. Such was the case on the Feather River, where 83 percent of known hatchery-origin SRFC harvested were from FRH (Table 3.3.2.d). The contribution from CNFH to the Feather River fishery was ample (14 percent), but lower than the American River fishery (Table 3.3.2.d). As expected, harvest of known hatchery-origin SRFC in the upper Sacramento was highly dominated (86 percent) by fish from CNFH (Table 3.3.2.d). Thus, available evidence from CWT recoveries suggests that the relatively high level of success in the American River fishery was due at least in part to the large influx of straying SRFC from out-of-basin hatcheries, particularly CNFH.

Table 3.3.2.d. Percentage breakdown by hatchery-of-origin of SRFC CWT recoveries in the four management zones of the 2016 Sacramento River Chinook Salmon sport fishery. The number of tags, n, recovered in each zone is provided. “Other” includes adipose fin-clipped Chinook salmon for which no tag was recovered or where the tag was lost.

Hatchery	Upper Sacramento	Feather River	American River	Lower Sacramento
	(*n* = 28)	(*n* = 126)	(*n* = 136)	(*n* = 59)
Coleman National	85.7	14.3	51.5	38.9
Feather River	10.7	83.3	19.9	18.6
Nimbus	0	0	22.1	23.7
Mokelumne River	0	0	4.4	13.6
Merced River	0	0	0.7	0
Other	3.6	2.4	1.5	5.1

Additionally, flow conditions on the American River decreased over the course of the SRFC fishing season, which may have enhanced the vulnerability of these fish in the fishery. The increase in harvest of SRFC from July through November coincided with a five-fold decrease in river flow from 5,000 cfs in mid-July to 1,000 cfs in October, when harvest peaked. While the monthly harvest trend was also certainly influenced by the increasing immigration of SRFC spawners into the American River, the lower flow conditions may have also increased angler access to the fish, and thus harvest. Angler counts during this period, among other observations by Survey biologists, suggest that there were periods of very intense fishing with anglers focused on SRFC that were heavily concentrated at certain locations on the American River, especially within the uppermost three miles of the fishery area.

2017 river sport fishery

Estimated harvest of SRFC (grilse + adults) in the 2017 river sport fishery was 39,237, which was more than six times greater than the river harvest model prediction of 6,348 (Figure 3.3.2.b). Estimated escapement was among the lowest on record at 68,949 SRFC (grilse + adults), yet estimated harvest was 18 percent greater than the 2016 harvest.

The estimated harvest of 24,969 adult SRFC was 15 percent greater than that forecasted by the PFMC (21,690) for 2017 (Table 3.3.2.b). This harvest estimate corresponded to an exploitation rate of 36 percent, the highest on record (Table 3.3.2.c).

Distribution of SRFC harvest in 2017 showed a similar overall pattern to that observed in 2016 (Figure 3.3.2.c). Low SFRC returns to the upper Sacramento River again resulted in unprecedented low fishing effort and harvest there. The percentage of harvest in the upper Sacramento River was seven percent. While harvest on the American River was still relatively high at 37 percent, the greatest harvest shift was on the Feather River, where the percentage of harvest increased from 8 percent in 2015, to 18 percent in 2016, to 31 percent in 2017. Displaced angling effort from the upper Sacramento River was reportedly redirected to the Feather River at the Thermalito Afterbay Outfall, resulting in a relatively high increase in the percentage of harvest that occurred there. Percentage of harvest on the lower Sacramento River remained consistent at about 25 percent over the three seasons (Figure 3.3.2.c).

3.4 Assessment and management

3.4.1 Overview

The Sacramento Harvest Model (SHM) is a model used by the PFMC during the annual season setting process to forecast the escapement of SRFC as a function of the SI forecast and ocean and river fishery management measures. The model is defined as

$$E = SI(1 - i_o)(1 - i_r), \qquad (1)$$

where E is the forecast escapement, SI is the forecast Sacramento Index, i_o is the forecast ocean fishery impact rate, and i_r is the forecast river fishery impact rate (Mohr and O'Farrell 2014). For Chinook retention fisheries, the impact rates in Equation (1) are equivalent to harvest rates.

To assess the roles of assessment and fisheries management on escapement in 2015, 2016, and 2017, we examined whether SRFC would have met the criteria for overfished status (1) in the absence of ocean and river fisheries and (2) with fisheries but assuming no forecast or implementation error. We then examined preseason predictions versus postseason estimates of the components on the right hand side of Equation (1) to assess how relative errors in the SHM components affected escapement projections in 2015-2017.

3.4.2 Performance

If no fishing mortality occurred on SRFC in 2015, 2016, and 2017, and escapement was assumed equal to the postseason estimate of the SI, escapement in each year would have exceeded the MSST of 91,500 and the S_{MSY} of 122,000 hatchery and natural-area adults. The stock would not be classified as overfished as the geometric mean of escapement absent fishing for 2015-2017 equals 194,048.

Using postseason estimates of the SI (i.e., assuming no SI forecast error) and imposing the exploitation rate defined by the control rule given the postseason estimates of the SI (i.e., assuming no fishery implementation error), the stock would not be overfished as the geometric mean of projected escapement would be 116,047. Projected escapements under this scenario equaled 122,000, 122,000, and 104,998, in 2015, 2016, and 2017, respectively.

Table 3.4.2.a displays preseason forecasts (pre) and postseason estimates (post) for the SI, survival rates $1 - i_o$ and $1 - i_r$, and SRFC escapement.

Table 3.4.2.a. Preseason forecasts (pre) and postseason estimates (post) of Sacramento Harvest Model (SHM) components for years 2015-2017. The Sacramento Index is denoted by SI and ocean and river survival rates are denoted by $(1 - i_o)$ and $(1 - i_r)$, respectively. E represents hatchery and natural-area escapement.

Year	Type	SI	$1\text{-}i_o$	$1 - i_r$	E
2015	pre	651,985	0.61	0.86	341,017
	post	254,240	0.51	0.87	112,947
	post/pre	0.39	0.84	1.01	0.33
2016	pre	299,609	0.59	0.86	151,129
	post	205,289	0.55	0.79	89,674
	post/pre	0.69	0.94	0.92	0.59
2017	pre	230,700	0.67	0.86	133,242
	post	139,997	0.50	0.64	44,574
	post/pre	0.61	0.74	0.75	0.33

In 2015, the postseason estimate of escapement was 0.33 of the predicted value, and this difference was largely the result of over-forecasting the SI (post/pre = 0.39). The ocean survival rate $(1 - i_o)$, was lower than predicted (post/pre = 0.84); this was mostly attributed to under-predicting the ocean harvest rate for the commercial fishery (the ocean recreational fishery was well predicted). The river survival rate $(1 - i_r)$ was well predicted (post/pre = 1.01).

In 2016, the postseason estimate of escapement was 0.59 of the predicted value, and this difference was also largely the result of over-forecasting the SI (post/pre = 0.69). However, both the ocean survival rate and the river survival rate were lower than predicted which also contributed to the difference in predicted versus observed escapement.

In 2017, the postseason estimate of escapement was 0.33 of the predicted value, and this difference again was primarily the result of over-forecasting the SI (post/pre = 0.61). The ocean survival rate was lower than predicted, owing primarily to under-predicting the ocean harvest rate in the recreational fishery. The river survival rate was substantially over-predicted as well.

The SI was over-forecasted in each of the three years contributing to the overfished status, and substantially so in 2015. These errors occurred despite relatively large reductions in the SI forecasts for 2016 and 2017 resulting from the autocorrelated error component in the SI forecast model (see PFMC 2016b, 2017). The downward correction in the SI forecast was appropriate in these years, but was not of sufficient magnitude to produce accurate forecasts.

Under-prediction of both ocean and river impact rates contributed to escapement shortfalls as well. In 2016, a modification to the data range used to forecast commercial fishery impact rates in the SHM was implemented in response to serial under-predictions of these rates (see PFMC 2016c, Appendix A, for a description of this modification). The result of this modification was to increase the predicted impact rates per unit of fishing effort in the commercial fishery, and commercial fishery impact rates in 2016 and 2017 were relatively well predicted. No such modification was needed at the time for the recreational ocean or river fisheries because they had been well forecast.

Since SRFC would not have been projected to be overfished (1) in the absence of fisheries in 2015-2017 and (2) under a scenario where fishing occurred but the level of fishing mortality was not influenced by assessment or management error, we conclude that aspects of the fishery assessment and management process contributed to the stock's overfished status. However, it is noted that the total exploitation rate, estimated postseason for 2015-2017, was well below the F_{MSY} level of 0.78 (PFMC 2018, Table II-1) and thus overfishing, as defined in the FMP, did not occur

3.5 Summary of potential causal factors

The critical broods of 2012-2014 resulted in well below average ocean abundance index values and adult spawner escapement in 2015-2017. Brood year 2014 appears to be the weakest of the critical broods as it was the primary contributor to the very low 2017 SI postseason estimate and one of the lowest spawner escapement estimates on record. The record low escapement to the upper Sacramento Basin in 2017 is particularly noteworthy.

Parental spawner levels for the critical broods were near or above average, and well above the S_{MSY} of 122,000 hatchery and natural-area adults. Brood year 2014 spawners in the upper Sacramento River experienced high temperatures and low flows that likely contributed to relatively high levels of pre-spawn mortality. High pre-spawn mortality was also noted in the Feather and American rivers, perhaps resulting from high water temperatures during the spawning period for the critical brood years. Juvenile production from the Sacramento Basin was very low, given the number of parental spawners, for brood year 2014. In the lower Sacramento River during the season of outmigration, temperatures were generally high, and flows low, for brood years 2013 and 2014.

Hatchery releases of SRFC were substantially reduced for the 2012-2014 broods as compared to earlier years. Also, shifting more of the hatchery production to offsite releases during the drought impacted SRFC escapement. Adults returning from offsite releases strayed into the San Joaquin Basin and were harvested in-river at higher rates than those returning from onsite releases. Straying of offsite-released CNFH-origin SRFC into the Feather and American basins caused a large influx of sport anglers into those basins in 2016 and 2017, which increased river harvest rates on the entire SRFC stock. However, offsite releases were deemed necessary during the drought to increase survival of smolts to the ocean.

A relatively cool, productive ocean was in place for brood year 2012 SRFC smolts entering the ocean in 2013. However, both basin- and smaller scale indices of ocean productivity changed in 2014. Warming sea surface temperatures, a shift from a lipid-rich to lipid-poor copepod community, and a seabird mass mortality event began in 2014 and continued into 2015. Record high sea surface temperatures and a very strong ENSO event characterized 2015. At the same time, there were indications that both forage conditions and predation risk in the Gulf of the Farallons were favorable for the outmigrating critical broods. These lines of evidence suggest that fish from brood years 2013 and 2014 encountered mixed conditions, making it difficult to assess the role of the marine environment on the low ocean abundance and escapement estimated for 2016 and 2017. The poor large-scale ocean conditions in 2014 and 2015 may have affected adult natural mortality for fish from brood year 2012, but we lack the data to directly evaluate this.

Assessment errors also contributed to low adult spawner escapement in 2015-2017. In each of these years, the SI was over-forecast, sometimes substantially, which led to higher allowable exploitation rates than would be allowed if forecasts were very accurate. Furthermore, both ocean and river fishery mortality rates were underpredicted on several occasions. Because SRFC would not have been overfished in the absence of assessment and management error, we conclude that aspects of the fishery assessment and management process contributed to the stock's overfished status.

The relative contributions of individual factors that led to the overfished status cannot be determined given the existing data for SRFC. Yet, it is clear that some combination of river conditions, ocean conditions, and the assessment and management of salmon fisheries all contributed to the overfished status.

4.0 RECOMMENDATIONS FOR ACTION

4.1 Recommendation 1: Rebuilt criterion

Consider the SRFC stock to be rebuilt when the 3-year geometric mean of hatchery and natural-area adult escapement meets or exceeds S_{MSY}. This is the default rebuilt criterion in the FMP.

4.2 Recommendation 2: Management strategy alternatives

Recommend the Council adopt a management strategy (control rule) that will be used to guide management of salmon fisheries that impact SRFC until rebuilt status is achieved. We offer three alternative management strategies for consideration. The rebuilding time frame under each of the three alternatives is not expected to exceed the maximum rebuilding time (T_{MAX}) of 10 years. The probability of achieving rebuilt status for year 1 (2019) through 10 is projected for the three alternatives in Section 4.6: *Analysis of alternatives*.

The description of alternatives may include references intended to meet NEPA or MSA criteria. Guidelines suggest that alternatives are identified as either an 'action' or a 'no-action' alternative, and that the minimum time (T_{MIN}) and the time estimated to achieve rebuilt status (T_{target}) are acknowledged within the suite of alternatives.

> <u>Alternative I.</u> Status quo control rule. During the rebuilding period continue to use the SRFC control rule and reference points, as defined in the FMP, to set maximum allowable exploitation rates on an annual basis. Projected rebuilding time, T_{target}, is three years (see Section 4.6). This is considered a 'no-action' alternative.
>
> <u>Alternative II.</u> Status quo control rule with buffers added to maximum exploitation rates and escapement-based reference points until rebuilt status is achieved. Specifically:
>
> Reduce the maximum allowable exploitation rate by 30 percent (to 49.0 percent), increase the S_{MSY} escapement level by 30 percent (to 158,600 hatchery and natural-area adult spawners), and maintain the current relationship between the increased S_{MSY} and MSST (MSST = 0.75*S_{MSY}*1.30).

Under this Alternative, changes to the S_{MSY} and MSST reference points defined in the salmon FMP are not proposed. Rather, these values are modified only for the purpose of reducing exploitation rates relative to the status quo control rule (Alternative I). Projected rebuilding time, T_{target}, is two years (see Section 4.6). This is considered an 'action' alternative.

Alternative III. Suspend all salmon-directed ocean fisheries in the area from Cape Falcon, OR south to the U.S./Mexico border, and all Sacramento Basin in-river fisheries, until rebuilt status is achieved. Projected rebuilding time is two years (see Section 4.6). This is considered an 'action' alternative, and represents T_{MIN}.

While the Council does not have jurisdiction over tribal and in-river recreational fisheries, this Alternative is provided to serve as a bookend in the analysis of rebuilding probabilities. Assuming an exploitation rate of zero also allows for establishment of T_{MIN}.

For the three alternatives, year 1 for the T_{MIN} and T_{target} calculations is defined as 2019. This convention was adopted for SRFC due to data availability, as the most recent estimates of ocean abundance and spawner escapement are from 2018. Rebuilding times projected here assume the control rules defined in the alternatives were first applied to 2019 fisheries, and each of the nine years thereafter. However, an adopted rebuilding plan will likely be first implemented in 2020

4.3 Recommendation 3: Fall fisheries

While the stock is rebuilding, consider eliminating, or limiting, "fall" (September-December) ocean fisheries. There are inherent uncertainties with fall fisheries as abundance forecasts are not yet available. Limiting fall fisheries is precautionary because fishing mortality is not incurred (or is limited) prior to obtaining a preseason abundance forecast for SRFC. Also, no or limited fall fisheries reduce the likelihood of heavily constrained fisheries in the spring and summer of the following year.

4.4 Recommendation 4: *de minimis* fisheries

While the stock is rebuilding, consider limiting *de minimis* fisheries specified by the control rule at low forecast abundance. The FMP provides a list of circumstances the Council shall consider when recommending *de minimis* exploitation rates, including whether the stock is currently overfished.

4.5 Recommendation 5: Habitat Committee

This report has identified that habitat conditions appear to have contributed to escapement shortfalls and thus the overfished status determination. It is recommended that the Council direct the Habitat Committee to work with tribal, federal, state, and local habitat experts to review the status of the essential fish habitat affecting SRFC and, as appropriate, provide recommendations to the Council for restoration and enhancement measures within a suitable time frame, as described in the FMP.

We also note that there are several habitat-related topics outlined, but not fully developed into recommendations, in Section 4.7 *Further recommendations*. Habitat-related topics lie outside the expertise of the STT and thus the Habitat Committee is better suited to conduct such reviews

4.6 Analysis of alternatives

The STT has developed a model to assess the probability of a stock achieving rebuilt status in the years following an overfished declaration. In this model, future abundance is based on a distribution fitted to past observed abundances, accounting for lag-1 autocorrelation (the dominant lag for SRFC). Realistic levels of error in abundance forecasts, escapement estimates, and exploitation rate implementation contribute to the projected adult spawner escapements. Replicate simulations are performed to allow for projecting of the probability of achieving rebuilt status by year. The model framework allows for evaluation of alternative rebuilding plans by specifying the rebuilding plans as alternative harvest control rules. Model structure, parameterization, and additional results are presented in Appendix B.

This model was applied to SRFC in order to provide projected rebuilding times, with year 1 representing 2019. The projected rebuilding time is defined here as the number of years needed for the probability of achieving rebuilt status to meet or exceed 0.50. Given this assumption, rebuilding times are projected to be three, two, and two years for Alternatives I, II, and III, respectively (Table 4.6.a). The rebuilding probabilities in Table 4.6.a are displayed graphically in Figure 4.6.a. The buffered control rule, Alternative II (Figure 4.6.b), has intermediate rebuilding probabilities in each year relative to the status quo control rule (Alternative I) and no fishing (Alternative III). While a probability of 0.5 has been used here to define rebuilding times, the Council has the discretion to recommend a probability greater than 0.5 to be used for this purpose.

If there have been trends in productivity, future abundance may be more similar to recent abundance estimates than abundance estimates from early in the available time series. To address this, we considered a “recent abundance” scenario where future abundance was based on abundance estimates from the relatively recent past. Results for the “recent abundance” scenario are presented in Appendix B. In addition, simulations were performed under a scenario where abundance forecasts were potentially biased. Results for this scenario can also be found in Appendix B.

Table 4.6.a. Projected rebuilding probabilities by year for each of the alternatives.

