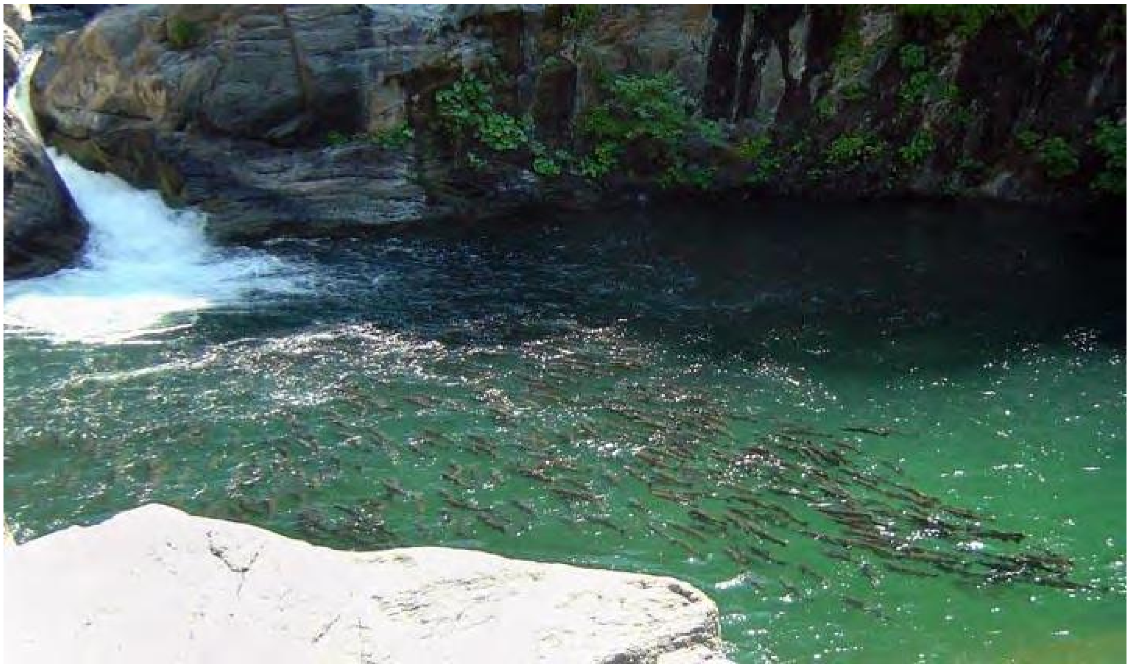
CALIFORNIA CENTRAL VALLEY RECOVERY DOMAIN

5-Year Review:
Summary and Evaluation of
Central Valley Spring-run Chinook Salmon Evolutionarily Significant Unit



Spring-run Chinook salmon holding in Quartz Bowl, Butte Creek. Photo credit David Little, Chico Enterprise-Record, CA. 2005

NOAA's National Marine Fisheries Service
West Coast Region

[April 2016]

5-YEAR REVIEW
Central Valley Recovery Domain

Species Reviewed	Evolutionarily Significant Unit or Distinct Population Segment
Chinook Salmon ***(Oncorhynchus tshawytscha)***	**Central Valley Spring-run Chinook Salmon Evolutionarily Significant Unit**

1.0 GENERAL INFORMATION

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Issued a Report to NOAA's National Marine Fisheries Service (NMFS), West Coast Region (WCR), titled: *Viability Assessment for Pacific Salmon and Steelhead Listed under the Endangered Species Act: Southwest.* Dated: February 2, 2016.

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1.2 Introduction

Many West Coast salmon and steelhead (*Oncorhynchus* sp.) stocks have declined substantially from their historic numbers and now are at a fraction of their historical abundance. There are several factors that contribute to these declines, including: overfishing, loss of freshwater and estuarine habitat, hydropower development, poor ocean conditions, and hatchery practices.

These factors collectively led to NMFS listing of 28 salmon and steelhead stocks in California, Idaho, Oregon, and Washington under the Federal Endangered Species Act (ESA).

The ESA, under Section 4(c)(2), directs the Secretary of Commerce to review the listing classification of threatened and endangered species at least once every five years. After completing this review, the Secretary must determine if any species should be: (1) removed from the list; (2) have its status changed from threatened to endangered; or (3) have its status changed from endangered to threatened. The most recent status reviews for West Coast salmon and steelhead occurred in 2010, and prior to that in 2005 and 2006. This document summarizes NMFS's 5-year review of the ESA-listed Central Valley (CV) spring-run Chinook salmon Evolutionarily Significant Unit **(**ESU).

1.2.1 Background on Listing Determinations

Under the ESA, a species, subspecies, or a distinct population segment (DPS) may be listed as threatened or endangered. To identify the proper taxonomic unit for consideration in an ESA listing for salmon we draw on our "Policy on Applying the Definition of Species under the ESA to Pacific Salmon" (ESU Policy) (56 FR 58612). According to this policy guidance, populations of salmon that are substantially reproductively isolated from other con-specific populations and are representing an important component in the evolutionary legacy of the biological species are considered to be an ESU. In our listing determinations for Pacific salmon under the ESA, we treated an ESU as constituting a DPS, and hence a ''species.''

Artificial propagation (fish hatchery) programs are common throughout the range of ESA-listed West Coast salmon and steelhead. On June 28, 2005, we announced a final policy addressing the role of artificially propagated Pacific salmon and steelhead in listing determinations under the ESA (70 FR 37204). Specifically, this policy: (1) establishes criteria for including hatchery stocks in ESUs and DPSs; (2) provides direction for considering hatchery fish in extinction risk assessments of ESUs and DPSs; (3) requires that hatchery fish determined to be part of an ESU or DPS to be included in any listing of those units; (4) affirms our commitment to conserving natural salmon and steelhead populations and the ecosystems upon which they depend; and (5) affirms our commitment to fulfilling trust and treaty obligations with regard to the harvest of some Pacific salmon and steelhead populations, consistent with the conservation and recovery of listed salmon ESUs and steelhead DPSs.

To determine whether a hatchery program was part of an ESU or DPS, NMFS convened the Salmon and Steelhead Hatchery Advisory Group (SSHAG), which evaluated all hatchery stocks and programs and divided them into 4 categories (SSHAG 2003):

Category 1: The hatchery population was derived from a native, local population; is released within the range of the natural population from which is was derived; and has experienced only relatively minor genetic changes from causes such as founder effects, domestication or non-local introgression.

Category 2: The hatchery population was derived from a local natural population, and is released within the range of the natural population from which is was derived, but is known or suspected to have experienced a moderate level of genetic change from causes such as founder effects, domestication, or non-native introgression.

Category 3: The hatchery population is derived predominately from other populations that are in the same ESU/DPS, but is substantially diverged from the local, natural population(s) in the watershed in which it is released.

Category 4: The hatchery population was predominately derived from populations that are not part of the ESU/DPS in question; or there is substantial uncertainty about the origin and history of the hatchery population.

Based on these categorical delineations, hatchery programs in SSHAG categories 1 and 2 are included as part of an ESU or DPS (70 FR 37204) although hatchery programs in other categories may also be included in an ESU or DPS under certain circumstances.

Because the new hatchery listing policy changed the way NMFS considered hatchery fish in ESA listing determinations, we conducted new status reviews and ESA-listing determinations for West Coast salmon ESUs and steelhead DPSs using this policy. On June 28, 2005, we issued final listing determinations for 16 ESUs of Pacific salmon and on January 5, 2006 we issued final listing determinations for 10 DPSs of steelhead.