	Year									
	1	2	3	4	5	6	7	8	9	10
Alternative I	0.003	0.418	**0.579**	0.684	0.768	0.827	0.865	0.898	0.923	0.940
Alternative II	0.025	**0.775**	0.870	0.908	0.937	0.956	0.970	0.980	0.985	0.990
Alternative III	0.218	**0.905**	0.943	0.959	0.974	0.983	0.989	0.992	0.995	0.997

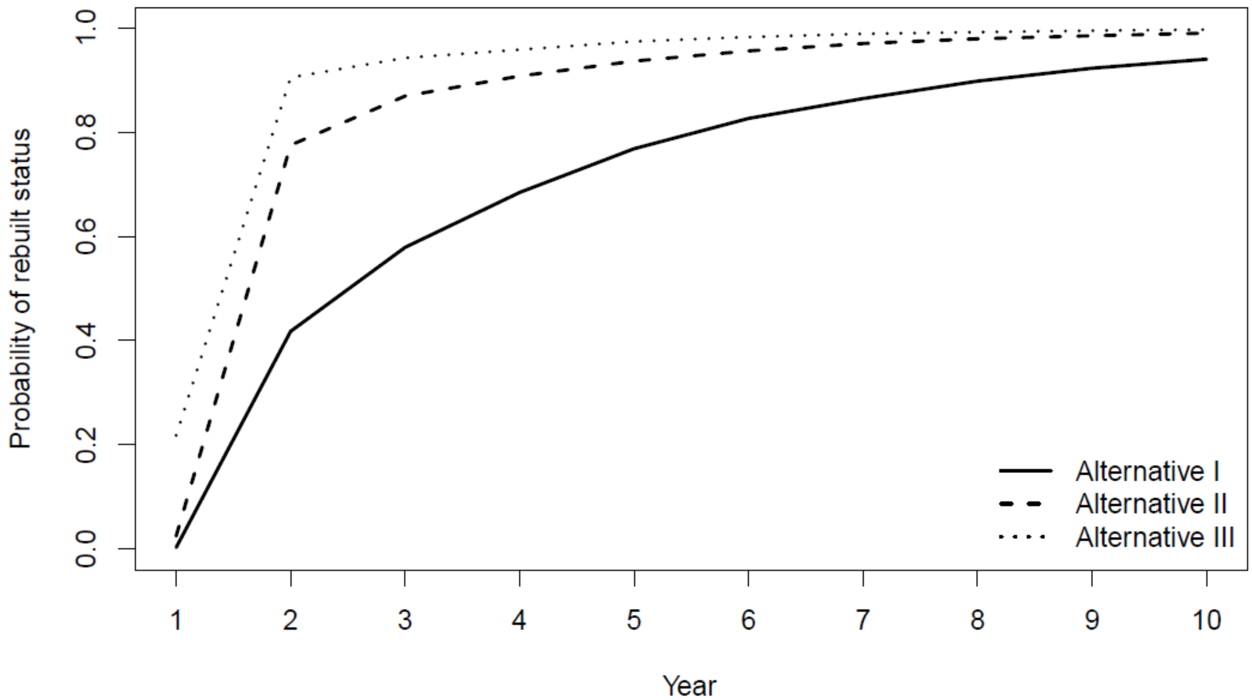

Figure 4.6.a. Projected probability of achieving rebuilt status by year under the three alternative rebuilding plans.

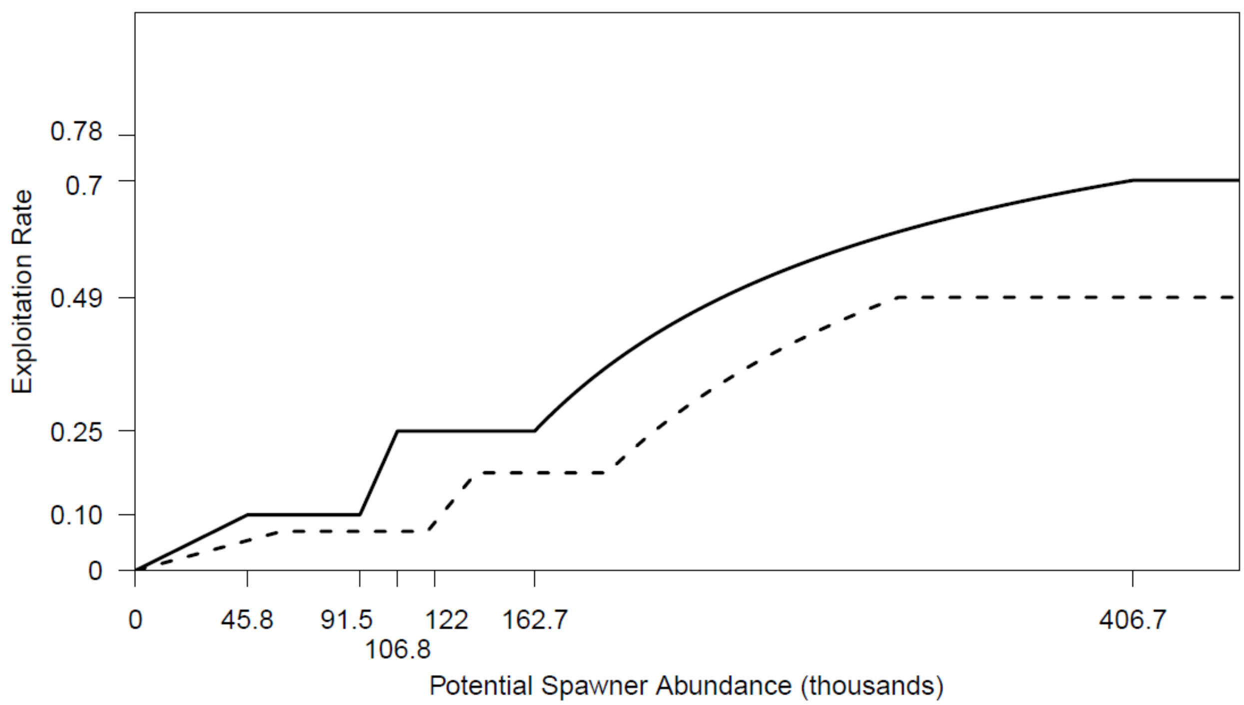

Figure 4.6.b. Control rules corresponding to Alternatives I (status quo, solid line) and II (buffered, dashed line). Alternative III (not pictured) is an exploitation rate of zero across all levels of potential spawner abundance.

The model described here was created to allow for a quantitative assessment of rebuilding alternatives. The tool has some elements of a management strategy evaluation (MSE), but lacks an explicit biological operating model. It relies on autocorrelated draws from an abundance distribution informed by past abundance levels. As such, no explicit population dynamics are included in the model. Data limitations and the short time frame for development of rebuilding plans did not allow constructing a more detailed operating model. The model also does not account for mixed-stock effects, where another stock could limit access to SRFC in ocean fisheries and prevent attainment of allowable exploitation rates. Rather, the model assumes that fisheries would be managed to target the exploitation rate specified by the control rule in each year and replicate simulation.

The probability of achieving rebuilt status for alternative rebuilding plans within a 10 year window is the core result of this analysis. The results for particular alternatives may be most useful if interpreted in a relative rather than absolute sense. Actual rebuilding periods may be somewhat shorter or longer than these results suggest due to the vagaries of future production and fisheries.

4.7 Further recommendations

1. Reconsider the current conservation objective for SRFC. The goal range of 122,000-180,000 hatchery and natural-area adult spawners was adopted as a proxy for maximum sustainable yield in 1984, and much has changed in the Sacramento Basin since that time. Consideration should be given to estimating productivity of natural-area spawners and development of management objectives for this component of the SRFC stock, as has previously been recommended by CA HSRG (2012) and Lindley et al. (2009). Consideration should also be given to development of sub-basin specific escapement goals. For example, the analysis presented in section 3.1.5 suggests that juvenile production above Red Bluff Diversion Dam is maximized at escapement levels of approximately 80,000 females. Analyses such as this applied across other portions of the Sacramento Basin could be useful in the development of new conservation objectives.

2. Develop an age-structured stock assessment for the SRFC stock using cohort reconstruction methods. The data needed to perform this assessment are largely available. Cohort reconstruction methods allow for estimation of exploitation rates, maturation rates, and other metrics of interest for SRFC. Such an assessment can also contribute to an assessment of productivity for natural-area spawners, as mentioned in Item 1 above.

3. Develop age-structured abundance forecasts. If there is evidence for changes in maturation rates for SRFC, consider evaluating forecasting models that allow for non-stationary sibling relationships or models with environmental variables that could be used to predict changes in maturation rates. Such forecasts are feasible given reconstructed cohort abundances. Forecasts of the aggregate-age SI have regularly been higher that postseason estimates of the SI, sometimes substantially. While salmon abundance forecast error is commonly high, even when age-structured methods are employed, age-structured forecast methods may result in improved forecast performance for SRFC.

4. Develop an age-structured SRFC harvest model similar in structure to the Klamath Ocean Harvest Model (KOHM). Development of such a model is contingent on the implementation of an age-structured stock assessment, as described in Recommendation 2 above.

5. There were several issues identified during the development of this Rebuilding Plan that have yet to be fully evaluated and formed into recommendations. The majority of these topics are habitat related, and include:
   a. Evaluate percent of unimpaired flow in February through June for major tributaries for years 2012 through 2015.
   b. Evaluate water quality of impaired flow reaches in major tributaries February through June for years 2012 through 2015. Determine to what extent water quality standards may have deviated from optimal conditions during the time period that the broods in question would have emigrated through those river reaches.
   c. Evaluate fall flow effects on redd de-watering.
   d. Evaluate fall Delta Cross Channel gate operations as they pertain to straying.
   e. Evaluate temperature control for SRFC spawning areas of the Feather, American, and upper Sacramento rivers. Dam operations do not cover all spawning habitat.
   f. Evaluate Delta water quality as it pertains to the requirements relative to optimal conditions for fish and how those water quality standards may have deviated during the time period that the broods in question would have emigrated through that part of the system.
   g. Examine changes in natural production over time in the Sacramento Basin. Recovery of natural populations is slower than hatchery stocks and impacts to natural production is likely to increase in the face of climate change.
   h. Incorporate age-2 river harvest in the forecasting of the SI.

5.0 SOCIO-ECONOMIC IMPACTS OF MANAGEMENT STRATEGY ALTERNATIVES

5.1 Approach to the Socio-economic analysis and benchmark/baseline

The approach for the analysis is to provide the best information possible on the impacts of each of the alternatives (including both qualitative and quantitative information). This analysis will use recent levels of economic activity and personal income going back to 2004 as a benchmark to indicate the general magnitude of the impacts of the alternatives (the rationale for the timeframe used is discussed later in this section). Even under no action, the baseline (a projection of these benchmark values into the future) would likely vary from the economic activity occurring in recent years—for example, due to changing oceanographic and market conditions. However, development of a projection model for the baseline would be difficult and there would be a great deal of uncertainty about the results. These difficulties are exemplified by the current need for this rebuilding plan. Despite basing management on the best projection models scientists have been able to develop and setting regulations that appropriately manage for MSY spawner levels, certain stocks have declined to levels that meet the criteria for an overfished determination. Furthermore, quantifying the change in the baseline from historic conditions is not practical because of the numerous factors that interact to determine future fishing conditions, including the trends of multiple salmon stocks other than KRFC and a Council season setting process during which various biological, economic, and social factors are balanced in shaping each season and determining fishing opportunities. Thus, the baseline must be qualitative, but quantitatively informed by the benchmark. Since the baseline is difficult to predict, the information resulting from this analysis that is derived from benchmark information is more useful in describing the differences in impacts between the alternatives rather than the differences between any of the alternatives and the expected baseline (benchmark projected into the future).

For the alternatives that would not change control rules or that would completely close fisheries south of Cape Falcon (Alternatives I and III, respectively), the analysis is relatively straightforward. For the intermediate alternative (Alternative II), development of quantitative information to inform the assessment is more difficult and results of the analysis are therefore more indirectly informative. The challenges are both in predicting future year stock condition for not only SRFC but also the multiple other stocks that co-occur in the fishery and might constrain harvest independent of any reduction in SRFC exploitation rates. Each year the Council engages in an intensive public process in which it shapes seasons to optimize harvest by addressing allocation issues among various harvesting sectors and geographic areas while ensuring that the preseason expectation is that escapement objectives are met for all stocks. Therefore, for Alternative II (modified control rule), the approach is to address the following. First is the question of whether this stock has typically been a constraint on ocean fisheries, i.e. historically, how frequently has the stock's status constrained ocean fisheries? To the degree that the stock has not or would not be a constraint, the short term economic impacts under a modified control rule would be minimal. Second, to what degree would the new control rule tighten that potential constraint, i.e. what is the effective percent reduction in exploitation rates that would result from the new control rule compared to the current rule for all possible stock abundance levels? And finally, what is the effect of a tightening of the constraint for ranges of potential abundances that may be more likely, i.e., for the actual stock abundances observed in recent years (2004 to the present), how much of a reduction in the exploitation rates would the new rule require as compared to the current control rule (this analysis also involves applying the current control rule to years prior to when the current control rule was adopted)? This quantitative information is intended to provide a sense of the degree of potential constraint that would be likely under the new control rule in the context of the recent benchmark. This comparison is then used as a rough indicator of the magnitude of potential impact, quantitatively informing the qualitative assessment of impacts for Alternative II.

For purposes of describing the benchmark to inform the qualitative assessment of the baseline, data for port areas in California and Oregon south of Cape Falcon during 2004 to 2016 are used, excluding the two closure years (2008 and 2009) since those two years are not expected to be representative of possible outcomes under the current status quo control rule. There are currently five salmon rebuilding plans in development that are using the same 2004-2016 range for the economic analysis, including for three Washington coho stocks. The year 2016 was selected for the last year of the period because it was the most recent year for which data was available when models were developed. Years prior to 2004 are not included because quality of the coho data in those years was not as strong as the more recent years, and the desire to maintain consistency across all rebuilding plans. There are not strong reasons to deviate from using these same years across all five plans, and this consistency is expected to simplify review and comprehension of the analyses for both decision makers and the public. These years span recent history and provide a range of escapement levels that could reasonably be expected in future years, although due to ocean, climate, and other conditions, the actual distribution may tend more toward one end of this spectrum than the other, or exhibit increased variability.

The main quantitative economic impact indicators used in this analysis are “personal income impacts.” Personal income impacts are the personal income generated as a result of direct expenditures related to fishing (recreational and commercial), processing, and support industry activities. These include personal income earned directly by those participating in fishing and processing activities (including charter vessels providing recreational trips), personal income earned by those employed in businesses that supply and service commercial fishing, recreational fishing, and processing support activities (e.g., fuel and bait suppliers and mechanics; also called indirect income), and the personal income generated by other businesses when those with direct and indirect income spend their money in the community (e.g., grocery stores and restaurants).

On the one hand, when fishing activity is reduced, personal income impacts may not be reduced proportionally because affected individuals may increase their activity in other fisheries or take up substitute economic activity in the same community. On the other hand, with respect to alternative fishing activity a recent study indicates that substitution may be minimal and there can be short and long term amplifications that result in impacts more than proportional to the reduction in the salmon fishery. For example, with respect to vessels that remained active during a closure, there was only limited evidence that more diversified vessels made up for their reduced salmon fishing with increases elsewhere (Richerson and Holland, 2017). Further, vessels that are more dependent on salmon are likely to cease all fishing activity during a salmon closure rather than increase activity in other fisheries and a portion of those will exit the fishery permanently (*Ibid.*). Even if other vessels take up the slack as opportunity returns they may be in different ports, causing geographic redistributions. Additional information on the modeling and interpretation of personal income impacts (also termed community income impacts) is provided in Chapter IV of the most recent annual salmon review make up substitute economic activity in the same community. Additional information on the modeling and interpretation of personal income impacts (also termed community income impacts) is provided in Chapter IV of the most recent annual salmon review (PFMC 2018c).

It is important to recognize that despite similarity in terminology, personal income impacts differ from the impacts of an alternative. Personal income impacts are the income associated with a particular activity, while the impacts of an alternative are the changes from status quo that occur as a result of implementing a new policy (an action alternative). For example, suppose that the personal income impacts associated with fishing under status quo are $10 million and those under an action alternative are $9 million. Therefore the impact of the action alternative, as represented by the reduction or redistribution of personal income compared with status quo, would be $1 million.

Estimates of total personal income impacts in the affected coastal communities in California and Oregon south of Cape Falcon during the period for the non-tribal commercial ocean troll salmon fishery averaged approximately $25.6 million (in inflation-adjusted 2016 dollars), ranging from $4.6 million in 2010 to $57.6 million in 2004, and for the ocean recreational salmon fishery averaged approximately $19.9 million, ranging from $10.2 million in 2010 to $29.7 million in 2013. Total coastal community personal income impacts in the affected coastal communities in California and Oregon south of Cape Falcon from the combined non-tribal commercial troll and recreational salmon fisheries conducted in ocean areas therefore averaged approximately $45.6

million during the period, ranging from $14.8 million in 2010 to $85.1 million in 2004[3] (Figure 5.1.a, Table 5.1.a).

For the five individual port areas in California, inflation-adjusted personal income impacts during the period from combined ocean non-tribal commercial troll and recreational salmon fisheries averaged approximately $5.3 million in Monterey, ranging from $1.9 million in 2016 to $11 million in 2005; $19.2 million in San Francisco, ranging from $3.9 million in 2010 to $36.9 million in 2004; $6.7 million in Fort Bragg, ranging from $2.4 million in 2010 to $12.8 million in 2013; $1.9 million in Eureka, ranging from $0.5 million in 2010 to $4.5 million in 2013; and $0.5 million in Crescent City, ranging from $21 thousand in 2010 to $2.2 million in 2004 (Figure 5.1.b, Table 5.1.a).

For the four individual port areas in Oregon south of Cape Falcon, inflation-adjusted personal income impacts during the period from combined ocean non-tribal commercial troll and recreational salmon fisheries averaged approximately $1.3 million in Brookings, ranging from $0.4 million in 2016 to $2.4 million in 2004; $4.7 million in Coos Bay, ranging from $1.4 million in 2006 to $9.5 million in 2004; $4.5 million in Newport, ranging from $1.8 million in 2011 to $9.7 million in 2004; and $1.4 million in Tillamook, ranging from $0.7 million in 2016 to $2.4 million in 2014 . (Figure 5.1.b, Table 5.1.a).

Excluding the two closure years (2008 and 2009), 2010 was the lowest year during the period for combined non-tribal ocean salmon fishery inflation-adjusted personal income impacts overall and for four of the nine affected port areas (San Francisco, Fort Bragg, Eureka, and Crescent City). Three port areas experienced their lowest year in 2016 (Monterey, Brookings and Tillamook). The remaining two port areas experienced their lowest year in 2006 (Coos Bay) and 2011 (Newport). The highest inflation-adjusted combined salmon fishery personal income impacts during the period overall was in 2004, which was also the highest year for five of the nine port areas (San Francisco, Crescent City, Brookings, Newport, and Tillamook). The highest years for the other port areas were 2005 for Monterey, 2013 for Eureka and Fort Bragg, and 2014 for Tillamook (Table 5.1.a). Note that the Astoria port area is not included. While some catch from south of Cape Falcon is landed in Astoria, the predominance of landings are from the north of Cape Falcon area. Therefore, management changes in areas south of Cape Falcon to rebuild SRFC are anticipated to have a relatively lesser effect on Astoria than the other Oregon and California port areas.

Although not included in these economic impact estimates, SRFC are also taken in recreational fisheries in the Sacramento River and its tributaries, which also contribute economically to the coastal communities and provide a benefit in addition to the economic contribution of the non-tribal ocean fisheries. Furthermore, in years when SRFC constrains ocean harvest, it may not be possible to fully access other stocks in ocean fisheries, resulting in increased ocean escapement and inside harvest opportunities and spawning for those stocks. This is particularly true for the

[3] It is important to note that income impact estimates produced for years prior to the 2010 data year were derived using a different methodology than estimates for subsequent years. While strictly speaking, estimates produced using the two methodologies may not be directly comparable, for simplicity this limitation was overlooked for this analysis, since the change more or less equivalently affected both the commercial and recreational sectors and all port areas. A description of the transition to the current income impact methodology and comparisons of results from the earlier and current models are found in Appendix E of the Review of 2014 Ocean Salmon Fisheries.

recreational inside fisheries in the Klamath Basin. While Klamath in-river recreational catch may be projected to increase under such a scenario, full realization of those increases is sometimes less certain. These estimates are sometimes increased more than actual expected catches in order to maintain the tribal share of the total harvest (which would otherwise decline if the non-tribal share declined).

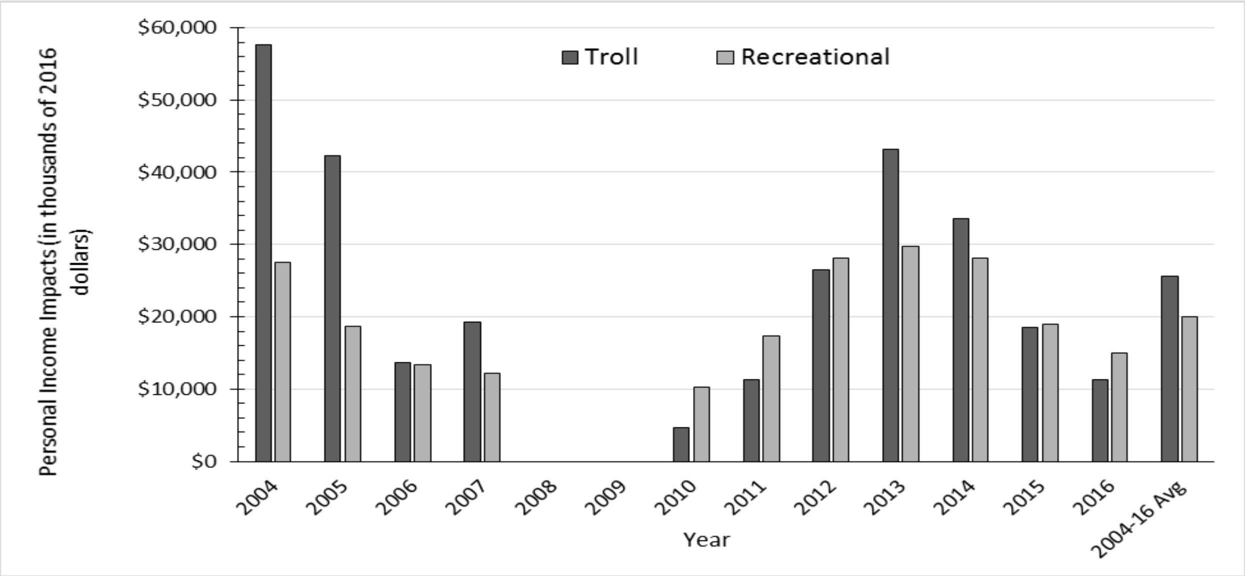

Figure 5.1.a. Estimates of total, aggregated personal income impacts in affected California and Oregon coastal communities south of Cape Falcon in thousands of real (inflation adjusted, 2016) dollars for the non-tribal commercial ocean troll and ocean recreational salmon fisheries.

Figure 5.1.b. Estimates of personal income impacts by coastal community in thousands of real (inflation adjusted, 2016) dollars for the combined non-tribal commercial ocean troll and ocean recreational salmon fisheries in California and Oregon south of Cape Falcon.

Table 5.1.a. Estimates of personal income impacts by coastal community in thousands of real (inflation adjusted, 2016) dollars for the non-tribal commercial ocean troll and ocean recreational salmon fisheries for major California and Oregon port areas south of Cape Falcon.

OCEAN TROLL	Tillamook	Newport	Coos Bay	Brookings	Crescent City	Eureka	Fort Bragg	San Francisco	Monterey	Total
2004	775	6,859	7,463	1,598	2,068	457	7,911	24,853	5,594	57,577
2005	1,336	5,713	5,660	1,340	154	465	5,767	14,360	7,537	42,332
2006	653	1,717	463	403	0	0	2,629	6,798	1,048	13,710
2007	439	715	2,085	830	354	877	3,625	8,651	1,764	19,338
2008	-	-	-	-	-	-	-	-	-	-
2009	-	-	-	-	-	-	-	-	-	-
2010	160	1,298	1,137	192	0	34	1,510	161	103	4,596
2011	59	531	2,366	264	36	442	4,247	2,690	655	11,290
2012	288	1,995	2,313	359	21	711	4,101	12,921	3,837	26,546
2013	496	1,570	6,675	625	111	1,746	10,203	19,792	2,008	43,226
2014	975	5,512	8,180	1,214	106	765	6,527	9,670	569	33,520
2015	650	2,633	3,810	515	27	440	5,175	4,409	836	18,495
2016	150	2,908	1,257	127	0	68	1,792	4,141	922	11,366
2004-16 Avg	**544**	**2,859**	**3,764**	**679**	**262**	**546**	**4,862**	**9,859**	**2,261**	**25,636**
Max	**1,336**	**6,859**	**8,180**	**1,598**	**2,068**	**1,746**	**10,203**	**24,853**	**7,537**	**57,577**
Min	**59**	**531**	**463**	**127**	**0**	**0**	**1,510**	**161**	**103**	**4,596**

RECREATIONAL	Tillamook	Newport	Coos Bay	Brookings	Crescent City	Eureka	Fort Bragg	San Francisco	Monterey	Total
2004	1,447	2,788	2,077	800	145	1,162	2,315	12,035	4,724	27,493
2005	597	947	1,291	534	110	736	1,872	9,102	3,442	18,630
2006	703	744	923	454	65	726	1,543	6,184	2,072	13,414
2007	955	1,444	1,155	465	92	948	1,245	4,383	1,518	12,204
2008	-	-	-	-	-	-	-	-	-	-
2009	-	-	-	-	-	-	-	-	-	-
2010	745	1,309	333	339	21	449	927	3,757	2,344	10,224
2011	726	1,245	407	356	80	1,625	2,107	7,151	3,618	17,315
2012	688	1,434	679	1,080	827	2,816	2,123	12,602	5,914	28,163
2013	806	1,533	1,163	1,197	735	2,793	2,554	15,172	3,754	29,707
2014	1,432	3,723	1,154	1,003	473	2,015	2,561	12,258	3,505	28,122
2015	876	1,830	563	513	68	1,061	1,698	10,505	1,831	18,943
2016	585	771	422	238	59	1,038	1,319	9,669	926	15,026
2004-16 Avg	**869**	**1,615**	**924**	**634**	**243**	**1,397**	**1,842**	**9,347**	**3,059**	**19,931**
Max	**1,447**	**3,723**	**2,077**	**1,197**	**827**	**2,816**	**2,561**	**15,172**	**5,914**	**29,707**
Min	**585**	**744**	**333**	**238**	**21**	**449**	**927**	**3,757**	**926**	**10,224**

Combined	Tillamook	Newport	Coos Bay	Brookings	Crescent City	Eureka	Fort Bragg	San Francisco	Monterey	Total
2004	2,222	9,647	9,540	2,397	2,213	1,619	10,225	36,888	10,318	85,071
2005	1,933	6,661	6,951	1,873	264	1,201	7,639	23,462	10,978	60,962
2006	1,357	2,460	1,386	856	65	726	4,172	12,982	3,120	27,124
2007	1,394	2,159	3,240	1,294	445	1,825	4,869	13,034	3,282	31,542
2008	-	-	-	-	-	-	-	-	-	-
2009	-	-	-	-	-	-	-	-	-	-
2010	905	2,606	1,471	531	21	484	2,438	3,918	2,446	14,821
2011	786	1,776	2,773	620	116	2,067	6,354	9,841	4,273	28,605
2012	976	3,430	2,992	1,438	848	3,527	6,224	25,523	9,751	54,709
2013	1,302	3,102	7,838	1,822	846	4,539	12,757	34,964	5,762	72,933
2014	2,407	9,235	9,334	2,217	579	2,780	9,088	21,927	4,074	61,642
2015	1,526	4,463	4,373	1,027	95	1,501	6,873	14,914	2,667	37,438
2016	735	3,679	1,679	365	59	1,106	3,111	13,809	1,849	26,392
2004-16 Avg	**1,413**	**4,474**	**4,689**	**1,313**	**505**	**1,943**	**6,704**	**19,206**	**5,320**	**45,567**
Max	**2,407**	**9,647**	**9,540**	**2,397**	**2,213**	**4,539**	**12,757**	**36,888**	**10,978**	**85,071**
Min	**735**	**1,776**	**1,386**	**365**	**21**	**484**	**2,438**	**3,918**	**1,849**	**14,821**

Income impact estimates from Review of 2017 Ocean Salmon Fisheries: Stock Assessment and Fishery Evaluation Document for the Pacific Coast Salmon Fishery Management Plan. Tables IV-16 and IV-17

5.2 Alternative I

Current management framework and reference points, as defined in the FMP, to set maximum allowable exploitation rates on an annual basis would remain in place. Domestic ocean fisheries impacting SRFC occur mainly in California and extend north into Oregon at least to Cape Falcon. These include ocean commercial and recreational fisheries and inside fisheries. When SRFC constrains ocean fisheries, there may be an impact to inside fishing opportunity. For example, when all KRFC impacts cannot be taken in the ocean fisheries due to an SRFC constraint then there is often an increase in opportunity in the Klamath Basin recreational fishery.

Status Quo and Alternative I would not change harvest policy for SRFC; thus by definition there would be no direct or indirect economic impact from the rebuilding plan. The estimated timeframe needed to achieve rebuilt status (with a probability of at least 50 percent) under Alternative I exploitation rates is three years (Figure 4.6.a). The actual probability of rebuilding in three years or less would be 58 percent and the probability of rebuilding in 6 years or less would be 83 percent. Since harvest policy would not change, economic activity associated with Alternative I would not be expected to change from the baseline, and the general magnitude of that activity is reflected in the benchmark economic data provided in Section 5.1 (i.e., inflation-adjusted 2004-2016 average of $45.6 million per year in income from combined non-tribal ocean commercial and recreational salmon fisheries in the affected communities south of Cape Falcon). At the same time, note that actions under rebuilding plans for other salmon stocks may cause a decline the baseline.

Because there would likely be no differences in ocean regulations relative to the baseline, there would be no impact on other stocks and subsequent fishing opportunities and economic benefits.

Not including differences in short term impacts (impacts during the rebuilding period), the long-term impacts of Alternative I are expected to be similar to the other alternatives in that all the alternatives are expected to achieve rebuilding in a relatively few number of years.

5.3 Alternative II

Under Alternative II, rebuilding is estimated to occur with at least a 50 percent probability in two years, one year less than under status quo or Alternative I. Under Alternative II, the stock would have a 78 percent chance of rebuilding in two years or less while under status quo or Alternative I it would only have a 42 percent chance of rebuilding in two years or less. The probability of rebuilding in three years or less would be 87 percent and the probability of rebuilding in six years or less is 96 percent. The cost of this increased probability of rebuilding is the reduced annual harvest times the number of years it takes to rebuild.[4] The baseline against which the reduction would be measured, and the general magnitude of that activity is reflected in the benchmark economic data provided in Section 5.1 (i.e., inflation-adjusted 2004-2016 average of $45.6 million per year in income from combined non-tribal ocean commercial and recreational salmon fisheries in the affected communities south of Cape Falcon). Additional detail is provided in Section 5.1. However, for Alternative II there are a number of uncertainties that must be taken into account in projecting harvest opportunities under reduced exploitation rates. These make it difficult to provide specific dollar value estimates for the reduced production expected under Alternative II.

[4] The analytical approach here is a quantitatively informed qualitative analysis. In an approach that was able to provide a more precise quantitative estimate of the expected annual changes in impacts, discount rates would be applied to the stream of expected changes.

The challenges include the degree to which the Alternative II control rule for SRFC will constrain ocean harvest in a particular year relative to the constraints imposed by other stocks and predicting the policy choices that the Council might make in its effort to balance maximization of harvest opportunity with between sector and geographic allocation issues (see additional discussion here and in Section 5.1).

The impact of the rebuilding policy in a particular year will depend first on the degree to which the new SRFC control rule constrains ocean regulations and harvest in a particular year. If SRFC is not constraining at either status quo or the Alternative II exploitation rates, then there would be no difference between Alternative I and II. The degree to which SRFC constrained ocean harvest in the past may indicate probability of constraints in the future (though the reduced exploitation rate control rule of Alternative II would increase the probability of constraint relative to the constraints shown in the historical data). For the 2004-2018 period, it appears that SRFC was likely constraining of the ocean fishery in 2008, 2009, 2010, and 2018. See Appendix C for more details.

The degree of constraint and resulting economic impacts under Alternative II might be indicated by the percentage reduction in the control rule exploitation rates. In general, Alternative II specifies a 30 percent reduction in exploitation rates. However, because the alternative also changes the thresholds used for applying *de minimis* exploitation rates, the percent change varies from 30 percent. Figure 5.3.a illustrates exploitation rates under Alternative II compared with status quo for a range of spawner abundance forecasts. Excluding from consideration very low abundance levels, the reductions shown in Figure 5.3.a range from a high of about 72 percent (at a potential spawner abundance of around 110,000 fish) to a low of about 19 percent (at around 310,000 fish).

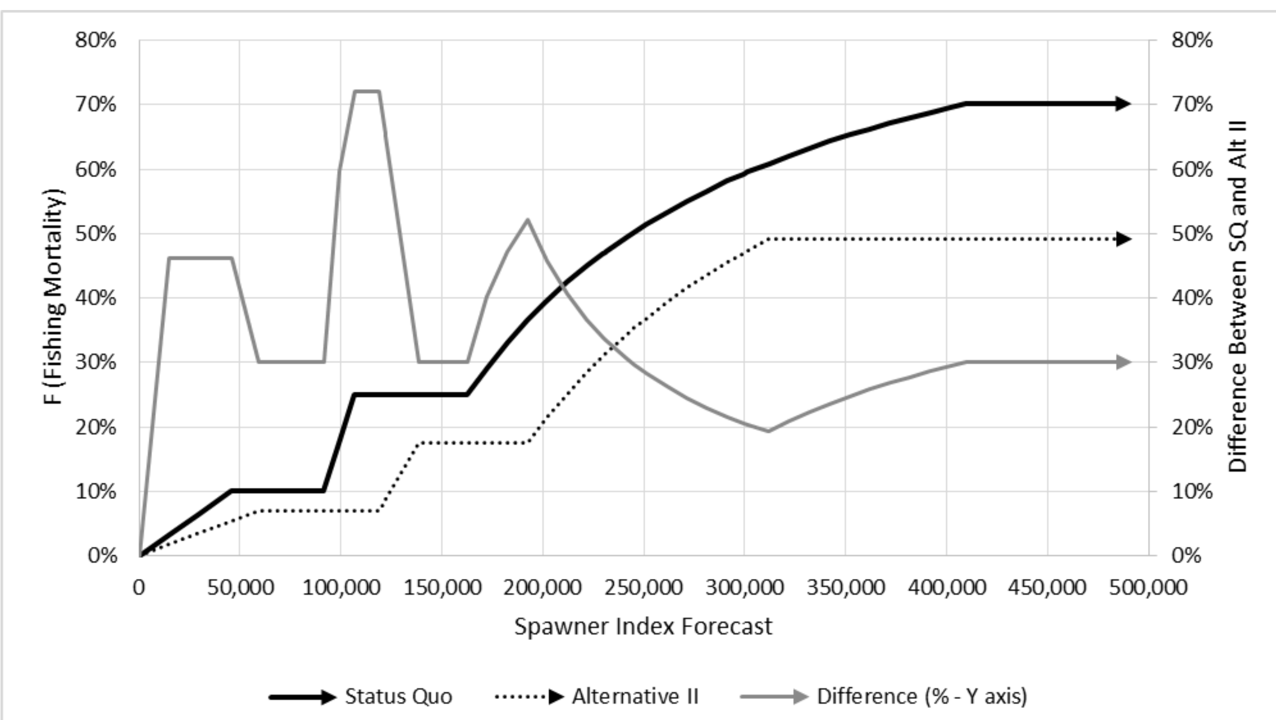

Figure 5.3.a. Comparison of Alternative I (status quo) and Alternative II exploitation rate policies.

For any particular level of exploitation rate reduction, the Council will have numerous options for shaping ocean seasons. One approach might be to scale back all time-area openings proportionally by the percent reduction in the exploitation rate. With such an approach, a 30 percent reduction in exploitation rates would be expected to result in a reduction of economic benefits of about 30 percent (compared to no action). However, in order to mitigate the impact of reduced escapement, the Council is likely to shape seasons so that more of the reduction is taken in the areas of higher stock impact, while at the same time taking allocation issues into consideration (such that harvest is not maximized to the degree it would be without these considerations). This shaping would reduce overall impacts by something less than would be projected based on proportional reductions in all times and areas. There are numerous alternative season shaping options that the Council could adopt to achieve the reductions, each with its own trade-off between total coastwide fishing opportunities and the burdens on sectors and/or local areas due to prioritizing the reductions in particular times and/or areas of higher impact.

Another indicator of the degree of impact that might be expected is a comparison of the exploitation rates that were in place (or for earlier years would have been in place) under current policy with those that would apply under Alternative II. The escapement rate in each year is determined by the SI that is used to forecast potential spawner abundance. Table 5.3.a provides a 15-year hindcast of the status quo policy and the Alternative II rebuilding policy. The percent difference column indicates the degree of additional constraint that Alternative II would have imposed and points to the magnitude of reductions in economic benefits that would be expected if the escapement rate objectives under Alternative II had been achieved through proportional reductions in all areas, without additional season shaping.

Table 5.3.a. Preseason predictions of potential spawner abundance (2004-2018) and a retrospective application of the corresponding exploitation rate policies for status quo/Alternative I and Alternative II (note the status quo policy was not in place prior to 2012).

Year	SI Forecast (Spawner Adbundance)	Allowed Exploitation Rate		Percent Difference
		Alternative I (Status Quo)	Alternative II	
2004	831,800	70.2%	49.1%	30%
2005	1,678,300	70.2%	49.1%	30%
2006	632,500	70.2%	49.1%	30%
2007	499,900	70.2%	49.1%	30%
2008	157,100	25.0%	17.5%	30%
2009	122,196	25.0%	8.7%	65%
2010	245,483	50.3%	35.4%	30%
2011	729,893	70.2%	49.1%	30%
2012	819,400	70.2%	49.1%	30%
2013	834,208	70.2%	49.1%	30%
2014	634,650	70.2%	49.1%	30%
2015	651,985	70.2%	49.1%	30%
2016	299,609	59.3%	47.1%	21%
2017	230,700	47.1%	31.3%	34%
2018	229,432	46.8%	30.9%	34%
Average (2004-18)	573,144	59.0%	40.9%	32%

For 2004 through 2018, on average the reduction in exploitation rate would have been 32 percent. If all openings are reduced, on average, by 32 percent then the economic activity associated with the fishery would be expected to be 32 percent lower, assuming that stock abundances in the period of rebuilding are similar to the recent past. As discussed above, the years in which ocean fisheries appear to have been constrained by SRFC were 2008, 2009, 2010, and 2018.