The 2005 listing determination concluded that Feather River Fish Hatchery (FRFH) spring-run Chinook salmon production should be included in the CV spring-run Chinook salmon ESU. In 2010/2011 we conducted a status review of CV spring-run Chinook salmon, and determined that the available information continues to support including the FRFH stock as part of the CV spring-run Chinook salmon ESU.

1.3 Methodology used to complete the review

A public notice announcing NMFS' intent to conduct 5-year status reviews for the 28 ESUs/DPSs of west coast anadromous salmonids was published in the Federal Register on February 6, 2015 (80 FR 6695). This notice initiated a 60-day period for the public to provide comments to NMFS related to the status of the species being reviewed. The West Coast Region (WCR) of NMFS coordinated informally with the State co-managers to ensure they were informed about the status review and had an opportunity to provide any comments or information. No comments relevant to CV spring-run Chinook salmon were provided during the 60-day period.

Following the comment period, three main steps were taken to complete the 5-year status review for the CV spring-run Chinook salmon. First, the SWFSC reviewed any new and substantial scientific information that had become available since the 2010 status review, and produced an updated biological status summary report (herein cited as Williams et al. 2016 and referred to as the "viability report"). The viability report was intended to determine whether or not the biological status of CV spring-run Chinook salmon had changed since the 2010 status review was conducted. Next, the California Central Valley Office (CCVO) reviewed the viability report and assessed whether the five ESA listing factors (threats) changed substantially since the 2010 status review. To assess the five ESA listing factors, several key documents/data were reviewed such as the Federal Register notices identified in Tables 1 and 2 and other relevant publications/personal communication including:

(1) The 5-year Status Review Report for CV spring-run Chinook salmon published in 2011 (NMFS 2011)
(2) Central Valley Salmon and Steelhead Recovery Plan (NMFS 2014)
(3) Discussions with California Department of Fish and Wildlife (CDFW) and the U.S. Fish and Wildlife Service (USFWS) on watershed assessments and recovery action implementation status
(4) Implementation of the reasonable and prudent alternative for the Biological Opinion on the Long-term Operations of the Central Valley Project (CVP) and State Water Project (SWP) (NMFS 2009)
(5) Grandtab (CDFW 2015)
(6) Framework for assessing viability of threatened and endangered Chinook salmon and steelhead in the Sacramento-San Joaquin Basin (Lindley et al. 2007)

Finally, the CCVO staff considered the viability report, the current threats to the species, recovery action implementation, and relevant conservation measures before making a determination whether the listing status of the species should be uplisted (*i.e.,* threatened to endangered), be delisted (*i.e.,* recovered), or remain unchanged. In the CCVO a team of four biologists formed the core working group that assimilated information from various sources to support this review and the reviews of Sacramento River winter-run Chinook salmon and California Central Valley steelhead.

1.4 Background – Summary of Previous Reviews, Statutory and Regulatory Actions, and Recovery Planning

1.4.1 Federal Register (FR) Notice citation announcing initiation of this review

80 FR 6695; February 6, 2015

1.4.2 Listing history

The CV spring-run Chinook salmon ESU was originally listed in 1999 as a threatened species (Table 1). Following the development of NMFS' hatchery listing policy, we re-evaluated the status of this ESU, and issued a final listing determination, that the ESU continued to warrant listing as a threatened species and that the FRFH stock of spring-run Chinook salmon should now be part of the ESU (Table 1).

Table 1. Summary of the listing history under the Endangered Species Act for the CV spring-run Chinook salmon ESU

Salmonid Species	ESU/DPS Name	Original Listing	Revised Listing(s)
Chinook Salmon (*O. tshawytscha*)	CV spring-run Chinook salmon	**FR notice:** 64 FR 50394 **Date listed:** 9/16/1999 **Classification:** Threatened	The ESA listing status of this ESU has not been revised since its original listing. On June 28, 2005, NMFS published the final hatchery listing policy (70 FR 37204) and reaffirmed the threatened status of the ESU (70 FR 37160).

1.4.3 Associated rulemakings

The ESA requires NMFS to designate critical habitat for any species it lists under the ESA. Critical habitat is defined as: (1) specific areas within the geographical area occupied by the species at the time of listing, on which are found those physical or biological features essential to the conservation of the species, and those features which may require special management considerations or protection; and (2) specific areas outside the geographical area occupied by the species if the agency determines that the area itself is essential for conservation of the species. We originally designated critical habitat for this ESU in 2000, but later withdrew that designation as a result of litigation. In 2005, we issued a new final critical habitat designation for this ESU (Table 2).

Section 4(d) of the ESA directs NMFS to issue regulations necessary and advisable to conserve species listed as threatened. This applies particularly to "take," which can include any act that kills, injures, or harms fish, and may include habitat modification. The ESA automatically prohibits the take of species listed as endangered. In 2002, we promulgated a 4(d) protective regulation for this ESU that applied the section 9 take prohibitions to west coast threatened salmonids and also created several "take limits" to define exceptions for when take prohibitions would apply. This rule was slightly revised when this and other ESUs were re-evaluated as part of the 2005 salmon listing determination process that also considered hatchery populations (see Table 1). In 2013, we included additional 4(d) take exceptions when designating a 10(j) nonessential experimental population (NEP) of spring-run Chinook salmon for reintroduction as part of the San Joaquin River Restoration Program (SJRRP) (Table 2).

Table 2. Summary of rulemaking for 4(d) protective regulations and critical habitat for CV spring-run Chinook salmon.

Salmonid Species	ESU/DPS Name	4(d) Protective Regulations	Critical Habitat Designations
Chinook Salmon *(O. tshawytscha)*	CV spring-run Chinook salmon	**FR notice:** 67 FR 1116 **Date:** 01/09/2002	**FR notice:** 70 FR 52488 **Date:** 09/02/2005
		FR notice: 78 FR 79622 **Date:** 12/31/2013	

1.4.4 Review History

Numerous scientific assessments have been conducted to assess the biological status of this ESU (Table 3).

Table 3. List of previous scientific assessments for CV spring-run Chinook salmon

Salmonid Species	ESU Name	Document Citation
Chinook Salmon *(O. tshawytscha)*	CV spring-run Chinook salmon	National Marine Fisheries Service 1998; West Coast Salmon Biological Review Team 2003; Lindley et al 2004; Good et al 2005; National Marine Fisheries Service 2005; Lindley et al 2007; Williams et al 2011; and Williams et al 2016

1.4.5 Species' Recovery Priority Number at start of 5-year review

On June 15, 1990, NMFS issued guidelines (55 FR 24296) for assigning listing and recovery priorities. For recovery plan development, implementation, and resource allocation, we assess three criteria to determine a species' recovery priority number from 1 (high) to 12 (low): (1) magnitude of threat; (2) recovery potential; and (3) conflict with development projects or other economic activity. NMFS re-evaluated the recovery priority numbers for listed species as part of the FY2013-FY2014 ESA Biennial Report to Congress (http://www.nmfs.noaa.gov/pr/laws/esa/biennial.htm) (NMFS 2015). As a result of the re-evaluation, the recovery potential for CV spring-run Chinook salmon increased, causing the species' recovery priority number to change from 7 to 5. Table 4 lists the current recovery priority numbers for the subject species, as reported in NMFS (2015). Regardless of a species' recovery priority number, NMFS remains committed to continued efforts to recovery all ESA-listed species under our authority.

1.4.6 Recovery Plan or Outline

In 2014, NMFS released a final multi-species recovery plan that addresses all three listed salmonids in the California Central Valley, including the CV spring-run Chinook salmon ESU (Table 4).

Table 4. Recovery Priority Number and Endangered Species Act Recovery Plan for CV Spring-run Chinook Salmon.

Salmonid Species	ESU/DPS Name	Recovery Priority Number	Recovery Plans/Outline
Chinook Salmon *(O. tshawytscha)*	CV spring-run Chinook salmon	5	**Name of Plan:** Recovery Plan for the Evolutionarily Significant Units of Sacramento River Winter-run Chinook Salmon and Central Valley Spring-run Chinook Salmon and the Distinct Population Segment of California Central Valley Steelhead (July 2014) **Plan Status:** Final http://www.westcoast.fisheries.noaa.gov/protected_species/salmon_steelhead/recovery_planning_and_implementation/california_central_valley/california_central_valley_recovery_plan_documents.html

2.0 REVIEW ANALYSIS

2.1 Delineation of Species under the Endangered Species Act

2.1.1 Is the species under review a vertebrate?

ESU/DPS Name	YES*	NO**
Central Valley Spring-run Chinook Salmon	X	

** if "Yes," go to section 2.1.2; ** if "No," go to section 2.2*

2.1.2 Is the species under review listed as a DPS?

ESU/DPS Name	YES*	NO**
Central Valley Spring-run Chinook Salmon	X	

** if "Yes," go to section 2.1.3; ** if "No," go to section 2.1.4*

2.1.3 Was the DPS listed prior to 1996?

ESU/DPS Name	YES*	NO**	Date Listed if Prior to 1996
Central Valley Spring-run Chinook Salmon		X	

** if "Yes," give date go to section 2.1.3.1*
*** if "No," go to section 2.1.4*

2.1.3.1 Prior to this 5-year review, was the DPS classification reviewed to ensure it meets the 1996 policy standards?

In 1991 NMFS issued a policy to provide guidance for defining ESUs of salmon and steelhead that would be considered for listing under the ESA (56 FR 58612; November 20, 1991). Under this policy a group of Pacific salmon populations is considered an ESU if it is substantially reproductively isolated from other con-specific populations and it represents an important component in the evolutionary legacy of the biological species. In listing the CV spring-run Chinook salmon ESU, NMFS treated the delineated ESU as a DPS, and hence a "species", under the ESA. The 1996 DPS policy affirmed that a stock of Pacific salmon is considered a DPS if it represents an ESU of a biological species and concluded that NMFS' ESU policy was a detailed extension of the joint DPS policy. In summary, therefore, the ESU meets the 1996 DPS policy standards.

2.1.4 Summary of relevant new information regarding the delineation of the Central Valley Spring-run Chinook Salmon ESU boundary

The ESU boundary for CV spring-run Chinook salmon contains the Sacramento River Basin downstream of impassible barriers. The ESU includes all naturally spawned populations of CV spring-run Chinook salmon in the Sacramento River and its tributaries, including the Feather River. Although there have been observations of springtime running Chinook salmon returning to the San Joaquin tributaries in recent years, there is insufficient information to determine the specific origin of these fish, and whether or not they are straying into the basin or returning to natal streams. Genetic assessment or natal stream analyses of hard tissues could inform our understanding of the relationship of these fish to the ESU. More information is needed when considering whether or not the presence of these fish would warrant a change to the ESU boundary. Additionally, there may be interest in modifying the ESU boundary in the future when spring-run Chinook salmon are successfully reintroduced into the San Joaquin River Basin and/or into Central Valley habitats upstream of currently impassable barriers. Based on this review, NMFS is not recommending a change to the boundary of this ESU.

NMFS concluded to include FRFH spring-run Chinook stock in the listed ESU in 2005 (70 FR 37160), which was reaffirmed in the 2010 review. As part of this 5-year review, we have re-evaluated the status of this hatchery stock and concluded that it should remain part of the CV spring-run Chinook salmon ESU.

2.2 Recovery Criteria

2.2.1 Does the species have a final, approved recovery plan containing objective, measurable criteria?

ESU/DPS Name	YES	NO
Central Valley Spring-run Chinook Salmon	X	

The ESA requires recovery plans to incorporate (to the maximum extent practicable) objective, measurable criteria which, when met, would result in a determination in accordance with the provisions of the ESA that the species can be removed from the Federal List of Endangered and Threatened Wildlife and Plants (50 CFR 17.11 and 17.12). NMFS issued a final approved recovery plan for this ESU in 2014. The plan contains recovery criteria that are objective and measurable, and reflect the best available and most-up-to-date information on the biology of this ESU and its habitat and address both biological parameters as well as the 5 listing factors. The biological recovery criteria in 2014 recovery plan are based on the Viable Salmon Population criteria developed by McElhany et al. (2000).

2.2.2 Adequacy of Recovery Criteria

2.2.2.1 Do the recovery criteria reflect the best available and most up-to date information on the biology of the species and its habitat?

ESU/DPS Name	YES	NO
Central Valley Spring-run Chinook Salmon	X	

The biological recovery criteria in the recovery plan are based on the best available information.

2.2.2.2 Are all of the 5 listing factors that are relevant to the species addressed in the recovery criteria?

ESU/DPS Name	YES	NO
Central Valley Spring-run Chinook Salmon	X	

The recovery plan contains threat abatement recovery criteria that address each of the five listing factors.

2.2.3 List the recovery criteria as they appear in the recovery plan, and discuss how each criterion has or has not been met, citing information

The recovery plan for the Central Valley contains the following ESU-level and population-level recovery criteria for CV spring-run Chinook salmon.

ESU-Level Recovery Criteria

- ❑ One population in the Northwestern California Diversity Group at low risk of extinction
- ❑ Two populations in the Basalt and Porous Lava Diversity Group at low risk of extinction
- ❑ Four populations in the Northern Sierra Diversity Group at low risk of extinction
- ❑ Two populations in the Southern Sierra Diversity Group at low risk of extinction
- ❑ Maintain multiple populations at moderate risk of extinction

In order to meet the recovery criteria for this ESU and thereby delist the species, there must be at least eight populations at a low risk of extinction distributed throughout the Central Valley, as well as additional populations at a moderate risk of extinction. As described in Williams et al. (2016) and below in Section 2.3, these recovery criteria are not currently being met.

Population-Level Extinction Risk Criteria

The criteria for assessing the extinction risk at the population level are identified in Table 5 and are summarized below. Estimators for the various extinction risk criteria are presented in Table 6 (from Lindley et al. 2007). The average run size is computed as the mean of the three most recent generations. Mean population size is estimated as the product of the mean run size and the average generation time. Population growth (or decline) rate is estimated from the slope of the natural logarithm of spawners versus time for the most recent 10 years of spawner count data. The fraction of naturally-spawning fish of hatchery origin is the mean fraction over one to four generations.