However, it should be noted that the status quo harvest policy hindcasted in Table 5.3.c was not in place prior to 2012. Therefore, while the comparison shown here provides an indication of what might happen in the future if a year similar to one in the past occurred, the difference between what actually occurred in a past year (prior to 2012) and the Alternative II policy would be different than indicated in the status quo verses Alternative II comparison in Table 5.3.c.

Additionally, while the average reduction was 32 percent, there is substantial variability in the reductions depending on the stock abundance. Given that the rebuilding periods are expected to be short, there may be more variability in the range of impacts experienced during rebuilding than indicated by the average from the longer term data series. For example, if the first two years of rebuilding are like 2009 and 2010, the reductions would be 65.1 percent and 29.6 percent, respectively, below the status quo exploitation rate policies (applied retrospectively back to 2004). Also, to the degree that SRFC is not constraining of ocean fisheries, the average reduction in ocean fisheries attributed to the Alternative II SRFC rebuilding policy would be lower.

With respect to the years of this retrospective application in which SRFC was not constraining, there still may have been an impact on ocean fisheries in those years if the reduction in exploitation rate policy were enough to make the stock a constraint. For example, if the stock is not constraining, but with a 5 percent reduction in the exploitation rate policy it becomes constraining, then the additional constraint implied by a 30 percent reduction in exploitation rate would be a potential 25 percent reduction in ocean fisheries (assuming all sectors, times, and areas are reduced by proportionally the same amount).

Alternative II (less than Alternative III) would also increase escapement that might benefit inside fisheries (e.g., Central Valley in-river recreational fisheries) and may affect productivity of other stocks which may then also have economic impacts. Depending on spawner-recruit relationships, increased escapement of other stocks that results in increased spawning may positively or negatively impact long-term production and concurrent economic benefits.

The previous discussion is focused on characterizing short term differences in socio-economic impacts. Not including differences in short term impacts (impacts during the rebuilding period), the long-term impacts of Alternative II are expected to be similar to the other alternatives in that all the alternatives are expected to achieve rebuilding in a relatively few number of years.

5.4 Alternative III

Under Alternative III, there is at least a 50 percent probability that rebuilding would occur in year two, assuming an exploitation rate of zero during that time. For the duration of the rebuilding period, Alternative III would entirely eliminate south of Cape Falcon fisheries, which are associated with the benchmark income impact values, i.e., an inflation-adjusted 2004-2016 average of $45.6 million per year in income from combined non-tribal ocean commercial and recreational salmon fisheries in the affected communities south of Cape Falcon. As discussed in Section 5.1, and for Alternative II in Section 5.3, substitute economic activity in coastal communities and increased inside fishing opportunities could make up for some of the potential loss. The total projected impact would be this annual impact multiplied by the number of years it takes to rebuild (if precise projections were being developed discount rates would also be applied reducing the weight of impacts in the more distant future relative to nearer term impacts).

While the 50 percent rebuilding probability level is reached by year two, the actual year two rebuilding probability is higher. There would be a 91 percent chance that rebuilding would occur by year two compared to a 78 percent chance under Alternative II and a 42 percent chance under Alternative I. There is also a 22 percent chance that rebuilding could occur in year 1 compared to a 3 percent chance under Alternative II and a fraction of a percentage chance under Alternative I (Table 4.6.a). The probability of rebuilding in three years or less would be 94 percent and the probability of rebuilding in 6 years or less is 98 percent.

Alternative III (more than Alternative II) would also increase escapement that might benefit inside fisheries (e.g., Central Valley in-river recreational fisheries) and may affect productivity of other stocks which may then also have economic impacts. Depending on spawner-recruit relationships, increased escapement of other stocks that results in increased spawning may positively or negatively impact long-term production and concurrent economic benefits.

Not including differences in short term impacts (impacts during the rebuilding period), the long-term impacts of Alternative III are expected to be similar to the other alternatives in that all the alternatives are expected to achieve rebuilding in a relatively few number of years.

5.5 Summary of economic impacts

The above estimates/indicators of short term impacts should be considered upper bounds on the magnitude of economic effect under the action alternatives because it is assumed that all ocean commercial and recreational time and area opportunities south of Cape Falcon would be reduced by the same proportions, whereas past experience has shown that overall economic impacts may be at least partially mitigated in many cases by using an approach in which fishery openings by area and sector in the affected region are managed differentially depending on the degree of interaction between fisheries and stocks of concern in each area. Additionally, the economic contribution to coastal communities from in-river recreational fisheries may also be affected by changes in ocean fisheries.

Table 5.5.a summarizes indications of the short-term economic trade-offs between the alternatives, assuming a 50 percent probability of rebuilding for each alternative. If rebuilding occurs more quickly (i.e., if a lower probability time to rebuilding occurs) then the impacts would be less than indicated, and if rebuilding occurs more slowly (i.e., if a higher probability time to rebuilding occurs) then the impacts would be greater than indicated. The quantitative summary of Alternative II, in particular, must be understood in the context of the qualitative analysis which both describes the derivation of the percent reduction based on past average stock abundances (which may or may not be observed over the rebuilding period) and the Council's opportunity to mitigate some of the socio-economic impacts by season shaping, as discussed in the previous paragraph.

Table 5.5.a. Summary of economic impacts of the SRFC rebuilding alternatives

	Alt I	Alt II	Alt III
Rebuilding Time Based on at least a 50% Rebuilding Probability	3 Years	2 Years	2 Years
Economic Impacts	None (no change from baseline)	Based on an average of the 2004-2018 hindcast years, a 32 percent reduction in ocean harvest-related economic activity each year during the rebuilding period (as an upper bound). However, the upper bound values may range widely depending on stock abundances during rebuilding (19% to 72% reductions), the degree to which SRFC constrains ocean harvest, the degree to which other stocks constrain harvest, and how the Council balances harvest maximizing with sector and geographic allocation. There may be some offsets through substitute economic activity and gains in in-river fisheries. There may also be economic effects of increased escapement of other stocks (either positive or negative).	Complete loss of ocean harvest-related economic activity south of Cape Falcon during rebuilding period (partially offset by gains through substitute economic activity and gains in in-river fisheries). There may also be economic effects of increased escapement of other stocks (either positive or negative and more than would occur under Alternative II).
Total Impacts (Years x Reduction in Economic Activity) (at least a 50% probability of rebuilding)	3 x (none) = 0 The probability of rebuilding in 3 years is 58%. The probability of rebuilding in one or two years is 42%. Regardless of the rebuilding time there would be no impact on economic benefits relative to the baseline.	2 x (economic effects of a 32% reduction in harvest, on average based on the hindcast--upper bound.) As noted above, in any particular year, the impacts would depend on the degree to which the stock was constraining in that year, other constraining stocks, how the Council balances maximizing harvest with allocation issues, and some small degree of partially offsetting gains. The probability of rebuilding in 2 years is 78%. The probability or rebuilding in one year is 3%, in which case there would be only a one year reduction of benefits.	2 x (complete loss of ocean fishery south of Cape Falcon, with the offsets noted above) Annual Personal Income Associated with the Fishery South of Cape Falcon , 2004-2016 (Com and Rec) Average: $45,567,000 Max: $85,071,000 Min: $14,821,000 The probability of rebuilding in 2 years is 91%.

With respect to projecting Alternative II impacts, note that Table C.2 in Appendix C shows that while SRFC was constraining in only 4 out of the last 15 years, and KRFC was constraining in only as many as 6 out of the last 15 years, if rebuilding plans are implemented for both of these stocks at the same time the likelihood that one stock or the other would constrain ocean seasons increases. Either SRFC or KRFC was constraining in 10 of the last 15 years, indicating the increased probability of a short term adverse economic impact from this policy. Additionally, while these stocks may not have been constraining in the other 5 years, it is possible that some of those years would have been constrained under the reduced exploitation rates that would be imposed under Alternative II.

6.0 AFFECTED ENVIRONMENT AND ENVIRONMENTAL EFFECTS OF MANAGEMENT STRATEGY ALTERNATIVES CONSIDERED

6.1 Introduction

This chapter will analyze the environmental impacts of the alternatives on the resources that would be more than minimally affected by the proposed action. This is a required component to adopt this integrated document as an environmental assessment under the National Environmental Policy Act (NEPA). The proposed action will have no impact on fish and fisheries other than salmon. The proposed action will affect commercial, recreational, and treaty tribal ocean salmon fisheries from Cape Falcon, OR to the U.S./Mexico border (as described in section 3.3.1).

6.2 Targeted salmon stocks

6.2.1 Affected environment

Ocean salmon fisheries in the analysis area target Chinook salmon; recreational fisheries from Cape Falcon to the Oregon/California border also target coho salmon. Coho are not targeted south of the Oregon/California border and have not been legal to retain in California commercial and recreational fisheries since the 1990s.

The Council manages several stocks of Chinook salmon under the FMP (PFMC 2016a). In the ocean, stocks of salmon comingle which results in mixed-stock fisheries. Non-target stocks, including ESA-listed stocks, will be encountered in mixed-stock fisheries. The Council's Salmon Technical Team (STT) models the degree to which target and non-target stocks are impacted by proposed fisheries, and the Council uses tools such as harvest restrictions, time and area closures, and mark-selective fisheries to limit impacts to non-target stocks (PFMC and NMFS 2017).

In the analysis area, the primary management tools are time and area closures and recreational bag limits; some fisheries also have quotas. The primary salmon stocks targeted in the analysis area are SRFC and KRFC. Fisheries in the analysis area are managed to meet FMP conservation objectives for these stocks, and to comply with ESA consultation requirements for any ESA-listed salmon stocks that are affected by salmon fisheries in the analysis area. As mentioned above, retention of coho in salmon fisheries off California has been unlawful since the 1990s.

Detailed information on spawning escapement and fisheries impacts on SRFC and KRFC are reported in the Council's annual Stock Assessment and Fishery Evaluation (SAFE) document, known as the annual Review of Ocean Salmon Fisheries. These documents are available on the Council's website (www.pcouncil.org/salmon/stock-assessment-and-fishery-evaluation-safe-documents/). Annual spawning escapement for these target stocks averaged 144,744 for SRFC (hatchery and natural-area adults) and 50,571 for KRFC (natural-area adults) for the period 2007-2017 (PFMC 2018b and PFMC 2013).

6.2.2 Environmental consequences of alternatives on target salmon stocks

{Section to be completed by NMFS after Council adopts a rebuilding plan}

6.3 Marine mammals

6.3.1 Affected environment

A number of non-ESA-listed marine mammal species occur in the analysis area. The non-ESA-listed marine mammal species that are known to interact with ocean salmon fisheries are California sea lion (*Zalophus californianus*) and harbor seals (Phoca vitulina), both species will feed on salmon, when available, and have been documented preying on hooked salmon in commercial and recreational fisheries (e.g., Weise and Harvey 1999). All marine mammals are protected under the Marine Mammal Protection Act (MMPA). Ocean salmon fisheries employ hook-and-line “troll” gear and are classified under NMFS’ MMPA List of Fisheries as Category III (83 FR 5349, February 7, 2018), indicating there is no record of substantive impacts to marine mammals from these fisheries (MMPA 118(c)(1)). Of the ESA-listed marine mammals that occur in the analysis area, only Southern Resident killer whales (a distinct population segment of Orcinus orca) are likely to be affected by salmon fisheries.

Salmon fisheries affect Southern Resident killer whales by removing Chinook salmon, an important prey species for the whales (NMFS 2009). NMFS issued a biological opinion evaluating the effects of the Pacific Coast salmon fisheries on Southern Resident killer whales in 2009 (NMFS 2009; Appendix B); this opinion concluded that the proposed ocean salmon fisheries were not likely to jeopardize the continued existence of the Southern Resident killer whales or adversely modify their critical habitat. NMFS completed a five-year review of the Southern Resident killer whale ESA listing in September 2016. There is new information regarding status, diet, and potentially the effects of fisheries on Southern Resident killer whale population trends. NMFS is reassessing the effects of salmon fisheries in light of this new information, and has reinitiated consultation on the effects of Council salmon fisheries (memorandum from Ryan Wulff, NMFS, to Chris Yates, NMFS, dated April 12, 2019).

6.3.2 Environmental consequences of alternatives on marine mammals

{Section to be completed by NMFS after Council adopts a rebuilding plan}

6.4 ESA listed salmon stocks

6.4.1 Affected environment

Several ESUs of Pacific salmon that are ESA-listed as threatened or endangered occur in the areas where Council-managed ocean salmon fisheries occur. As stated above, the only salmon species encountered in fisheries in the action area are Chinook and coho salmon. ESA-listed Chinook and coho salmon ESUs that occur within the analysis area are listed in Table 6.4.1.a.

Table 6.4.1.a. ESA-listed Chinook and coho salmon that occur within the analysis area.

ESA-listed ESUs		Status	Most recent citation
Chinook (*Oncorhynchus tshawytscha*)			
	Sacramento River Winter-run	Endangered	70 FR 37160 (June 28, 2005)
	Lower Columbia River	Threatened	70 FR 37160 (June 28, 2005)
	Central Valley Spring-run	Threatened	70 FR 37160 (June 28, 2005)
	California Coastal	Threatened	70 FR 37160 (June 28, 2005)
Coho (*Oncorhynchus kisutch)*			
	Central California Coastal	Endangered	77 FR 19552 (April 2, 2012)
	Southern Oregon/Northern California Coastal	Threatened	70 FR 37160 (June 28, 2005)
	Oregon Coastal	Threatened	76 FR 35755 (June 20, 2011)
	Lower Columbia River	Threatened	70 FR 37160 (June 28, 2005)

NMFS has issued biological opinions on the impacts of Council-managed salmon fisheries on ESA-listed salmon. Based on those biological opinions, NMFS provides guidance to the Council during the preseason planning process for setting annual management measures for ocean salmon fisheries based on the coming year's abundance projections. This guidance addresses allowable impacts on ESA-listed salmon. The Council structures fisheries to not exceed those allowable impacts. As mentioned above (Section 6.2.1), retention of coho in California fisheries is prohibited.

NMFS has previously consulted on the effects of Council-area salmon fisheries on the ESA-listed salmon ESUs in the analysis area, and has produced the biological opinions listed in Table 6.4.1.b.

Table 6.4.1.b. NMFS biological opinions regarding ESA-listed salmon ESUs likely to be affected by Council-area ocean salmon fisheries in the analysis area.

Date	Duration	Citation	Species Considered
28-Apr-99	Until reinitiated	NMFS 1999	S. Oregon/N. California Coasts coho Central California Coast coho Oregon Coast coho
28-Apr-00	Until reinitiated	NMFS 2000	Central Valley Spring-run Chinook California Coastal Chinook
13-Jun-05	Until reinitiated	NMFS 2005	California Coastal Chinook
26-Apr-12	Until reinitiated	NMFS 2012	Lower Columbia River Chinook
9-Apr-15	Until reinitiated	NMFS 2015	Lower Columbia River coho
30-Mar-18	Until reinitiated	NMFS 2018	Sacramento River winter-run Chinook

6.4.2 Environmental consequences of the alternatives on ESA-listed salmon stocks

{Section to be completed by NMFS after Council adopts a rebuilding plan}

6.5 Non-target fish species

6.5.1 Affected environment

Pacific halibut, and Pacific halibut fisheries, occur north of Point Arena, CA. Reduced fishing opportunities in California for salmon and groundfish since 2006 have resulted in a shift of fishing effort toward halibut (CDFW 2017b). Halibut allocations are established annually in the International Pacific Halibut Commission's (IPHC) regulations and the PFMC's Area 2A Catch

Sharing Plan (e.g., 82 FR 18581, April 20, 2017). Allocation of halibut quota to fisheries in the analysis area would not be affected by the Proposed Action, as the IPHC's halibut quota for the U.S. West Coast and the sub-area allocations set forth in the Catch Sharing Plan are set annually under separate processes from setting the annual salmon management measures.

Fisheries for coastal pelagic species (e.g., northern anchovy, market squid, Pacific sardine, Pacific mackerel, and jack mackerel), Dungeness crab, shrimp/prawns, and sea cucumbers occur in the analysis area and are managed by either NMFS and the PFMC (coastal pelagics) or the states (crab, shrimp/prawns, and sea cucumbers). The species targeted in these fisheries are not encountered in ocean salmon fisheries. It is possible that reductions in salmon fishing opportunities could result in a shift of effort toward these other species in California; however, we could not find any documentation to support this.

Fishermen that participate in salmon fisheries, both commercial and recreational, may also fish for groundfish (species such as rockfish and flatfish that live on or near the bottom of the ocean). Groundfish fisheries are managed under the Council's Groundfish FMP. Commercial salmon trollers that retain groundfish are considered to be participating in the open access groundfish fishery with non-trawl gear; therefore, they must comply with the regulations for the open access groundfish fishery. Likewise, recreational fishers that retain groundfish, must comply with recreational groundfish regulations. As fishery impacts to groundfish are managed under the Groundfish FMP and regulations, there would be no measurable effect on these species from the proposed action.

Albacore (*Thunnus alalunga*) is harvested on the West Coast, including the analysis area, by many of the same commercial and recreational fishermen that fish for salmon. Fishery impacts to albacore are managed under the Council's Highly Migratory Species FMP. Commercial and recreational fishers shift effort between salmon and albacore in response to available fishing opportunities, catch limits, angler demand (recreational fisheries), and changing prices for the species being harvested (commercial fisheries). As fishery impacts to albacore are managed under the Highly Migratory Species FMP and regulations, there would be no measurable effect on these species from the proposed action.

6.5.2 Environmental consequences of the alternatives on non-target fish species

{Section to be completed by NMFS after Council adopts a rebuilding plan}

6.6 Seabirds

6.6.1 Affected environment

Numerous seabird species, as well as raptors, are protected under the Migratory Bird Treaty Act, including several species that are present in areas coincident with Pacific salmon. These seabirds include grebes, loons, petrels, albatrosses, pelicans, double-crested cormorants, gulls, terns, auks, and auklets (PFMC 2013c). ESA-listed seabird species include short-tailed albatross (endangered) and marbled murrelet (threatened). Interactions with the Pacific salmon fishery typically occur in two ways: when seabirds feed on outmigrating juvenile salmon, and when seabirds are entangled or otherwise interact with fishing gear or activities. Predation on juvenile salmon by seabirds is known to occur in estuarine environments, such as the lower Columbia River, as salmon smolts migrate downstream and into marine waters. We do not know the extent to which seabirds in the analysis area depend upon juvenile salmonids as prey. Council-managed ocean salmon fisheries are limited to hook-and-line tackle. Interactions with seabirds are uncommon in these fisheries.