Low Risk Extinction Criteria

- ❑ Census population size is >2,500 adults -or- Effective population size is >500
- ❑ No productivity decline is apparent
- ❑ No catastrophic events occurring or apparent within the past 10 years
- ❑ Hatchery influence is low

Moderate Risk Extinction Criteria

- ❑ Census population size is 250 to 2,500 adults -or- Effective population size is 50 to 500 adults
- ❑ Productivity: Run size may have dropped below 500, but is stable
- ❑ No catastrophic events occurring or apparent within the past 10 years
- ❑ Hatchery influence is moderate or hatchery operates as a conservation hatchery using best management practices

In the recovery plan, CV spring-run Chinook salmon populations are prioritized based on their potential or known extinction risk. Of highest priority are "Core 1" populations, which have been identified based on their known ability or potential to meet the low extinction risk criteria. "Core 2" populations are assumed to have the potential to meet the moderate risk of extinction criteria.

Table 5. Criteria for assessing the level of risk of extinction for populations of Pacific salmonids, including the CV spring-run Chinook ESU. Overall risk is determined by the highest risk score for any category.

Criterion	Risk of Extinction		
	High	Moderate	Low
Extinction risk from PVA	> 20% within 20 years	> 5% within 100 years	< 5% within 100 years
	– or any ONE of –	– or any ONE of –	– or ALL of –
Population size[a]	$N_e \leq 50$	$50 < N_e \leq 500$	$N_e > 500$
	–or–	–or–	–or–
	$N \leq 250$	$250 < N \leq 2500$	$N > 2500$
Population decline	Precipitous decline[b]	Chronic decline or depression[c]	No decline apparent or probable
Catastrophe, rate and effect[d]	Order of magnitude decline within one generation	Smaller but significant decline[e]	not apparent
Hatchery influence[f]	High	Moderate	Low

a - Census size N can be used if direct estimates of effective size N_e are not available, assuming $N_e/N = 0.2$.
b - Decline within last two generations to annual run size ≤ 500 spawners, or run size > 500 but declining at ≥ 10% per year. Historically small but stable population not included.
c - Run size has declined to ≤ 500, but now stable.
d - Catastrophes occurring within the last 10 years.
e - Decline < 90% but biologically significant.
f - See Williams et al. (2011) for assessing hatchery impacts.

Table 6. Estimation Methods and Data Requirements for Population Metrics. S_t denotes the number of spawners in year t; g is mean generation time, assumed as three years for California salmon (from Lindley et al. 2007)

Metric	Estimator	Data	Criterion
$\hat{S}_t$	$\sum_{i=t-g+1}^{t} S_i/g$	$\geq$ 3 years spawning run estimates	Population decline
N_e	$N \times 0.2$ or other	varies	Population size
N	$\hat{S}_t \times g$	$\geq$ 3 years spawning run estimates	Population size
Population growth rate (% per year)	slope of $\log(S_t)$ v. time $\times 100$	10 years S_t	Population decline
c	$100 \times (1 - \min(N_{t+g}/N_t))$	time series of N	Catastrophe
h	average fraction of natural spawners of hatchery origin	mean of 1-4 generations	Hatchery influence

2.3 Updated Information and Current Species Status

2.3.1 Analysis of Viable Salmonid Population Criteria

Summary of Previous Biological Review Team Conclusions

At the last listing determination, Good et al. (2005) reported that a majority of the biological review team (BRT) felt that the CV spring-run Chinook salmon ESU was likely to become endangered, while a minority thought that it was in danger of extinction. The major concerns of the BRT were the low diversity, poor spatial structure, and low abundance of this ESU. The BRT recognized that the ESU once contained many large populations that have been extirpated.

Brief Review of Technical Recovery Team Documents and Findings

The Central Valley Technical Recovery Team delineated 18 or 19 historic independent populations of CV spring-run Chinook salmon, and a number of smaller dependent populations, that are distributed among four diversity groups (Lindley et al. 2004). Of these independent populations, only three are extant (Mill, Deer, and Butte creeks) and they represent only the Northern Sierra Nevada diversity group. The three extant populations passed through prolonged periods of low abundance before increasing in abundance moderately (Mill, Deer creeks) or robustly (Butte Creek) in the 1990s. All independent populations in the Basalt and Porous Lava group and the Southern Sierra Nevada group were extirpated, and only a few dependent populations persist in the Northwestern California group.

Using data through 2005 and the criteria in Table 5, Lindley et al. (2007) found that the populations in Mill, Deer, and Butte creeks were each at or near low risk of extinction. The ESU as a whole, however, could not be considered viable because there were no extant populations in the three other diversity groups. In addition, Mill, Deer, and Butte creeks are close together geographically, decreasing the independence of their extinction risks due to catastrophic disturbance.

Abundance and Trends

As shown in Figure 1, overall, most CV spring-run Chinook salmon escapement have increased slightly in recent years (2012-2014), however, as shown in Figure 2, abundance dropped dramatically in 2015. Abundance and trend statistics for this ESU related to the viability criteria are presented in Table 7. Until 2015, Mill Creek and Deer Creek populations both improved from high extinction risk in 2010 to moderate extinction risk due to recent increases in abundance. Butte Creek continued to satisfy the criteria for low extinction risk. Additionally, since 1996, partly due to increased flows provided in upper Battle Creek, the CV spring-run Chinook salmon population began and are continuing to naturally repopulate Battle Creek, home to a historical independent population in the Basalt and Porous Lava diversity group that was extirpated for many decades. This population has increased in abundance to levels that would qualify it for a moderate extinction risk score. Similarly, the CV spring-run Chinook salmon population in Clear Creek has been increasing, and currently meets the moderate extinction risk score. Returns in 2015, were much lower than the increases observed in 2012 to 2014, and are described further below.

In contrast, since 2007, the dependent (Core 2) populations of Cottonwood, Antelope, and Big Chico creeks, have continued to remain very low, with often zero or near zero returns in recent years. New data for the lower Yuba River suggests that the population's size, based on VAKI counts, meets the low extinction risk criteria for abundance, ranging from a few hundred to a few thousand, however the population is likely at high extinction risk due to hatchery influence.

The Feather River population continues to have high returns (1,000-20,000), but is heavily influenced by the FRFH. The population spawning in-river is difficult to determine because they are not counted when entering, and monitoring during spawning results in difficulties distinguishing between races. The returns to the FRFH collected for propagation have remained fairly consistent, generally between 1,000 to 4,000 fish.

The Sacramento River aerial redd surveys continue to indicate that a small population of CV spring-run Chinook salmon, spawning in September, may exist. Although the origin of these spawners is unknown, redd surveys conducted in September between 2001 and 2011 have observed an average of 36 Chinook salmon redds from Keswick Dam downstream to the Red Bluff Diversion Dam (RBDD), ranging from 3 to 105 redds; 2012 observed zero redds, and 2013, 57 redds in September (CDFW 2015).

For many decades, CV spring-run Chinook salmon were considered extirpated from the Southern Sierra Nevada diversity group in the San Joaquin River Basin, despite their historical numerical dominance in the Basin (Fry 1961, Fisher 1994). More recently, there have been reports of adult

Chinook salmon returning in February through June to San Joaquin River tributaries, including the Mokelumne, Stanislaus, and Tuolumne rivers (Franks 2014, Workman 2003, FishBio 2015). These spring-running adults have been observed in several years and exhibit typical spring-run life history characteristics, such as returning to tributaries during the springtime, over-summering in deep pools, and spawning in early fall (Franks 2014, Workman 2003, FishBio 2015). For example, 114 adult were counted on the video weir on the Stanislaus River between February and June in 2013 with only 7 individuals without adipose fins (FishBio 2015). Additionally, in 2014, implementation of the spring-run Chinook salmon reintroduction plan into the San Joaquin River has begun, which if successful will benefit the spatial structure, and genetic diversity of the ESU. These reintroduced fish have been designated as a 10(j) NEP when within the defined boundary in the San Joaquin River (78FR79622). Furthermore, while the SJRRP is managed to imprint CV spring-run Chinook salmon to the mainstem San Joaquin River, we do anticipate that the reintroduced spring-run Chinook salmon are likely to stray into the San Joaquin tributaries at some level, which will increase the likelihood for CV spring-run Chinook salmon to repopulate other Southern Sierra Nevada diversity group rivers where suitable conditions exist.

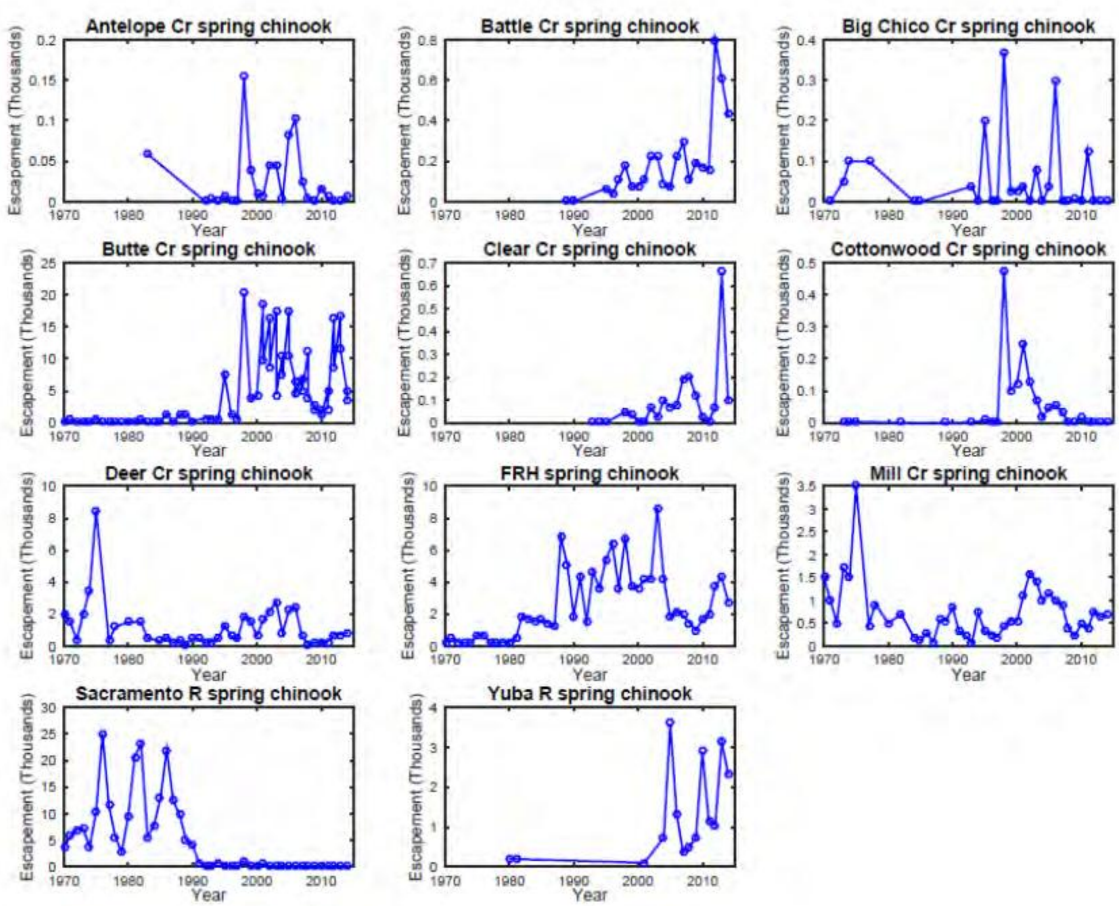

Figure 1. Escapement for CV spring-run Chinook salmon over time in thousands of fish (1970 to 2014). Note: Beginning in 2009, Red Bluff Diversion Dam estimates of CV spring-run Chinook salmon in the Upper Sacramento River were no longer available.

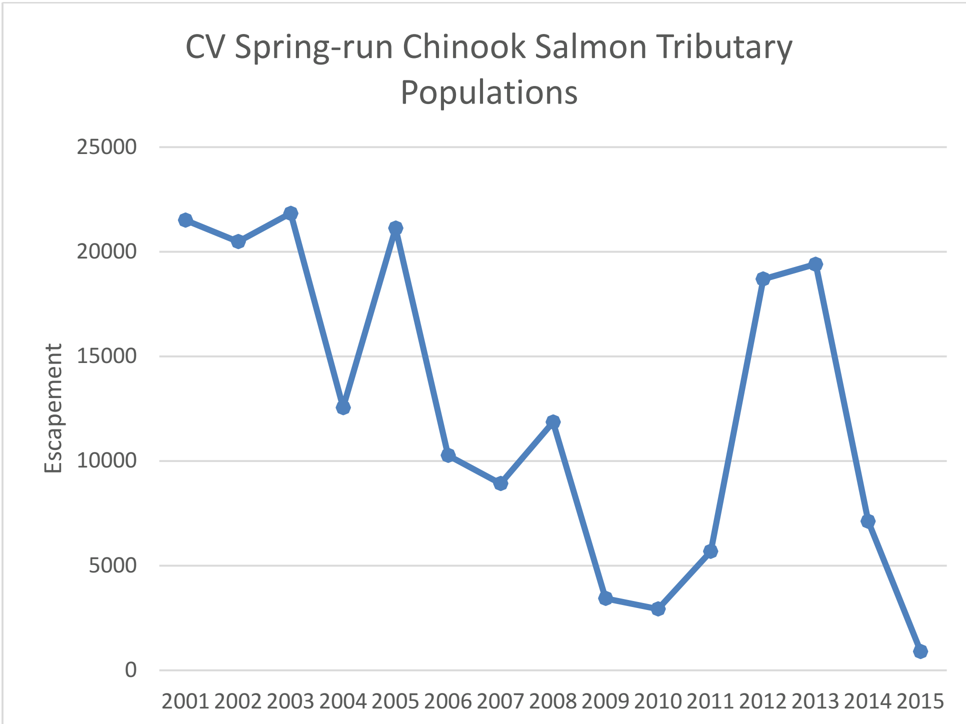

Figure 2. Combined escapement for Central Valley spring-run Chinook salmon tributary populations (Butte, Mill, Deer, Battle, Clear creeks) since 2001. Butte Creek numbers drive the curve and are taken from carcass survey counts.

Table 7. Viability metrics for Central Valley spring-run Chinook salmon ESU populations. Total population size (N) is estimated as the sum of estimated run sizes over the most recent three years for Core 1 populations (bold) and Core 2 populations. The mean population size ($\hat{S}$) is the average of the estimated run sizes for the most recent 3 years (2012 to 2014). Population growth/decline rate (10 year trend) is estimated from the slope of log-transformed estimated run size. The catastrophic metric (recent decline) is the largest year-to-year decline in total population size (N) over the most recent 10 such ratios.