6.6.2 Environmental consequences of the alternatives on seabirds

{Section to be completed by NMFS after Council adopts a rebuilding plan}

6.7 Ocean and coastal habitats and ecosystem function

6.7.1 Affected environment

Salmon FMP stocks interact with a number of ecosystems along the Pacific Coast, including the California Current Ecosystem (CCE), numerous estuary and freshwater areas and associated riparian habitats. Salmon contribute to ecosystem function as predators on lower trophic level species, as prey for higher trophic level species, and as nutrient transportation from marine ecosystems to inland ecosystems. Because of their wide distribution in both the freshwater and marine environments, Pacific salmon interact with a great variety of habitats and other species of fish, mammals, and birds. The analysis area for the Proposed Action is dominated by the CCE. An extensive description of the CCE can be found in chapter three of the Council's Pacific Coast Fishery Ecosystem Plan (PFMC 2013c). Council managed salmon fisheries use hook and line gear, exclusively. This gear does not touch the ocean floor and does not disturb any habitat features. Therefore, salmon fisheries have no physical impact on habitat

6.7.2 Environmental consequences of the alternatives on ocean and coastal habitats and ecosystem function

{Section to be completed by NMFS after Council adopts a rebuilding plan}

6.8 Cultural resources

6.8.1 Affected environment

{Section to be completed by NMFS after Council adopts a rebuilding plan}

6.8.2 Environmental consequences of the alternatives on cultural resources

{Section to be completed by NMFS after Council adopts a rebuilding plan}

6.9 Cumulative impacts

{Section to be completed by NMFS after Council adopts a rebuilding plan}

7.0 REFERENCES

Anchor QEA. 2016. Conservation Planning Foundation for Restoring Chinook Salmon (*Oncorhynchus tshawytscha*) and *O. mykiss* in the Stanislaus River. Seattle.

Bakun, A. 1973. Coastal upwelling indices, West Coast of North America, 1946– 71. NOAA Tech. Rep., NMFS SSRF-671, 114 pp.

BDCP (Bay-Delta Conservation Plan). 2012. Appendix 3.G: Proposed Interim Delta Salmonid Survival Objectives. State of California.

Bowerman, T., A. Roumasset, M. L. Keefer, C. S. Sharp, and C. C. Caudill. 2017. Prespawn Mortality of Female Chinook Salmon Increases with Water Temperature and Percent Hatchery Origin. Transactions of the American Fisheries Society 147:31-42.

CA HSRG (California Hatchery Scientific Review Group). 2012. California Hatchery Review Statewide Report. Prepared for the U.S. Fish and Wildlife Service and Pacific States Marine Fisheries Commission. April 2012. 100 pp.

CDFW (California Department of Fish and Wildlife). 2017. Pacific halibut website. Available online at: https://www.wildlife.ca.gov/conservation/marine/pacific-halibut#31670773-pacific-halibut-fisheries-in-california (website accessed December 22, 2017).

CDWR (California Department of Water Resources). 2007. California Central Valley Unimpaired Flow Data Fourth Edition Draft. Bay-Delta Office, California Department of Water Resources. Available at: https://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/water_quality_control_planning/docs/sjrf_spprtinfo/dwr_2007a.pdf.

CDWR and CDFG (California Department of Water Resources and California Department of Fish and Game). 1983. Agreement concerning the operation of the Oroville Division of the State Water Project for management of fish and wildlife. Available at: https://nrm.dfg.ca.gov/documents/DocViewer.aspx.

Dick, E. J. 2011. Cowcod Status Report. NOAA Southwest Fisheries Science Center, 17 p. Available online at: https://swfsc.noaa.gov/publications/CR/2011/2011Dick2.pdf (website accessed December 13, 2017).

Fisher, F. W. 1994. Past and present status of Central Valley Chinook salmon. Conservation Biology 8:870-873.

Foott, J. S. 2013. Sacramento and Feather River Juvenile Chinook Pathogen Survey Spring 2013. U.S. Fish & Wildlife Service California – Nevada Fish Health Center, Anderson, California. Available at: http://www.fws.gov/canvfhc/reports.asp.

Foott, J. S. 2014. Sacramento and Feather River Juvenile Chinook Pathogen Survey Spring 2014. U.S. Fish & Wildlife Service California – Nevada Fish Health Center, Anderson, California. Available at: http://www.fws.gov/canvfhc/reports.asp.

Foott, J. S., J. Jacobs, and A. Imrie. 2016. Prevalence and severity of *Ceratonova shasta* and *Parvicapsula minibicornis* infection of natural Feather River Juvenile Chinook Salmon (January – May 2015). U.S. Fish & Wildlife Service California – Nevada Fish Health Center, Anderson, California. Available at: http://www.fws.gov/canvfhc/reports.asp.

Foott, J. S. and A. Imrie. 2016. Prevalence and severity of Ceratonova shasta and Parvicapsula minibicornis infection of natural Feather River Juvenile Chinook Salmon (January – May 2016). U.S. Fish & Wildlife Service California – Nevada Fish Health Center, Anderson, California. Available at: http://www.fws.gov/canvfhc/reports.asp.

Griswold, J. and R. Nielson. 2011. Review of the Central Valley Angler Survey. Prepared by Western EcoSystems Technology, Inc. for Pacific States Marine Fisheries Commission. 13 pp.

Healey, T. P. 1979. The Effect of High Temperature on the Survival of Sacramento River Chinook (King) Salmon, *Oncorhynchus tshawytscha*, Eggs and Fry. California Department of Fish and Game. Inland Fisheries Administrative Report 79-10.

Henderson, J. H., I. S. Iglesias, C. J. Michel, A. J. Ammann, and D. D. Huff. 2018. Estimating spatial-temporal differences in Chinook salmon outmigration survival with habitat and predation related covariates. U.S. Geological Survey, California Cooperative Fish and Wildlife Research Unit, Department of Fisheries Biology, Humboldt State University, Arcata, California.

Hinze, J. A. 1959. Annual Report: Nimbus Salmon and Steelhead Hatchery Fiscal Year of 1957-58. California Department of Fish and Game. Inland Fisheries Administrative Report 59-4.

HVT v. NMFS (Hoopa Valley Tribe v. National Marine Fisheries Service). 2017. Case No. 16-cv-04294-WHO (N.D. Cal. 2017).

IEA (Integrated Ecosystem Assessment). 2014. Annual State of the California Current Ecosystem report. A report of the NMFS Northwest and Southwest Fisheries Science Centers. Available at: https://www.pcouncil.org/ecosystem-based-management/annual-state-of-the-california-current-ecosystem/.

IEA. 2015. A report of the CCIEA Team (NOAA Northwest, Southwest, and Alaska Fisheries Science Centers) to the Pacific Fishery Management Council, March 8, 2015. Available at: https://www.pcouncil.org/ecosystem-based-management/annual-state-of-the-california-current-ecosystem/.

IEA. 2016. California Current Integrated Ecosystem Assessment (CCIEA) state of the California Current report, 2016. A report of the NOAA CCIEA Team to the Pacific Fishery Management Council, March 9, 2016. Editors: Dr. Toby Garfield (SWFSC) and Dr. Chris Harvey (NWFSC). Available at: https://www.pcouncil.org/ecosystem-based-management/annual-state-of-the-california-current-ecosystem/.

Johnson, M. and K. Merrick. 2012. Juvenile Salmonid Monitoring Using Rotary Screw Traps in Deer Creek and Mill Creek, Tehama County, California, Summary Report: 1994-2010. California Department of Fish and Wildlife, Northern Region Red Bluff Fisheries Office. RBFO Technical Report No. 04-2012.

Jones, T., J. K. Parrish, W. T. Peterson, E. P. Bjorkstedt, N. A. Bond, L. T. Ballance, V. Bowes, J. M. Hipfner, H. K. Burgess, J. E. Dolliver, K. Lindquist, J. Lindsey, H. M. Nevins, R. R. Robertson, J. Roletto, L. Wilson, T. Joyce, and J. Harvey. 2018. Massive mortality of a planktivorous seabird in response to a marine heatwave. Geophysical Research Letters. 45:3193–3202. Available at: https://doi.org/ 10.1002/2017GL076164.

Killam, D. and B. Mache. 2018. Salmonid Populations of the Upper Sacramento River Basin in 2017. California Department of Fish and Wildlife, Northern Region. USRBFP Technical Report No. 02-2018.

Killam, D. and K. Thompson. 2015. Drought Monitoring of Water Quality for Spawning Chinook Salmon in the Upper Sacramento River In 2014. California Department of Fish and Wildlife, Red Bluff Fisheries Office, RBFO Technical Report No. 01-2015.

Kormos, B., M. Palmer-Zwahlen, and A. Low. 2012. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement and Ocean Harvest in 2010. California Department of Fish and Game, Fisheries Branch Administrative Report 2012-02. Santa Rosa.

Leising, A. W. and 37 additional authors. 2014. State of the California Current 2013-14: El Nino looming. CalCOFI Reports 55:51-87.

Leising, A. W. and 32 additional authors. 2015. State of the California Current 2014-15: impacts of the warm-water "blob". CalCOFI Reports 56:31-68.

Lindley, S. T. and 25 additional authors. 2009. What caused the Sacramento River fall Chinook stock collapse? Pre-publication report to the Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

Mantua, N. J., S. R. Hare, Y. Zhang, J. M. Wallace, and R. C. Francis. 1997. A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the American Meteorological Society 78:1069–1079.

Martin, B. T., A. Pike, S. N. John, N. Hamda, J. Roberts, S. T. Lindley, and E. M. Danner. 2017. Phenomenological vs. biophysical models of thermal stress in aquatic eggs. Ecology Letters 20:50-59.

McClatchie, S. and 43 additional authors. 2016. State of the California Current 2015-16: comparisons with the 1997-1998 El Nino. CalCOFI Reports 57: 1-57.

Mendelssohn, R., Schwing, F. B., and Bograd, S. J. (2003), Spatial structure of subsurface temperature variability in the California Current System, 1950–1993, J. Geophys. Res., https://doi.org/10.1029/2002JC001568.

Michel, C. J. 2018. Decoupling outmigration from marine survival indicates outsized influence of streamflow on cohort success for California's Chinook salmon populations. University of California, Santa Cruz and Fisheries Ecology Division, Southwest Fisheries Science Center, National Marine Fisheries Service. Santa Cruz.

Michel, C. J., A. J. Ammann, S. T. Lindley, P. T. Sandstrom, E. D. Chapman, M. J. Thomas, G. P. Singer, A. P. Klimley, and R. B. MacFarlane. 2015. Chinook salmon outmigration survival in wet and dry years in California's Sacramento River. Canadian Journal of Fisheries and Aquatic Sciences 72:1749-1759.

Mohr, M. S. and M. R. O'Farrell. 2014. The Sacramento Harvest Model (SHM). U.S. Department of Commerce, NOAA Technical Memorandum. NOAA-TM-NMFS-SWFSC-525.

Myrick, C. A. and J. J. Cech. 2001. Temperature Effects on Chinook Salmon and Steelhead: a Review Focusing on California's Central Valley Populations. Bay-Delta Modeling Forum. Technical Publication.

NMFS (National Marine Fisheries Service). 1999. Endangered Species Act - Section 7 Consultation - Supplemental Biological Opinion and Incidental Take Statement; The Pacific Coast Salmon Plan and Amendment 13 to the Plan. Dept. of Commerce. NMFS, Protected Resources Division. NWR-1999-1855. April 28, 1999.

NMFS. (National Marine Fisheries Service) 2000. Endangered Species Act - Reinitiated Section 7 Consultation – Biological Opinion and Incidental Take Statement. Effects of Pacific Coast Salmon Plan on California Central Valley spring-run Chinook, and California coastal Chinook salmon. Dept. of Commerce. NMFS, Protected Resources Division. April 28, 2000.

NMFS. (National Marine Fisheries Service) 2005. Memo from NMFS to The Record. Endangered Species Section 7 Consultation on the Effects of Ocean Salmon Fisheries on California Coastal Chinook Salmon: Performance of the Klamath Ocean Harvest Model in 2004 and Implementation of the Reasonable and Prudent Alternative of the April 28, 2000, Biological Opinion. 14 p. R.R. McInnis. June 13, 2005. Available online at: http://www.pcouncil.org/bb/2005/0605/D2b_SUP_NMFS_June2005BB.pdf (website accessed December 22, 2017).

NMFS. (National Marine Fisheries Service) 2009a. Biological Opinion and Conference Opinion on the Long-term Operations of the Central Valley Project and State Water Project (File No. 2008/09022). Long Beach, California. Available at: https://www.westcoast.fisheries.noaa.gov/central_valley/water_operations/ocap.html.

NMFS. (National Marine Fisheries Service) 2009b. Endangered Species Act Section 7(a)(2) Consultation Biological Opinion: Effects of the Pacific Coast Salmon Plan on the Southern Resident Killer Whale (*Orcinus orca*) Distinct Population Segment. F/NWR/2009/02298, dated May 5, 2009. 82 pp.

NMFS. (National Marine Fisheries Service) 2012. Endangered Species Act Section 7(a)(2) Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat (EFH) Consultation: Effects of the Pacific Coast Salmon Plan Fisheries on the Lower Columbia River Chinook Evolutionarily Significant Unit. F/NWR/2011/06415, dated April 26, 2012. 120 pp. Available at: https://www.westcoast.fisheries.noaa.gov/publications/fishery_management/salmon_steelhead/2012-tule-chinook-biop.pdf.

NMFS (National Marine Fisheries Service). 2015. Endangered Species Act (ESA) Section 7(a)(2) Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat Consultation. Effects of the Pacific Coast Salmon Plan on the Lower Columbia River Coho Evolutionarily Significant Unit Listed Under the Endangered Species Act. NMFS Consultation Number: 2015-2026. April 9, 2015. 67 pp.

NMFS. NMFS (National Marine Fisheries Service). 2018. Endangered Species Act Section 7(a)(2) Biological Opinion and Magnuson-Stevens Fishery Conservation and Management Act Essential Fish Habitat (EFH) Response. Effects of the Pacific Coast Salmon Plan Fisheries on the Sacramento River Winter-run Chinook salmon Evolutionarily Significant Unit. NMFS Consultation Number: WCR-2017-8012. March 30, 2018. 97 pp.

Notch, J. J. 2017. Out-migration survival of wild Chinook salmon (*Oncorhynchus tshawytscha*) smolts from Mill Creek through the Sacramento River during drought conditions. University of California, Santa Cruz.

O'Farrell, M. R., M. S. Mohr, M. L. Palmer-Zwahlen, and A. M. Grover. 2013. The Sacramento Index (SI). U.S. Department of Commerce, NOAA Technical Memorandum. NOAA-TM-NMFS-SWFSC-512.

Palmer-Zwahlen, M., V. Gusman, and B. Kormos. 2018. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2013. Pacific States Marine Fisheries Commission and California Department of Fish and Wildlife. Santa Rosa.

Palmer-Zwahlen, M. and B. Kormos. 2013. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement and Ocean Harvest in 2011. California

Department of Fish and Wildlife, Fisheries Branch Administrative Report 2013-02. Santa Rosa.

Palmer-Zwahlen, M. and B. Kormos. 2015. Recovery of Coded-Wire Tags from Chinook Salmon in California's Central Valley Escapement, Inland Harvest, and Ocean Harvest in 2012. California Department of Fish and Wildlife, Fisheries Administrative Report 2015-4. Santa Rosa.

PFMC (Pacific Fishery Management Council). 2013a. Pacific Coast Fishery Ecosystem Plan for the U.S. Portion of the California Current Large Marine Ecosystem and Appendix. Portland, Oregon. 195 p.

PFMC (Pacific Fishery Management Council). 2013b. Review of 2012 Ocean Salmon Fisheries. Pacific Fishery Management Council, Portland, Oregon. (Document prepared for the Council and its advisory entities.) Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384. 375 p.

PFMC (Pacific Fishery Management Council). 2014. Preseason Report I: Stock Abundance Analysis and Environmental Assessment Part 1 for 2014 Ocean Salmon Fishery Regulations. (Document prepared for the Council and its advisory entities.) Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

PFMC. 2016a. Pacific Coast Salmon Fishery Management Plan for Commercial and Recreational Salmon Fisheries off the Coasts of Washington, Oregon, and California as Amended through Amendment 19. PFMC, Portland, OR. 91 p. Available at: http://www.pcouncil.org/salmon/fishery-management-plan/current-management-plan/.

PFMC. 2016b. Preseason Report I: Stock Abundance Analysis and Environmental Assessment Part 1 for 2016 Ocean Salmon Fishery Regulations. (Document prepared for the Council and its advisory entities.) Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

PFMC. 2016c. Preseason Report II: Proposed Alternatives and Environmental Assessment - Part 2 for 2016 Ocean Salmon Fishery Regulations. (Document prepared for the Council and its advisory entities.) Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

PFMC. 2017. Preseason Report I: Stock Abundance Analysis and Environmental Assessment Part 1 for 2017 Ocean Salmon Fishery Regulations. (Document prepared for the Council and its advisory entities.) Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

PFMC. 2018a. Preseason report III: analysis of Council adopted management measures for 2018 ocean salmon fisheries. (Document prepared for the Council and its advisory entities.)

Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 200, Portland, Oregon 97220-1384.

PFMC. 2018b. Review of 2017 ocean salmon fisheries. (Document prepared for the Council and its advisory entities.) Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 200, Portland, Oregon 97220-1384.

PFMC. 2018c. Preseason report I: stock abundance analysis for 2018 ocean salmon fisheries. (Document prepared for the Council and its advisory entities.) Pacific Fisheries Management Council, 7700 NE Ambassador Place, suite 101, Portland Oregon 97220-1384.

PFMC and NMFS. 2017. Environmental Assessment for 2017 Ocean Salmon Fisheries Management Measures. Environmental Assessment dated April 2017. 299 p.

PSMFC (Pacific States Marine Fisheries Commission). 2014a. Juvenile Salmonid Emigration Monitoring in the Lower American River, California, January – June 2013. Unpublished report prepared for the U.S. Fish and Wildlife Service and California Department of Fish and Wildlife. Sacramento.

PSMFC. 2014b. Juvenile Salmonid Emigration Monitoring in the Lower American River, California, January – May 2014. Unpublished report prepared for the U.S. Fish and Wildlife Service and California Department of Fish and Wildlife. Sacramento.

Quinn, T. P. 2005. The Behavior and Ecology of Pacific Salmon and Trout. American Fisheries Society. Bethesda, Maryland.

Richerson, K., and Holland. D. S. 2017. Quantifying and predicting responses to a US West Coast Salmon fishery closure. ICES Journal of Marine Science, doi:10.1093/icesjms/fsx093.

Ralston, S., K.M. Sakuma, and J. C. Field. 2013. Interannual variation in pelagic juvenile rockfish abundance—going with the flow. Fisheries Oceanography 22:288–308. doi:10.1111/fog.12022.

Ralston, S., J.C. Field, and K.S. Sakuma. 2015. Longterm variation in a central California pelagic forage assemblage. Journal of Marine Systems 146:26–37. http://dx.doi.org/10.1016/j.jmarsys.2014.06.013.