Population	N	$\hat{S}$	10-year trend (95% CI)	Recent Decline (%)
Antelope Creek	8.0	2.7	-0.375 (-0.706, -0.045)	87.8
Battle Creek	1836	612	0.176 (0.033, 0.319)	9.0
Big Chico Creek	0.0	0.0	-0.358 (-0.880, 0.165)	60.7
Butte Creek	20169	6723	0.353 (-0.061, 0.768)	15.7
Clear Creek	822	274	0.010 (-0.311, 0.330)	63.3
Cottonwood Creek	4	1.3	-0.343 (-0.672, -0.013)	87.5
Deer Creek	2272	757.3	-0.089 (-0.337, 0.159)	83.8
Feather River Fish Hatchery	10808	3602.7	0.082 (-0.015, 0.179)	17.1
Mill Creek	2091.0	697.0	-0.049 (-0.183, 0.086)	58.0
Sacramento River[a]	-	-	-	-
Yuba River	6515	2170.7	0.67 (-0.138, 0.272)	9.0

[a] Beginning in 2009, estimates of spawning escapement of Upper Sacramento River spring chinook were no longer monitored. Historically, this estimate was derived by the total Red Bluff Diversion Dam (RBDD) counts minus the spring run numbers in the upper Sacramento tributaries. Beginning in 2009, RBDD gates were partially operated in the up position and in 2012 they were entirely removed and thus spring run estimates no longer available.

Productivity

Cohort replacement rates (CRR) are indications of whether a cohort is replacing itself in the next generation. The majority of CV spring-run Chinook salmon are found to return as three-year-olds, therefore looking at returns every three years is used as an estimate of the CRR. In the past the CRR has fluctuated between just over 1.0 to just under 0.5, and in the recent years with high returns (2012 and 2013), CRR jumped to 3.84 and 8.68 respectively. CRR for 2014 was 1.85, and the CRR for 2015 with very low returns was a record low of 0.14. Low returns in 2015 were further decreased due to high temperatures and most of the CV spring-run Chinook salmon tributaries experienced some pre-spawn mortality. Butte Creek experienced the highest pre-spawn mortality in 2015, resulting in a carcass survey CRR of only 0.02.

Spatial Structure

The extirpation of CV spring-run Chinook salmon from three of the four historically utilized diversity groups has greatly decreased the ESU's spatial structure. The northern Sierra Nevada diversity group populations (Mill, Deer, and Butte creeks) have been the only persisting populations. Restoration and more recently consistent returns in Battle Creek (basalt and porous lave diversity group) and Clear Creek (northwestern California diversity group), have begun to improve the spatial structure of the ESU. Additionally, the reintroduction efforts into the San Joaquin, and the spring-running Chinook salmon returning to the San Joaquin tributaries is promising for even further improvement to spatial structure.

Diversity

As described above, since the majority of CV spring-run Chinook salmon returns have been in one diversity group, genetic and behavioral diversity has been decreased compared to historical levels. Populations continuing to return to the other three diversity groups have the potential to increase the diversity of the ESU.

Some concerns remain with the spring-run Chinook salmon hatchery that is part of the ESU, as there has been and continues to be some introgression with other CV spring-run Chinook salmon populations as well as fall-run Chinook salmon. The majority of the FRFH spring-run Chinook salmon broodstock and in-river spawning population on the Feather River are first generation hatchery-produced fish (Kormos et al., 2012, Palmer-Zwahlen and Kormos 2013). The proportion of natural-origin fish in the broodstock is estimated to be 18 percent and 6 percent in 2010 and 2011 respectively (Kormos et al., 2012, Palmer-Zwahlen and Kormos 2013). Thus, the minimum criteria of greater than 10 percent of natural-origin fish in the broodstock is not being met annually (CA HSRG 2012). The proportion of hatchery-origin spring- or fall-run Chinook salmon contributing to the natural spawning spring-run Chinook salmon population on the Feather River remains unknown due to overlap in the spawn timing of spring-run and fall-run Chinook salmon, and lack of physical separation. However, the hatchery component is likely to be high. For example, 78 percent and 90 percent of spawners in the 2010/2011 spring-/fall- run Chinook salmon carcass survey were estimated to be from the FRFH respectively (Kormos et al., 2012, Palmer-Zwahlen and Kormos 2013).

FRFH-origin spring-run Chinook salmon adults have been recovered in other CV spring and fall-run Chinook salmon populations outside of the Feather River. Up until 2015, at least half of the FRFH spring-run Chinook salmon production has been trucked to release sites such as the San Francisco Bay, which leads to the returns straying to other watersheds at a relatively high rate, posing genetic risk to those other Central Valley salmon populations (Kormos et al., 2012, Palmer-Zwahlen and Kormos 2013). The annual spawning run size of CV spring-run Chinook salmon on the Yuba River follows the annual abundance trend of the FRFH spring-run Chinook salmon population. On Battle Creek, as high as 29 percent of CV spring-run Chinook salmon in 2010 were estimated to have originated from the FRFH (USFWS 2014). On Clear Creek, up to five percent of CV spring-run Chinook salmon carcasses above the segregation weir in 2010 to 2013 were from the FRFH (unpublished data, USFWS, Red Bluff FWO). A significant number of FRFH spring-run Chinook salmon strays have been observed in the Keswick Dam fish trap, with a high in 2015, of 114 fish. This indicates a likelihood that they could be interbreeding with natural-origin CV spring- or fall-run Chinook salmon in the Sacramento River (Rueth 2015). A prolonged influx of FRFH spring-run Chinook salmon strays to other CV spring-run Chinook salmon populations even at levels of less than one percent is undesirable and can cause the receiving population to shift to a moderate risk after four generations of such impact (Lindley et al. 2007). More information on the incidence of FRFH spring-run straying is desirable to more accurately estimate the extent to which spawning and introgression is occurring between fall- and spring-run Chinook salmon populations outside of the Feather River.

Viability Discussion

The status of the CV spring-run Chinook salmon ESU has probably improved on balance since the 2010 status review, through 2014, with two of the three extant independent populations of improving from high extinction risks to moderate extinction risks. The third, Butte Creek, has remained at low risk, and all viability metrics had been trending in a positive direction, up until 2015. The Butte Creek spring-run Chinook salmon population has increased in part due to extensive habitat restoration and the accessibility of floodplain habitat in the Sutter-Butte Bypass for juvenile rearing in the majority of years. Additionally, spring-run Chinook salmon in both Battle Creek and Clear Creek continue to repopulate those watersheds, and now fall into the moderate extinction risk category for abundance. In contrast, most dependent spring-run populations have been experiencing continued and somewhat drastic declines.

The CV spring-run Chinook salmon ESU has experienced two drought periods over the past decade. From 2007 to 2009, and now 2012 to 2015, the Central Valley experienced drought conditions and low river and stream discharges, which are generally associated with lower survival of Chinook salmon (Michel et al. 2015). The impacts of the recent drought years and warm ocean conditions on the juvenile life stage (see Ocean Conditions discussion below) will not be fully realized by the viability metrics until they manifest in potential low run size returns in 2015 through 2018 (Williams et al. 2016). This is already being realized with very low returns in 2015.

The recent drought impacts on Butte Creek can be seen from the lethal water temperatures in traditional and non-traditional spring-run Chinook salmon holding habitat during the summer. A large number of adults (903 and 232) were estimated to have died prior to spawning in the 2013 and 2014 drought respectively (Garman 2015). Pre-spawn mortality was also observed during the 2007 to 2009 drought with an estimate of 1,054 adults dying before spawning (Garman 2015). In 2015, late arriving adults in the Chico vicinity experienced exceptionally warm June air temperatures coupled with the PG&E flume shutdown resulting in a fish die off. Additionally, adult spring-run Chinook salmon in Mill, Deer, and Battle creeks were exposed to warm temperatures, and pre-spawn mortality was observed. Thus, while the independent CV spring-run Chinook populations have generally improved since 2010, and are considered at moderate (Mill and Deer) or low (Butte Creek) risk of extinction, these populations are likely to deteriorate over the next three years due to drought impacts, which may in fact result in severe declines.

Continued introgression between fall- and spring-run Chinook salmon in the FRFH breeding program and straying of FRFH spring-run Chinook salmon to other CV spring-run Chinook salmon populations where genetic introgression would be possible is unfavorable. However, beginning in 2015, and expected to continue, the FRFH released all spring-run Chinook salmon production into the Feather River rather than releasing in the San Francisco Bay which is hypothesized to reduce straying (CA HSRG 2012).

At the ESU level, the spatial diversity within the CV spring-run Chinook salmon ESU is increasing, with presence (albeit at low numbers in some cases) in all four diversity groups. The continued repopulation and increasing abundance of spring-run Chinook salmon to Battle and Clear creeks is benefiting the viability of the ESU. Similarly, the reappearance of phenotypic spring-run Chinook salmon to the San Joaquin River tributaries may be the beginning of natural recolonization processes in rivers where they were once extirpated. Reintroduction planning on the upper Yuba River shows promise, and will be necessary for the ESU to reach viable status. Just as necessary is the active reintroduction efforts below Friant Dam on the mainstem San Joaquin River.

In summary, the status of the CV spring-run Chinook salmon ESU has probably improved since the 2010 status review. The largest improvements are due to extensive restoration, and increases in spatial structure with historically extirpated populations trending in the positive direction. Improvements, evident in the moderate and low risk of extinction of the three independent populations, however, are certainly not enough to warrant the delisting of the ESU. The recent declines of many of the dependent populations, high pre-spawn and egg mortality during the 2012 to 2015 drought, and uncertain juvenile survival during the drought, and ocean conditions, as well as the level of straying of FRFH spring-run Chinook salmon to other CV spring-run Chinook salmon populations are all causes for concern for the long-term viability of the CV spring-run Chinook salmon ESU.

2.3.2 Five-Factor Analysis (threats, conservation measures, and regulatory mechanisms)

The last listing determination, Good et al. (2005), and last 5-year Status Review (NMFS 2011) described the major threats to CV spring-run Chinook salmon as falling into three broad categories[1]: loss of historical spawning habitat, degradation of remaining habitat, and genetic threats from the FRFH spring-run Chinook salmon program. The first two categories are discussed below in section 2.3.2.1, and genetic threats resulting from the hatchery program are discussed below in section 2.3.2.5. Also discussed in section 2.3.2.5 are the increasing concerns due to continued severe drought conditions. This section includes discussion of the five listing factors, and concludes with a summary discussion of whether the threats associated with these listing factors have substantially changed in magnitude since the 2010/2011 status review (Table 8).

2.3.2.1 Present or threatened destruction, modification or curtailment of its habitat or range:

Loss of Historical Spawning Habitat

Loss of historic spawning habitat for CV spring-run Chinook salmon remains a major threat, as most of that habitat continues to be blocked by the direct or indirect effects of dams. Since CV spring-run Chinook salmon were originally listed as threatened in 1999, spawning habitat for those fish has been expanded very little compared to the hundreds of miles of habitat blocked by dams. The removal of Saeltzer Dam on Clear Creek in 2000 opened up 10 miles of habitat. A partial low flow barrier on Cottonwood Creek was fixed in 2010, improving access to 30 miles of habitat. Additionally, the removal of Wildcat Dam in 2010 provided easier passage up to Eagle Canyon Dam in North Fork Battle Creek.

The Battle Creek Salmon and Steelhead Restoration Project (Restoration Project) will, upon completion, remove five dams on Battle Creek, install fish screens and ladders on three dams, and end the diversion of water from the North Fork to the South Fork. When the Restoration Project is completed, a total of 42 miles of mainstem habitat and 6 miles of tributary habitat will be restored and available to anadromous salmonids. Delays in completion, due to construction issues and funding shortages, have resulted in delays to benefits from the Project. Completion is currently expected to be in 2020.

Efforts to reintroduce CV spring-run Chinook salmon to historic habitat are underway in the San Joaquin River. The SJRRP calls for a combination of channel and structural modifications along the San Joaquin River below Friant Dam, releases of water from Friant Dam to the confluence of the Merced River, and the reintroduction of CV spring-run Chinook salmon. The San Joaquin River Restoration Settlement Act required an ESA 10(j) NEP with additional 4(d) exceptions. The first required flow releases from Friant Dam in support of the SJRRP occurred in October 2009. The first release of CV spring-run Chinook salmon into the San Joaquin River occurred in April, 2014. A second release occurred in 2015, and future releases are planned to continue annually in the spring. A conservation hatchery and captive broodstock program was initiated in 2012 to support the reintroduction with limited impact on source populations. The 2016 release will include the first generation of spring-run Chinook salmon reared entirely in the San Joaquin River in over 60 years. Key near-future SJRRP milestones include providing additional channel

[1] These are also the three major threat categories that were identified in the 1998 proposed rule to list Central Valley spring-run Chinook salmon as endangered (63 FR 11482). The ESU was ultimately listed as threatened in the 1999 final rule (64 FR 50394) based on information that was not considered in the proposed rule.

capacity in the San Joaquin River and complete the Friant-Kern Canal and Madera Canal Capacity Restoration projects during 2015 to 2022. Other high priority channel and structural construction activities are currently planned to begin 2022 to 2030 to realize the full intent of the SJRRP (SJRRP 2015).

The 2009 CVP-SWP biological opinion includes a phased fish passage program that is intended to expand habitat for winter-run Chinook salmon, spring-run Chinook salmon, and steelhead to areas upstream of Shasta Dam on the Sacramento River. Efforts thus far have focused on winter-run Chinook salmon and a pilot reintroduction plan for that species is scheduled for implementation starting in 2017. This reintroduction work will help with subsequent planning and implementation for reintroducing CV spring-run Chinook salmon upstream from Shasta Dam.

In the Yuba River watershed, government agency and non-government groups are engaging in a collaborative, science-based initiative to contribute to the recovery of CV spring-run Chinook salmon by enhancing habitat in the Yuba River downstream of Englebright Dam and reintroduction into their historic habitat in the North Yuba River upstream of New Bullards Bar Dam. This Yuba Salmon Partnership Initiative represents a promising opportunity to rebuild CV spring-run Chinook salmon in the lower Yuba River, as well as begin a pilot reintroduction program within 5-7 years and a full-scale reintroduction which could potentially begin within 10-15 years, under ideal circumstances.