Sakuma, K.M, J.C. Field, N.J. Mantua, S. Ralston, B.B. Marinovic, and C.N. Carrion. 2016. Anomalous epipelagic micronekton assemblage patterns in the neritic waters of the California Current in spring 2015 during a period of extreme ocean conditions. CalCOFI Reports 57:163-183.

Santora, J.A., E.L. Hazen, I.D. Schroeder, S.J. Bograd, K.M. Sakuma, and J.C. Field. 2017. Impacts of ocean climate variability on biodiversity of pelagic forage species in an upwelling ecosystem. Marine Ecology Progress Series 580:205-220. https://doi.org/10.3354/meps12278.

Schwing, F. B., M. O'Farrell, J. M. Steger, and K. Baltz. 1996. Coastal upwelling indices, West Coast of North America, 1946–1995. NOAA Tech. Memo., NOAA-TM-NMFS-SWFSC-231, 144 pp.

Silva, J. and K. Bouton. 2015. Juvenile Salmonid Emigration Monitoring in the Lower American River, California, January – May 2015. Unpublished report prepared for the U.S. Fish and Wildlife Service and California Department of Fish and Wildlife. Sacramento.

Smith, S. 1950. Upper Sacramento River sport fishery. U.S. Fish and Wildlife Service, Special Scientific Report - Fisheries, No. 34. 44 pp.

Snider, B. and K. Vyverberg. 1995. Chinook salmon redd survey: lower American River, fall 1993. California Department of Fish and Game, Environmental Sciences Division, Stream Flow and Habitat Evaluation Program. Sacramento.

USBR and CDWR (United States Bureau of Reclamation and California Department of Water Resources). 2014. Central Valley Project and State Water Project drought operations plan and operational forecast, April 1, 2014 through November 15, 2014: Balancing multiple needs in a third dry year. Sacramento. Available at: https://water.ca.gov/LegacyFiles/waterconditions/docs/2014-Operations-Plan.pdf.

USFWS (United States Fish and Wildlife Service). 2014. Contingency release strategies for Coleman National Fish Hatchery juvenile fall Chinook salmon due to severe drought conditions in 2014. Sacramento.

Voss, S. D. and W. R. Poytress. 2017. Brood year 2015 juvenile salmonid production and passage indices at the Red Bluff Diversion Dam. Report of U.S. Fish and Wildlife Service to U.S. Bureau of Reclamation, Sacramento.

Ward et al (2015) Peggy Mundy to provide (App D)

Warzybok, P., J.A. Santora, D.G. Ainley, R.W. Bradley, J.C. Field, P.J. Capitolo, R.D. Carle, M. Elliott, J.N. Beck, G.J. McChesney, M.M. Hester, and J. Jahncke. 2018 Prey switching and consumption by seabirds in the central California Current upwelling ecosystem: Implications for forage fish management. Journal of Marine Systems 185:25:39. https://doi.org/10.1016/j.jmarsys.2018.04.009.

Weise, M.J. and J.T. Harvey. 1999. Food habits of California sea lions (*Zalophus californicus*) and their impact on salmonid fisheries in Monterey Bay, California. Report submitted to Fishermen's Alliance of California. Moss Landing Marine Laboratories (MLML) Technical Publication No. 99-01, 39 p. Available online at: http://islandora.mlml.calstate.edu/islandora/object/islandora%3A2382/datastream/OBJ/view (website accessed December 22, 2017).

Wells, B.K, J.A. Santora, M.J. Henderson, P. Warzybok, J. Jahncke, R.W. Bradley, D.D. Huff, I.D. Schroeder, P. Nelson, J.C. Field, and D.G. Ainley. 2017. Environmental conditions and prey-switching by a seabird predator impact juvenile salmon survival. Journal of Marine Systems 174:54-63. http://dx.doi.org/10.1016/j.jmarsys.2017.05.008.

Wells, B.K., J.A. Santora, I.D. Schroeder, N. Mantua, W.J.Sydeman, D.D. Huff, and J.C. Field. 2016. Marine ecosystem perspectives on Chinook salmon recruitment: a synthesis of empirical and modeling studies from a California upwelling system. Marine Ecology Progress Series 552:271-284. doi: 10.3354/meps11757.

Wells, B.K, J.A. Santora, J.C. Field, R.B. MacFarlane, B.B. Marinovic, and W.J. Sydeman. 2012. Population dynamics of Chinook salmon *Oncorhynchus tshawytschsa* relative to prey availability in the central California coastal region. Marine Ecology Progress Series 457:125-137. doi: 10.3354/meps09727.

Wells, B. K. and 43 additional authors. 2017. State of the California Current 2016-17: still anything but “normal” in the north. CalCOFI Reports 58:1:55.

Wixom, L. H., J. Pisciotto, and C. Lake. 1995. Final performance report: Sacramento River system sport fish catch inventory. California Department of Fish and Game, Inland Fisheries Division. 53 pp.

Yoshiyama, R. M., F. W. Fisher, and P. B. Moyle. 1998. Historical abundance and decline of Chinook salmon in the Central Valley region of California. North American Journal of Fisheries Management 18:487-521.

APPENDIX A - STATUS DETERMINATION CRITERIA

The following is an excerpt from the Salmon Fishery Management Plan

3.1 STATUS DETERMINATION CRITERIA

"Overfished. A stock or stock complex is considered ''overfished'' when its biomass has declined below a level that jeopardizes the capacity of the stock or stock complex to produce MSY on a continuing basis."

NS1Gs (600.310 (e)(2)(i)(E))

In establishing criteria by which to determine the status of salmon stocks, the Council must consider the uncertainty and theoretical aspects of MSY as well as the complexity and variability unique to naturally producing salmon populations. These unique aspects include the interaction of a short-lived species with frequent, sometimes protracted, and often major variations in both the freshwater and marine environments. These variations may act in unison or in opposition to affect salmon productivity in both positive and negative ways. In addition, variations in natural populations may sometimes be difficult to measure due to masking by hatchery produced salmon.

3.1.1 General Application to Salmon Fisheries

In establishing criteria from which to judge the conservation status of salmon stocks, the unique life history of salmon must be considered. Chinook, coho, and pink salmon are short-lived species (generally two to six years) that reproduce only once shortly before dying. Spawning escapements of coho and pink salmon are dominated by a single year-class and Chinook spawning escapements may be dominated by no more than one or two year-classes. The abundance of year-classes can fluctuate dramatically with combinations of natural and human-caused environmental variation. Therefore, it is not unusual for a healthy and relatively abundant salmon stock to produce occasional spawning escapements which, even with little or no fishing impacts, may be significantly below the long-term average associated with the production of MSY.

Numerous West Coast salmon stocks have suffered, and continue to suffer, from non-fishing activities that severely reduce natural survival by such actions as the elimination or degradation of freshwater spawning and rearing habitat. The consequence of this man-caused, habitat-based variation is twofold. First, these habitat changes increase large scale variations in stock productivity and associated stock abundances, which in turn complicate the overall determination of MSY and the specific assessment of whether a stock is producing at or below that level. Second, as the productivity of the freshwater habitat is diminished, the benefit of further reductions in fishing mortality to improve stock abundance decreases. Clearly, the failure of several stocks managed under this FMP to produce at an historical or consistent MSY level has little to do with current fishing impacts and often cannot be rectified with the cessation of all fishing.

To address the requirements of the MSA, the Council has established criteria based on biological reference points associated with MSY exploitation rate and MSY spawning escapement. The criteria are based on the unique life history of salmon and the large variations in annual stock abundance due to numerous environmental variables. They also take into account the uncertainty and imprecision surrounding the estimates of MSY, fishery impacts, and spawner escapements. In recognition of the unique salmon life history, the criteria differ somewhat from the general guidance in the NS1 Guidelines (§600.310).

3.1.4 Overfished

"For a fishery that is overfished, any fishery management plan, amendment, or proposed regulations… for such fishery shall (A) specify a time period for ending overfishing and rebuilding the fishery that shall:(i) be as short as possible, taking into account the status and biology of any overfished stocks of fish, the needs of the fishing communities, recommendations by international organizations in which the United States participates, and the interaction of the overfished stock within the marine ecosystem; and (ii) not exceed 10 years, except in cases where the biology of the stock of fish, other environmental conditions, or management measures under an international agreement in which the United States participates dictate otherwise…."

Magnuson-Stevens Act, §304(e)(4)

A stock will be considered overfished if the 3-year geometric mean of annual spawning escapements falls below the MSST, where MSST is generally defined as $0.5*S_{MSY}$ or $0.75*S_{MSY}$, although there are some exceptions (Table 3-1). Overfished determinations will be made annually using the three most recently available postseason estimates of spawning escapement.

3.1.4.1 Council Action

When the overfished status determination criteria set forth in this FMP have been triggered, the Council shall:

1) notify the NMFS NWR administrator of this situation;
2) notify pertinent management entities;
3) structure Council area fisheries to reduce the likelihood of the stock remaining overfished and to mitigate the effects on stock status;
4) direct the STT to propose a rebuilding plan for Council consideration within one year.

Upon formal notification from NMFS to the Council of the overfished status of a stock, a rebuilding plan must be developed and implemented within two years.

The STT's proposed rebuilding plan shall include:

1) an evaluation of the roles of fishing, marine and freshwater survival in the overfished determination;
2) any modifications to the criteria set forth in section 3.1.6 below for determining when the stock has rebuilt,
3) recommendations for actions the Council could take to rebuild the stock to S_{MSY}, including modification of control rules if appropriate, and;
4) a specified rebuilding period.

In addition, the STT may consider and make recommendations to the Council or other management entities for reevaluating the current estimate of S_{MSY}, modifying methods used to forecast stock abundance or fishing impacts, improving sampling and monitoring programs, or changing hatchery practices.

Based on the results of the STT's recommended rebuilding plan, the Council will adopt a rebuilding plan for recommendation to the Secretary. Adoption of a rebuilding plan will require implementation either through an FMP amendment or notice and comment rule-making process. Subject to Secretarial approval, the Council will implement the rebuilding plan with appropriate actions to ensure the stock is rebuilt in as short a time as possible based on the biology of the stock but not to exceed ten years, while taking into consideration the needs of the commercial, recreational and tribal fishing interests and coastal communities. The existing control rules provide a default rebuilding plan that targets spawning escapement at or above MSY, provided sufficient recruits are available, and targets a rebuilding period of one generation (two years for pink salmon, three years for coho, and five years for Chinook). If sufficient recruits are not available to achieve spawning escapement at or above MSY in a particular year, the control rules provide for the potential use of *de minimis* exploitation rates that allow continued participation of fishing communities while minimizing risk of overfishing. However, the Council should consider the specific circumstances surrounding an overfished determination and ensure that the adopted rebuilding plan addresses all relevant issues.

Even if fishing is not the primary factor in the depression of the stock, the Council must act to limit the exploitation rate of fisheries within its jurisdiction so as not to limit rebuilding of the stock or fisheries. In cases where no action within Council authority can be identified which has a reasonable expectation of contributing to the rebuilding of the stock in question, the Council will identify the actions required by other entities to recover the depressed stock. Due to a lack of data for some stocks, environmental variation, economic and social impacts, and habitat losses or problems beyond the control or management authority of the Council, it is possible that rebuilding of depressed stocks in some cases could take much longer than ten years. The Council may change analytical or procedural methodologies to improve the accuracy of estimates for abundance, harvest impacts, and MSY escapement levels, and/or reduce ocean harvest impacts when it may be effective in stock recovery. For those causes beyond Council control or expertise, the Council may make recommendations to those entities which have the authority and expertise to change preseason prediction methodology, improve habitat, modify enhancement activities, and re-evaluate management and conservation objectives for potential modification through the appropriate Council process.

In addition to the STT assessment, the Council may direct its Habitat Committee (HC) to work with federal, state, local, and tribal habitat experts to review the status of the essential fish habitat affecting the overfished stock and, as appropriate, provide recommendations to the Council for restoration and enhancement measures within a suitable time frame. However, this action would be a priority only if the STT evaluation concluded that freshwater survival was a significant factor leading to the overfished determination. Upon review of the report from the HC, the Council will consider appropriate actions to promote any solutions to the identified habitat problems.

3.1.5 Not Overfished-Rebuilding

After an overfished status determination has been triggered, once the stock's 3-year geometric mean of spawning escapement exceeds the MSST, but remains below S_{MSY}, or other identified rebuilding criteria, the stock status will be recognized as "not overfished-rebuilding". This status level requires no Council action, but rather is used to indicate that stock's status has improved from the overfished level but the stock has not yet rebuilt.

3.1.6 Rebuilt

The default criterion for determining that an overfished stock is rebuilt is when the 3-year geometric mean spawning escapement exceeds S_{MSY}; the Council may consider additional criteria for rebuilt status when developing a rebuilding plan and recommend such criteria, to be implemented subject to Secretarial approval.

Because abundance of salmon populations can be highly variable, it is possible for a stock to rebuild from an overfished condition to the default rebuilding criterion in as little as one year, before a proposed rebuilding plan could be brought before the Council.

In some cases it may be important to consider other factors in determining rebuilt status, such as population structure within the stock designation. The Council may also want to specify particular strategies or priorities to achieve rebuilding objectives. Specific objectives, priorities, and implementation strategies should be detailed in the rebuilding plan.

3.1.6.1 Council Action

When a stock is determined to be rebuilt, the Council shall:

1) notify the NMFS NWR administrator of its finding, and;
2) notify pertinent management entities.

3.1.7 Changes or Additions to Status Determination Criteria

Status determination criteria are defined in terms of quantifiable, biologically-based reference points, or population parameters, specifically, S_{MSY}, MFMT (F_{MSY}), and MSST. These reference points are generally regarded as fixed quantities and are also the basis for the harvest control rules, which provide the operative guidance for the annual preseason planning process used to establish salmon fishing seasons that achieve OY and are used for status determinations as described above. Changes to how these status determination criteria are defined, such as MSST = $0.50*S_{MSY}$, must be made through a plan amendment. However, if a comprehensive technical review of the best scientific information available provides evidence that, in the view of the STT, SSC, and the Council, justifies a modification of the estimated values of these reference points, changes to the values may be made without a plan amendment. Insofar as possible, proposed reference point changes for natural stocks will only be reviewed and approved within the schedule established for salmon methodology reviews and completed at the November meeting prior to the year in which the proposed changes would be effective and apart from the preseason planning process. SDC reference points that may be changed without an FMP amendment include: reference point objectives for hatchery stocks upon the recommendation of the pertinent federal, state, and tribal management entities; and Federal court-ordered changes. All modifications would be documented through the salmon methodology review process, and/or the Council's preseason planning process.

APPENDIX B - MODEL DESCRIPTION

Introduction

Salmon rebuilding plans must include, among other requirements, a specified rebuilding period. In addition, the National Environmental Policy Act (NEPA) analysis of rebuilding plans requires the development of rebuilding plan alternatives. In past assessments, the rebuilding period and alternative rebuilding plans were developed using expert knowledge, with no particular quantitative assessment. Beginning in 2018, the Salmon Technical Team (STT) developed a simple tool to assess the probability of a stock achieving rebuilt status in each year following an overfished declaration. Here we describe this model and provide additional results for the Sacramento River fall Chinook (SRFC) salmon stock.

Methods

The methods described here are for a single replicate simulation.

For SRFC, there is substantial evidence for positive lag-1 autocorrelation in log-transformed values of the index of abundance (Sacramento Index, SI), with autocorrelation coefficient $\rho = 0.802$. To account for this, model log-scale abundance, $\log(N_t)$, is characterized by lag-1 autocorrelated draws from a Normal distribution with parameters estimated from the SI series. Simulated abundance $\log(N_t)$ is thus a function of $\log(N_{t-1})$, ρ, and the distribution of past abundance on the log scale,

$$\log(N_t) = \rho[\log(N_{t-1})] + (1-\rho)Y_t, \tag{1}$$

with Y_t a random draw from the distribution

$$Y_t \sim \text{Normal}\left[\log(\overline{\text{SI}}) - 0.5\sigma^2_{\log(\text{SI})}, \sqrt{\frac{(1-\rho^2)\sigma^2_{\log(\text{SI})}}{(1-\rho)^2}}\right] \tag{2}$$

where $\overline{\text{SI}}$ is the arithmetic mean of the observed SI time series and $\sigma^2_{\log(\text{SI})}$ is the variance of the log-transformed SI time series. The standard deviation term in Equation 2 is derived from the expression for the standard deviation of a sum of two random variables. Simulated log-scale abundance in year *t* is then back-transformed to the arithmetic scale, $N_t = \exp[\log(N_t)]$.

The forecast abundance ($\hat{N}$) is drawn from a lognormal distribution,

$$\hat{N}_t \sim \text{Lognormal}[\log(N_t) - 0.5\sigma^2_{\log(\hat{N})},\ \sigma_{\log(\hat{N})}] \tag{3}$$

with the bias corrected mean and standard deviation specified on the log scale. The log-scale standard deviation was calculated as

$$\sigma_{\log(\hat{N})} = \sqrt{\log\left(1 + \mathrm{CV}_{\hat{N}}^2\right)} \quad (4)$$

with $\mathrm{CV}_{\hat{N}}$ representing the coefficient of variation for the abundance forecast. $\mathrm{CV}_{\hat{N}}$ is a model parameter that defines the degree of abundance forecast error.

The forecast abundance $\hat{N}_t$ is applied to the harvest control rule to determine the allowable exploitation rate, $\hat{F}_t$. The hat notation for $\hat{F}$ indicates that this exploitation rate is a target exploitation rate that is derived from an abundance forecast.

Adult spawner escapement E_t is thus

$$E_t = N_t \times (1 - F_t) \quad (5)$$

where N_t is the "true" abundance and F_t is the realized exploitation rate. The realized exploitation rate is a random draw from the beta distribution

$$F \sim \mathrm{Beta}(\alpha, \beta) \quad (6)$$

with parameters

$$\alpha = \frac{1 - \hat{F}_t(1 + \mathrm{CV}_F^2)}{\mathrm{CV}_F^2} \quad (7)$$

and

$$\beta = \frac{\frac{1}{\hat{F}_t} - 2 + \hat{F}_t + \left(\hat{F}_t - 1\right)\mathrm{CV}_F^2}{\mathrm{CV}_F^2}. \quad (8)$$

The coefficient of variation for the exploitation rate implementation error, CV_F, is a model parameter that determines the degree of error between the target and realized exploitation rates.

Because escapement is estimated with error, escapement estimates $\hat{E}_t$ are drawn from a lognormal distribution,

$$\hat{E} \sim \mathrm{Lognormal}[\log(E_t) - 0.5\sigma_{\log(\hat{E})}^2,\ \sigma_{\log(\hat{E})}] \quad (9)$$

where the bias corrected mean and standard deviation are specified on the log scale. The log-scale standard deviation was computed in the same manner as Equation 4.

The procedure described above is repeated for each year (years 1 [2019] through 10 following the overfished status determination), and each replicate. Simulations are initiated with the 2018 estimated abundance; simulated abundance in t = 1 is therefore a function of the 2018 abundance, the autocorrelation coefficient, and a draw from the abundance distribution (Equation 1).

A stock is assumed to be rebuilt when the geometric mean of $\hat{E}$ computed over the previous three years exceeds the maximum sustainable yield spawner escapement, S_{MSY}. The probability of achieving rebuilt status in year t is the cumulative probability of achieving a 3-year geometric mean greater than or equal to S_{MSY} by year t.

Results

Results for SRFC presented here are the product of 10,000 replicate simulations of 10 years. The probability of being rebuilt in year t = 1 is the proportion of the 10,000 simulations that resulted in the geometric mean of the estimated SRFC escapement in t = -1 (42,714: the 2017 hatchery and natural-area adult escapement), the estimated escapement in t = 0 (105,739: the 2018 hatchery and natural-area adult escapement), and the simulated escapement estimate in year t = 1 (2019) exceedingS_{MSY}. For t = 2, the probability of being rebuilt is the probability that the stock was rebuilt in either t = 1 or t = 2.

Table 4.6.a and Figure 4.6.a in the body of the report display the probabilities of achieving rebuilt status under three management strategies: (I) the status quo control rule, (II) a buffered control rule (Figure 4.6.b), and (III) no fishing. For these simulations the following parameter values were assumed: $\mathrm{CV}_{\hat{N}} = 0.2$, $\mathrm{CV}_{\hat{E}} = 0.2$, and $\mathrm{CV}_F = 0.1$. The parameter values were chosen because they produce plausible levels of abundance forecast error, escapement estimation error, and implementation error for realized exploitation rates.

Rebuilding probabilities were also computed for the status quo control rule under an increased CV of the abundance forecast error($\mathrm{CV}_{\hat{N}} = 0.6$), the escapement estimation error($\mathrm{CV}_{\hat{E}} = 0.5$), and the exploitation rate implementation error (CV_F = 0.2). Figure 1 displays distributions of the abundance forecast error, escapement estimation error, and exploitation rate implementation error given the base case CVs and the CVs used for the alternative scenarios. Figure 2 displays results for these alternative scenarios under the status quo control rule. Overall, the probability of achieving rebuilt status by year is relatively insensitive to increased values of these parameters.

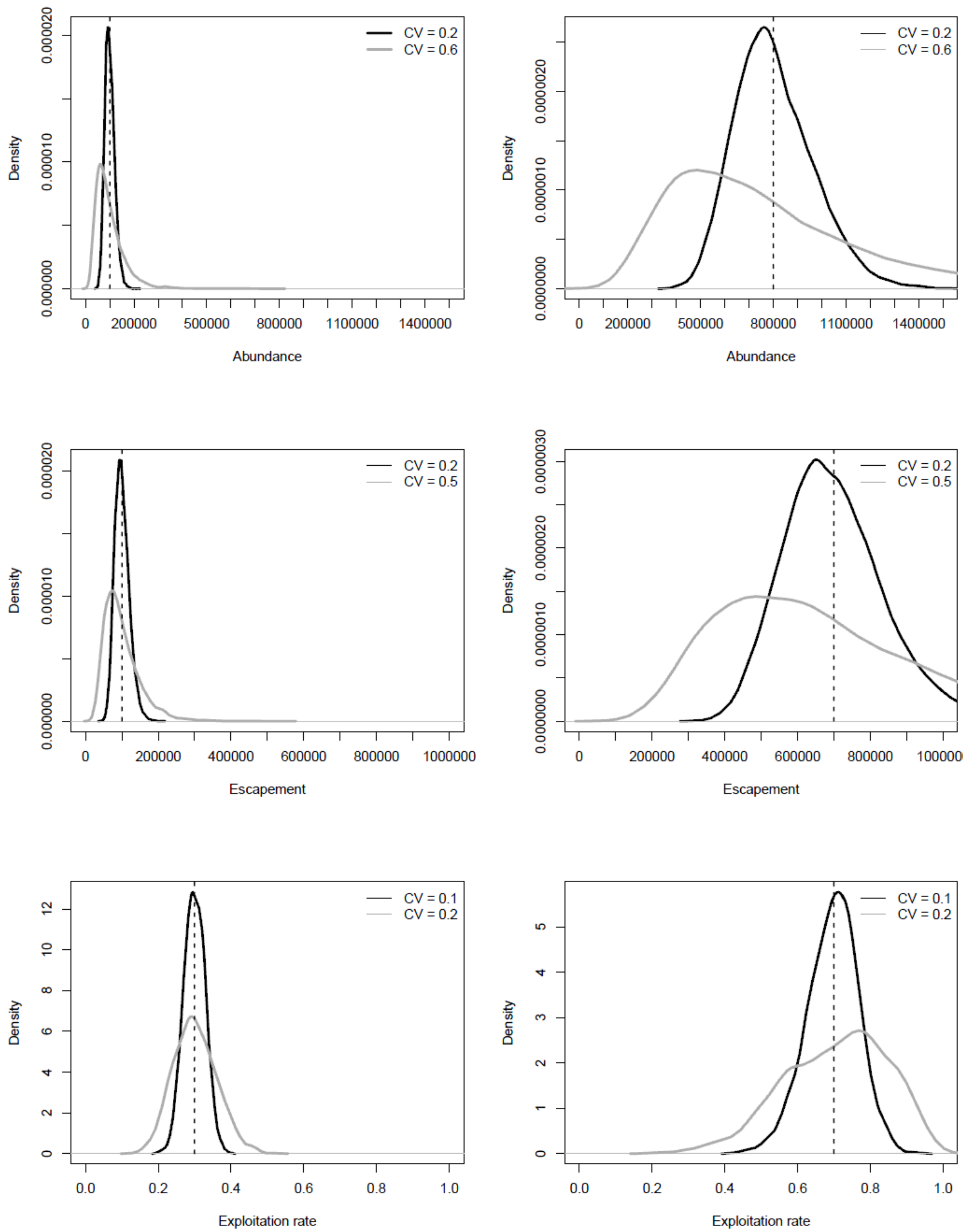

Figure 1. Distributions of the forecast abundance (top row), estimated escapement (middle row), and realized exploitation rate (bottom row) under different levels of known abundance, known escapement, and predicted exploitation rate. Known values are indicated by vertical dashed lines.

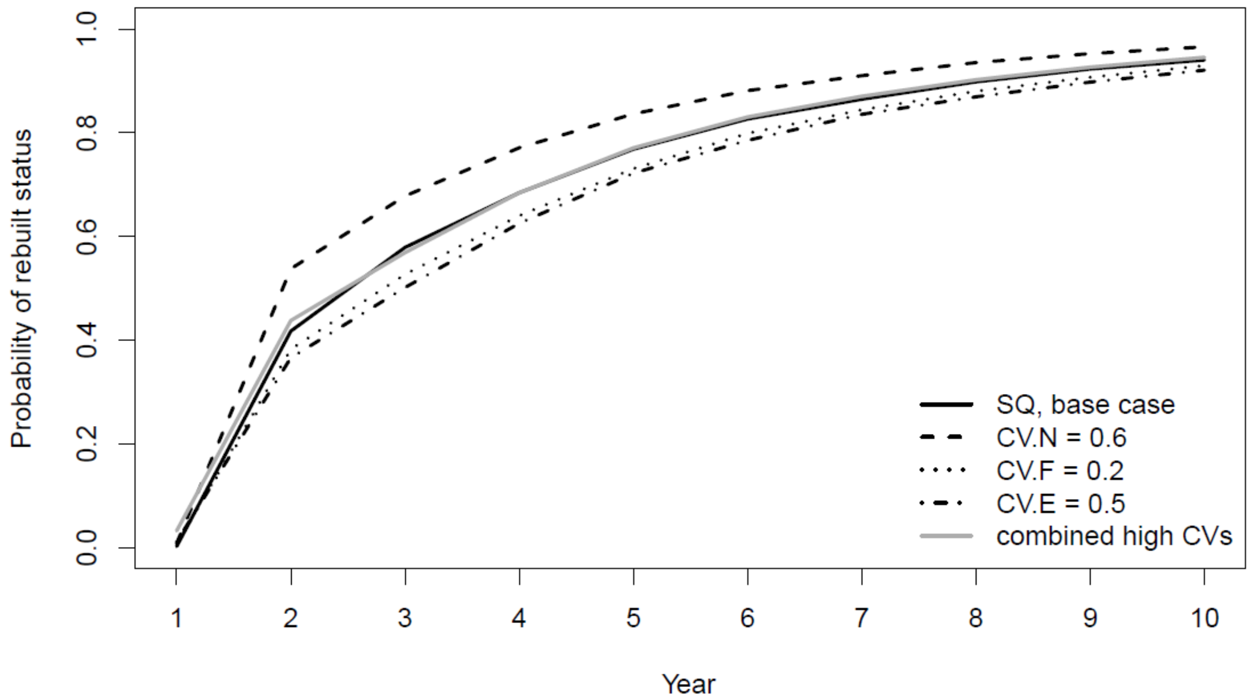

Figure 2. Probability of achieving rebuilt status in years 1 through 10 for the status quo control rule (Alternative I), given different parameter values.

Simulations were also performed assuming biased abundance forecasts, as the forecasted SI has frequently exceeded the postseason estimate. Bias was incorporated by modifying the log-scale mean term in Equation 3 by adding the log of the observed ratio of the preseason forecast of the SI to the postseason estimate of the SI. Thus, the mean term in Equation 3 becomes $\log(N_t) - 0.5\sigma^2_{\log(\hat{N})} + \log(r)$, where r is a draw (with replacement) from the set of 11 ratios of forecast to observed SI. On the arithmetic scale this ratio ranges from 3.53 to 0.78 and r > 1 in 9 of 11 years. Figure 3 displays the effect of including this bias in abundance forecasts for SRFC, given management under the status quo control rule. Positively biased forecasts (on average) result in lower probabilities of achieving rebuilt status beginning in year 2, and continue through the end of the 10 year rebuilding period.

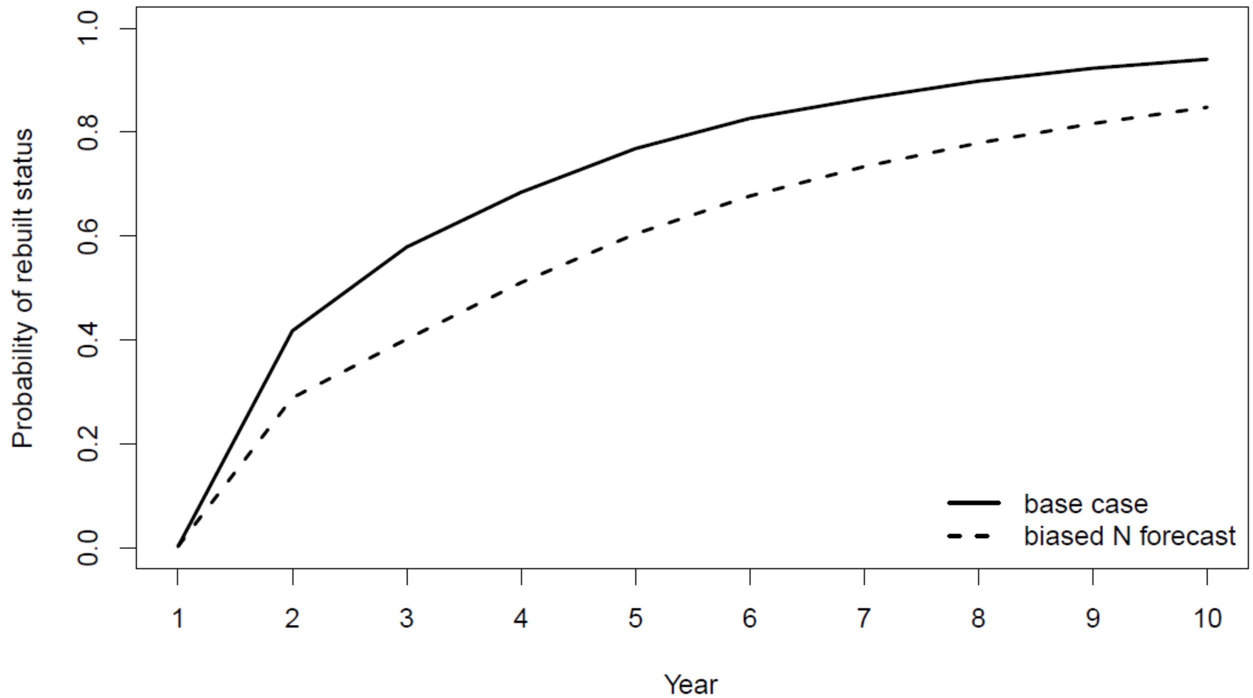

Figure 3. Probability of achieving rebuilt status for the status quo control rule (Alternative I) under unbiased abundance forecasts and abundance forecasts that are on average biased high.

Finally, a "recent abundance" scenario was considered. There has been a downward trend in the SI over time, with two stock collapses in the relatively recent past (see Figure II-1 in PFMC 2018c). For the simulations described thus far the log-scale mean abundance, standard deviation of abundance, and autocorrelation coefficient have been estimated from the entire 1983-2018 set of SI values. For the recent abundance scenario, the mean and log-scale standard deviation are estimated over a more contemporary set of years, while the autocorrelation coefficient is estimated over the entire SI time series. Figure 4 displays results for the recent abundance scenario, where mean and log-scale standard deviation were estimated over years 2004-2018. Unsurprisingly for SRFC, the probability of achieving rebuilt status is lower under all three alternatives when contemporary levels of abundance, and variation in abundance, are assumed (compare Figure 4 to Figure 4.6.a). It should be noted, however, that this result can be sensitive to the choice of the range of years considered to be "recent". Using a year range of 2007-2018 results in a notable reduction in the probability of achieving rebuilt status relative to the base case simulations and a relatively small reduction in rebuilding probabilities relative to simulations based on observed abundances from 2004-2018 (Figure 5).

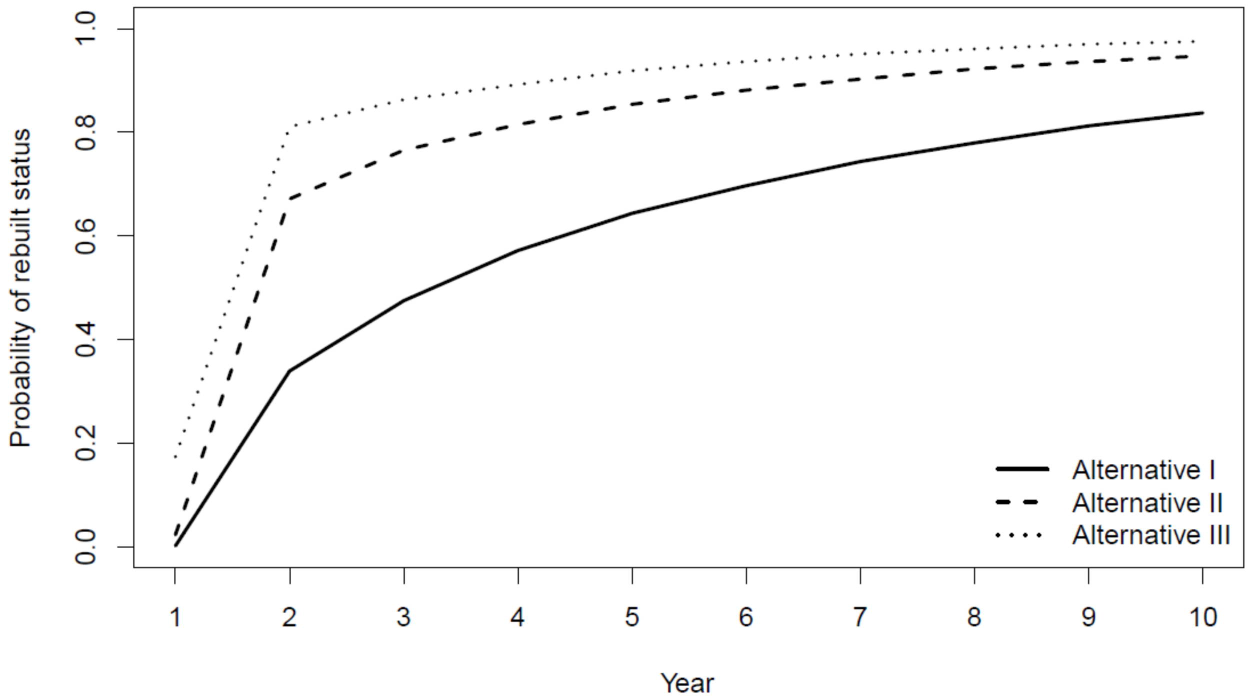

Figure 4. Probability of achieving rebuilt status in years 1 through 10, under the status quo control rule (Alternative I), the buffered control rule (Alternative II), and no fishing (Alternative III), using recent SI values (2004-2018) to estimate the log-scale mean and standard deviation.

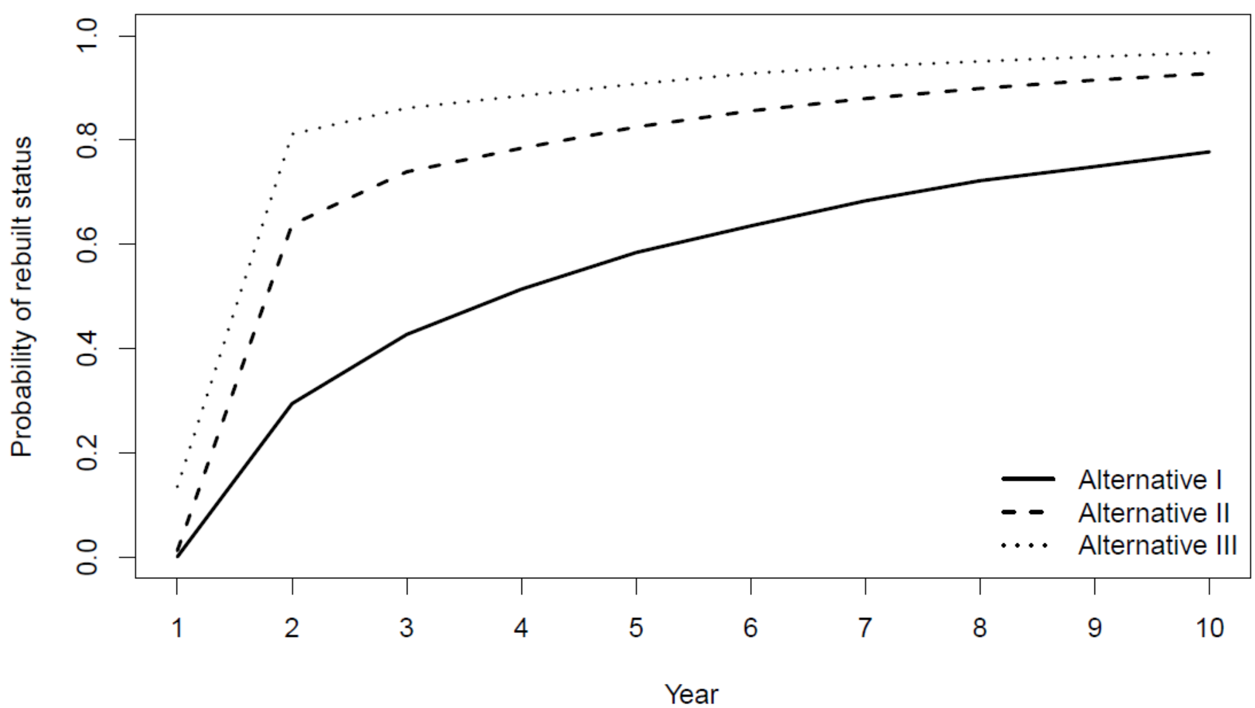

Figure 5. Probability of achieving rebuilt status in years 1 through 10, under the status quo control rule (Alternative I), the buffered control rule (Alternative II), and no fishing (Alternative III), using recent SI values (2007-2018) to estimate the log-scale mean and standard deviation.

APPENDIX C: CHINOOK STOCKS THAT HAVE HISTORICALLY CONSTRAINED SOUTH OF CAPE FALCON FISHERIES

Because of the large number of considerations that go into the deliberations on each year's salmon season it is sometimes difficult to determine with certainty whether or not SRFC was a constraint in any particular year. One indicator of whether SRFC was a constraint is to compare the projected spawning escapement to the spawning escapement goal. SRFC escapement equal to the goal would indicate a constraint on ocean fishery regulations, while excess escapement would indicate some stock other than SRFC was constraining ocean fisheries. Table C.1 illustrates these comparisons, indicating that in 2008, 2009, 2010, and 2018 SRFC may have been constraining.

Table C.1. Historic SRFC spawner escapement criteria and preseason projections.

	Escapement (Number of Adults)		Exploitation Rate	
Year	Minimum	Preseason Projected	Criteria	Preseason Projected
2004	122k-180k	457,500		
2005	122k-180k	983,600		
2006	122k-180k	368,000		
2007	122k-180k	265,500		
2008	122k-180k	**59,000**		
2009	122k-180k	**122,050**		
2010	180,000	**180,000**		
2011	180,000	377,000		
2012	>245,820	455,800	<70.0%	44.40%
2013	>250,300	462,600	<70.0%	44.60%
2014	>190,395	314,700	<70.0%	50.40%
2015	>195,600	341,000	<70.0%	47.70%
2016	>122,000	151,100	<59.3%	49.60%
2017	>122,000	133,200	<47.1%	42.20%
2018	>151,000	**151,000**	<46.8%	34.20%

In determining whether SRFC was a constraint in a particular year, it is helpful to examine indicators of whether other stocks may have been constraining. Table C.2 displays information indicating whether these other stocks and stock components have been constraining and summarizes which stocks likely constrained development of the ocean harvest regulations in each year. KRFC and California coastal Chinook (an ESA-listed stock for which the age-4 KRFC ocean harvest rate serves as a proxy) also constrain the south of Cape Falcon salmon fisheries impacting Chinook. Additionally, ESA-listed SRWC may constrain seasons south of Point Arena. When KRFC constrains ocean harvest, the excess is often absorbed by projections for the inside fisheries. A larger than normal share of Chinook for the Klamath in-river recreational fishery (i.e., more than 15 percent) is an indicator that a stock other than KRFC constrains ocean fisheries. When the preseason projections for the CCC and/or SRWC impact rate are equal to the management criteria, it is likely that the stock(s) with projections equal to the management criteria constrained the development of ocean fishery regulations.

Table C.2. Other potential constraints on ocean fishery regulations (KRFC, CCC and SRWC) and summary of likely constraints.

Year	SRWC Impact rates South of Pt. Arena		Klamath In-River Recreational Share		CCC (KRFC Age-4)		Likely Constraint on Ocean Fishery Regulation
	Criteria	Pre-season Projection	Criteria	Pre-season Projection	Criteria	Pre-season Projection	
2004	NMFS ESA Guidance	Met	>15%	15.0%	<16%	15.0%	KRFC
2005	NMFS ESA Guidance	Met	>15%	15.0%	<16%	7.7%	KRFC
2006	NMFS ESA Guidance	Met	>15%	0.0%	<16%	11.5%	KRFC
2007	NMFS ESA Guidance	Met	>15%	26.0%	<16%	16.0%	CCC
2008	NMFS ESA Guidance	Met	>15%	83.3%	<16%	2.4%	**SRFC**
2009	NMFS ESA Guidance	Met	>15%	99.6%	<16%	<0.1%	**SRFC**
2010	NMFS ESA Guidance	Met	>15%	34.6%	<16%	12.3%	**SRFC**
2011	NMFS ESA Guidance	Met	>15%	22.8%	<16%	16.0%	CCC
2012	<13.7%	13.7%	NA	42.3%	<16%	16.0%	CCC, SRWC
2013	<12.9%	12.9%	NA	34.8%	<16%	16.0%	CCC, SRWC
2014	<15.4%	15.4%	NA	15.1%	<16%	16.0%	KRFC (possibly), CCC; SRWC
2015	<19.0%	17.5%	NA	32.4%	<16%	16.0%	CCC
2016	<19.9%	12.8%	NA	15.0%	<16%	8.4%	KRFC
2017	<15.8%	12.2%	NA	15.9%	<16%	3.1%	KRFC
2018	<14.4%	8.5%	NA	19.3%	<16%	11.5%	**SRFC**

On the basis of data shown in Table C.1 and Table C.2, it seems likely that the SRFC rebuilding policy may result in additional constraints on ocean harvest in some years. For the 2004-2018 period, it appears that SRFC was likely constraining of the ocean fishery in 2008, 2009, 2010, and 2018. It appears that KRFC was constraining in 2004, 2005, 2006, and 2016, and possibly in 2014 and 2017. CCC appear to have been constraining in 2007, 2011, 2012, 2013, 2014, and 2015. And SRWC may have been constraining south of Point Arena, CA in 2012, 2013, and 2014. SRWC may have been constraining in some earlier years as well, however there was insufficient information in Table 5 of the salmon Preseason Report III (PFMC 2018a) documents for those years to make that determination.

APPENDIX D - DRAFT FINDING OF NO SIGNIFICANCE

{Section to be completed by NMFS after Council adopts a rebuilding plan}

APPENDIX E - PAST, PRESENT, AND REASONALBY FORESEEABLE FUTURE IMPACTS

{Section to be completed by NMFS after Council adopts a rebuilding plan}

Fishery Actions

The Council sets management measures for ocean salmon fisheries annually based on stock forecasts and in accordance with conservation objectives set in the FMP and guidance provided by NMFS for managing impacts to ESA listed stocks. The Council manages ocean salmon fisheries through an intensive preseason analysis process to shape salmon fisheries impacts on salmon stocks within the parameters of the FMP conservation measures and ESA requirements.

Fisheries outside of the Council's jurisdiction also impact the Council-area salmon fishery. The Council considers fisheries managed by the states and treaty Indian tribes in the North of Falcon management process and Columbia River fisheries managed under *U.S. v. Oregon* Management Plan, as well as obligations for fisheries off Alaska and Canada under the Pacific Salmon Treaty (PFMC and NMFS 2014). Additionally, the Council and NMFS manage ocean salmon fisheries inseason to keep fisheries impacts within the constraints set preseason. The Council also conducts annual methodology reviews to improve models and other tools for assessing salmon stocks.

Non-Fishing Related Actions

Because salmon spend part of their lifecycle in fresh water, they are more vulnerable to a broad range of human activities (since humans spend most of their time on land) that affect the quantity and quality of these freshwater environments. These effects are generally well known and diverse. They include physical barriers to migration (dams), changes in water flow and temperature (often a secondary effect of dams or water diversion projects), and degradation of spawning environments (such as increased silt in the water from adjacent land use). Non-fishing activities in the marine environment can introduce chemical pollutants and sewage; and result in changes in water temperature, salinity, dissolved oxygen, and suspended sediment which poses a risk to the affected resources. Human-induced non-fishing activities tend to be localized in nearshore areas and marine project areas. When these activities co-occur, they are likely to work additively or synergistically to decrease habitat quality and may indirectly constrain the sustainability of the managed resources, non-target species, and protected resources. Decreased habitat suitability tends to reduce the tolerance of affected species to the impacts of fishing effort. Mitigation through regulations that would reduce fishing effort could negatively impact human communities. The overall impact to the affected species and their habitats on a population level is unknown, but likely neutral to low negative, since a large portion of these species have a limited or minor exposure to the localized non-fishing perturbations.

For many of the proposed non-fishing activities to be permitted by other Federal agencies, those agencies would examine the potential impacts on the affected resources. The Magnuson-Stevens Act (50 CFR 600.930) imposes an obligation on other Federal agencies to consult with the Secretary of Commerce on actions that may adversely affect EFH. The eight fishery management councils engage in the review process by making comments and recommendations on any Federal or state action that may affect habitat, including EFH, for their managed species and by commenting on actions likely to substantially affect habitat, including EFH. In addition, under the Fish and Wildlife Coordination Act (Section 662), "whenever the waters of any stream or other body of water are proposed or authorized to be impounded, diverted, the channel deepened, or the stream or other body of water otherwise controlled or modified for any purpose whatever, including navigation and drainage, by any department or agency of the U.S., or by any public or private agency under Federal permit or license, such department or agency first shall consult with the U.S. Fish and Wildlife Service (USFWS), Department of the Interior, and with the head of the agency exercising administration over the wildlife resources of the particular state wherein the" activity is taking place. This act provides another avenue for review of actions by other Federal and state agencies that may impact resources that NMFS manages in the reasonably foreseeable future. In addition, NMFS and the USFWS share responsibility for implementing the ESA. ESA requires NMFS to designate "critical habitat" for any species it lists under the ESA (i.e., areas that contain physical or biological features essential to conservation, which may require special management considerations or protection) and to develop and implement recovery plans for threatened and endangered species. The ESA provides another avenue for NMFS to review actions by other entities that may impact endangered and protected resources whose management units are under NMFS' jurisdiction.

The effects of climate on the biota of the California Current ecosystem have been recognized for some time. The El Niño-Southern Oscillation (ENSO) is widely recognized to be the dominant mode of inter-annual variability in the equatorial Pacific, with impacts throughout the rest of the Pacific basin and the globe. During the negative (El Niño) phase of the ENSO cycle, jet stream winds are typically diverted northward, often resulting in increased exposure of the Pacific Coast of the U.S. to subtropical weather systems. The impacts of these events to the coastal ocean generally include reduced upwelling winds, deepening of the thermocline, intrusion of offshore (subtropical) waters, dramatic declines in primary and secondary production, poor recruitment, reduced growth and survival of many resident species (such as salmon and groundfish), and northward extensions in the range of many tropical species. Concurrently, top predators such as seabirds and pinnipeds often exhibit reproductive failure. In addition to inter-annual variability in ocean conditions, the North Pacific seems to exhibit substantial inter-decadal variability, which is referred to as the Pacific (inter) Decadal Oscillation (PDO).

Anomalously warm sea surface temperatures in the northeast Pacific Ocean developed in 2013 and continued to persist through much of 2015; this phenomenon was termed "the Blob." During the persistence of the Blob, distribution of marine species was affected (e.g., tropical and subtropical species were documented far north of their usual ranges), marine mammals and seabirds starved, and a coastwide algal bloom that developed in the summer of 2015 resulted in domoic acid poisoning of animals at various trophic levels, from crustaceans to marine mammals. In 2015-2016, a very strong El Niño event disrupted the Blob, which was declared "dead" by climatologists in December 2015. The extent of the impact of The Blob on salmon and salmon fisheries has not yet been fully determined. It is also uncertain if or when environmental conditions would cause a repeat of this event. However, NMFS' Northwest and Southwest Fisheries Science Centers presented information to the Council indicating that the broods that will contribute to 2018 harvest and escapement encountered poor ocean conditions in the California Current Ecosystem.

Within the California Current itself, Mendelssohn et al, (2003) described long-term warming trends in the upper 50 to 75 meters of the water column. Recent paleoecological studies from marine sediments have indicated that 20th century warming trends in the California Current have exceeded natural variability in ocean temperatures over the last 1,400 years. Statistical analyses of past climate data have improved our understanding of how climate has affected North Pacific ecosystems and associated marine species productivities.

In addition, changes in river flows and flow variability may affect population growth of anadromous fishes. Ward et al. (2015) found that increases in variability in freshwater flows may have a more negative effect than any other climate signal included in their model. Some climate change models predict that in the Pacific Northwest, there will be warmer winters and more variable river flows, which may affect the ability of anadromous fishes to recover in the future (Ward et al. 2015). However, our ability to predict future impacts on a large scale ecosystem stemming from climate forcing events remains uncertain.

APPENDIX F - LIST OF AGENCIES AND PERSONS CONSULTED

{Section to be completed by NMFS after Council adopts a rebuilding plan}

The following public meetings were held as part of the salmon management process (Council-sponsored meetings in bold):

March 2018	**Rohnert Park, CA**
April 2018	**Portland, OR**
May 2018	Public Webinar
June, 2018	Public Meeting in Redding, CA
August 2018	Public Webinar
September 2018	Public Webinar
September 2018	**Seattle, WA**
November 2018	**San Diego, CA**
March 2019	**Vancouver, WA**
April 2019	**Rohnert Park, CA**
June 2019	**San Diego, CA**

The following organizations were consulted and/or participated in preparation of supporting documents:

Northwest Indian Fisheries Commission
Columbia River Intertribal Fish Commission
West Coast Indian Tribes

California Department of Fish and Wildlife
Oregon Department of Fish and Wildlife
Washington Department of Fish and Wildlife

National Marine Fisheries Service, West Coast Region, Sustainable Fisheries Division
National Marine Fisheries Service, Northwest Fisheries Science Center
National Marine Fisheries Service, Southwest Fisheries Science Center
U.S. Fish and Wildlife Service, Columbia River Fisheries Program Office
United States Coast Guard

APPENDIX G - REGULATORY IMPACT REVIEW

{Section to be completed by NMFS after Council adopts a rebuilding plan}

Regulatory Impact Review and Initial Regulatory Flexibility Analysis for the
[*Insert Rule Name and RIN #*]

National Marine Fisheries Service, West Coast Region
[*Insert date*]

As applicable, rulemakings must comply with Executive Order (E.O.) 12866 and the Regulatory Flexibility Act (RFA). To satisfy the requirements of E.O. 12866, the National Marine Fisheries Service (NMFS) undertakes a regulatory impact review (RIR). To satisfy the requirements of the RFA, NMFS prepares an initial regulatory flexibility analysis (IRFA) and final regulatory flexibility analysis (FRFA), or a certification.

> The NMFS Economic Guidelines that describe the RFA and E.O. 12866 can be found at: http://www.nmfs.noaa.gov/op/pds/documents/01/111/01-111-05.pdf
>
> The RFA, 5 U.S.C. § 601 *et seq.*, can be found at: http://www.nmfs.noaa.gov/sfa/laws_policies/economic_social/rfa_revised_through_2010_jobs_act.pdf
>
> Executive Order 12866 can be found at: http://www.nmfs.noaa.gov/sfa/laws_policies/economic_social/eo12866.pdf

---

REGULATORY IMPACT REVIEW

The President of the United States signed E.O. 12866, "Regulatory Planning and Review," on September 30, 1993. This order established guidelines for promulgating new regulations and reviewing existing regulations. The E.O. covers a variety of regulatory policy considerations and establishes procedural requirements for analysis of the benefits and costs of regulatory actions. The E.O. stresses that in deciding whether and how to regulate, agencies should assess all of the costs and benefits of available regulatory alternatives. Based on this analysis, they should choose those approaches that maximize net benefits to the Nation, unless a statute requires another regulatory approach.

NMFS satisfies the requirements of E.O. 12866 through the preparation of an RIR. The RIR provides a review of the potential economic effects of a proposed regulatory action in order to gauge the net benefits to the Nation associated with the proposed action. The analysis also provides a review of the problem and policy objectives prompting the regulatory proposal and an evaluation of the available alternatives that could be used to solve the problem.

The RIR provides an assessment that can be used by the Office of Management and Budget to determine whether the proposed action could be considered a significant regulatory action under E.O. 12866. E.O. 12866 defines what qualifies as a "significant regulatory action" and requires agencies to provide analyses of the costs and benefits of such action and of potentially effective and reasonably feasible alternatives. An action may be considered significant if it is expected to: (1) Have an annual effect on the economy of $100 million or more or adversely affect in a material way the economy, a sector of the economy, productivity, competition, jobs, the environment, public health or safety, or state, local, or tribal governments or communities; (2) Create a serious inconsistency or otherwise interfere with an action taken or planned by another agency; (3) Materially alter the budgetary impact of entitlement, grants, user fees, or loan programs or the rights and obligations of recipients thereof; or (4) Raise novel legal or policy issues arising out of legal mandates, the President's priorities, or the principles set forth in the EO.

Statement of the Problem
See Purpose and Need statement in this document (Section 2.1.2).

Description of the fishery and other affected entities
See Ocean and in-river fishery descriptions in this document (Section 3.3.1, and Section 3.3.2).

Description of the management goals and objectives
See conservation objectives and management strategy in this document (Section 2.3.1 and Section 2.3.2).

Description of the Alternatives
See management strategy alternatives, analysis, and additional information in this document (Section 4.2, Section 4.6, and Appendix B).

An Economic Analysis of the Expected Effects of Each Selected Alternative Relative to the No Action Alternative
See socioeconomic impact of management strategy alternatives considered in this document (Section 5.0 and Appendix C).

RIR-Determination of Significant Impact
As noted above, under E.O. 12866, a regulation is a "significant regulatory action" if it is likely to: (1) have an annual effect on the economy of $100 million or more or adversely affect in a material way the economy, a sector of the economy, productivity, competition, jobs, the environment, public health or safety, or State, local, or tribal governments or communities; (2) create a serious inconsistency or otherwise interfere with an action taken or planned by another agency; (3) materially alter the budgetary impact of entitlements, grants, user fees, or loan programs or the rights and obligations of recipients thereof; or (4) raise novel legal or policy issues arising out of legal mandates, the President's priorities, or the principles set forth in this Executive Order. Pursuant to the procedures established to implement section 6 of E.O. 12866, the Office of Management and Budget has determined that this action is XXX.

APPENDIX H - INITIAL REGULATORY FLEXIBILITY ANALYSIS

{Section to be completed by NMFS after Council adopts a rebuilding plan}

APPENDIX I - NATIONAL STANDARDS ANALYSIS

{Section to be completed by NMFS after Council adopts a rebuilding plan}

APPENDIX J - CONSISTENCY WITH OTHER APPLICABLE LAWS ANALYSIS

{Section to be completed by NMFS after Council adopts a rebuilding plan}

- MSA
- CZMA
- ESA
- MMPA
- MBTA
- PRA
- EO 12898 Environmental Justice
- EO 13132 Federalism
- EO 13175 Tribal Consultation and Coordination
- Regulatory Flexibility Act
- EO 12866 Regulatory Planning and Review
- EO 13771 Reducing Regulation and Controlling Regulatory Costs