Developed parallel to the Oroville Hydroelectric License, California Department of Water Resources (CDWR), Pacific Gas and Electric Company (PG&E), and NMFS entered into a Habitat Expansion Agreement (HEA) to select the most promising and cost-effective action(s) to expand spawning, rearing, and adult holding habitat sufficient to accommodate an estimated net increase of 2,000 to 3,000 CV spring-run Chinook salmon in the Sacramento River Basin. The expansion is to be accomplished through enhancements to existing accessible habitat, or improving access to habitat (including historical habitat currently blocked), to fully mitigate for any presently unmitigated impacts due to the blockage of fish passage of all fish species caused by the Feather River Hydroelectric Projects. The HEA calls for the development of a Habitat Expansion Plan (HEP). NMFS determined that the most recently proposed HEP (in 2010) did not meet the HEA criteria. Discussions are ongoing regarding the development of a new HEP.

Although the loss of historical spawning habitat remains a major threat to the ESU, the release of CV spring-run Chinook salmon into the San Joaquin River is an unprecedented step towards alleviating this threat. Collectively, the habitat expansion and reintroduction efforts taking place in the Sacramento and San Joaquin basins hold a tremendous amount of promise. If each effort is successful, the ESU will be on its way to recovery.

Degradation of Remaining Habitat

Previous status reviews for CV spring-run Chinook salmon (Myers et al. 1998, Good et al. 2005, NMFS 2011) have indicated that the remaining spawning and rearing habitat for this species is severely degraded. Threats to CV spring-run Chinook salmon habitat include, but are not limited to: (1) operation of antiquated fish screens, fish ladders, diversion dams, and inadequate flows on streams throughout the Sacramento River Basin including on Deer, Mill, and Antelope creeks; (2) levee construction and maintenance projects that have greatly simplified riverine habitat and have disconnected rivers from the floodplain; and (3) water delivery and hydroelectric operation on Butte Creek, Battle Creek, the main-stem Sacramento River (CVP), and the Feather River (SWP).

Cummins et al. (2008) attributed the much reduced biological status of Central Valley anadromous salmonid stocks, including CV spring-run Chinook salmon, to habitat effects related to the construction and operation of the CVP-SWP:

> "*Construction and operation of the CVP and SWP have altered flows, reduced water quality, and degraded environmental conditions and reduced habitat for fish and wildlife in the Central Valley from the headwaters to the Delta. This includes the native anadromous fish of the Central Valley -- winter, spring, fall and late-fall chinook, steelhead and sturgeon. Adult runs that once numbered in the millions have been reduced to thousands or less.*
>
> *The transformation of the natural Sacramento/San Joaquin river systems into a massive water storage and delivery system includes dams and diversions that have blocked access for anadromous salmonids to much of their historical habitat. Development of the CVP and State Water Project has significantly modified the natural hydrologic, geomorphic, physical and biological systems. The modified river system significantly impacts the native salmon and steelhead production as a result of fragmented habitats, migration barriers, and seasonally altered flow and habitat regimes*."

The degradation and simplification of aquatic habitat in the Central Valley has greatly reduced the resiliency of CV spring-run Chinook salmon to respond to additional stressors, such as an extended drought, which has been occurred every year since the last status review. The impacts of the extended drought will unfold over the next several years as fish return from the ocean.

One conservation measure with the potential to greatly improve habitat and increase the ability of CV spring-run Chinook salmon to cope with future stressors, is NMFS's 2009 biological opinion on the long-term operations of the CVP and SWP (NMFS 2009). The CVP/SWP biological opinion contained a reasonable and prudent alternative, which has mandatory actions that are intended to avoid jeopardy to anadromous fish, including CV spring-run Chinook salmon, and avoid destruction of critical habitat, resulting from the long-term operations of those projects. Actions in the CVP/SWP biological opinion that are intended to improve CV spring-run Chinook salmon habitat include:

- implementing multiple actions on Clear Creek to provide more suitable flows and water temperatures, and increase the availability of spawning habitat through gravel additions;
- implementing Keswick Dam release schedules and procedures designed to provide more suitable water temperatures for holding and spawning - through discussions with NMFS, in 2010, U.S. Bureau of Reclamation (Reclamation) began implementation of an improved

Shasta Reservoir storage plan and year-round Keswick Dam release schedule to provide cold water, although continued drought has made meeting temperature criteria difficult;

- modifying gate operations at RBDD – beginning in 2012, operation has included gates-out year-round (to improve upstream migration for adults as well as downstream survival of juveniles);
- providing funding to help complete the Battle Creek Restoration Project (project is briefly describe above);
- providing funding to support the Central Valley Improvement Act (CVPIA) Anadromous Fish Screen Program (AFSP);
- providing significantly increased acreage of seasonally inundated floodplain habitat to improve juvenile rearing in the lower Sacramento River basin – formal planning began in 2011, with completed actions expected to be completed by 2023; and
- implementing multiple actions to improve flow and habitat conditions in the Delta.

Other recent or ongoing programs and projects that have provided benefits to the habitat or range of the CV spring-run Chinook salmon ESU, or are expected to do so in the near future, are discussed below.

Central Valley Improvement Act programs. The CVPIA established the Anadromous Fish Restoration Program (AFRP) in 1992 with the goal of making "all reasonable efforts to at least double natural production of anadromous fish in California's Central Valley streams on a long-term, sustainable basis". The AFRP is administered jointly by Reclamation and USFWS. Approximately $8 million of CVPIA restoration funds are provided annually for the purpose of protecting, restoring, and enhancing special-status species and their habitats in areas directly or indirectly affected by the CVP.

Between 2010 and 2015, AFRP funded several projects benefitting CV spring-run Chinook salmon:

1) Fish passage project at Ward Dam on Mill Creek in 2015
2) Fish passage project at Hammer Dam (removal) on Cottonwood Creek in 2014
3) Gravel augmentation and other habitat enhancement activities on Clear Creek
4) Fish Passage at the lower falls on Deer Creek
5) Riparian Enhancement Pilot Project on five acres of Hammon Bar on the Yuba River (involving planting cottonwood and three species of willow pole cuttings in 2011 and 2012)

The AFSP and Ecosystem Restoration Program (ERP) conducted a fish entrainment monitoring study at 11 diversions on the Sacramento River (ranging from 9 cfs to 128 cfs) from 2009 through 2012 to obtain critical fish entrainment monitoring data in order to better understand the potential effects of diversions on fish losses and to assist resource managers in evaluating which diversions are most important to screen. Since 2010, the CVPIA AFSP has provided cost share funding to complete 15 fish screen projects on the Sacramento River resulting in the screening of diversions with a total capacity of 1,241 cubic feet per second. Twelve of the fish screen projects completed from 2010 to 2013 were part of a fish entrainment monitoring study that was conducted from 2009-2012.

Additionally, the purpose of section B13 of the CVPIA is to increase availability of spawning and rearing habitat for Sacramento River Basin salmonids. One project was completed in 2014, a side channel rehabilitation at Painter's Riffle. A Restoration Project programmatic biological opinion was completed in 2015, analyzing the proposed project, which will provide improvements and increases to spawning and rearing habitat each year in the upper Sacramento River.

Ecosystem Restoration Program. The ERP has completed seven years of an ambitious 30-year plan to restore ecological health and improve water management in the San Francisco Bay and Sacramento-San Joaquin Delta. Starting under the CALFED Record of Decision in 2000, the California Department of Fish and Game (now CDFW) now fulfills the role of the State's Implementing Agency for the ERP, and is currently managing more than 85 ongoing and approximately 10 newly funded projects. The objectives of the ERP are: 1) to prepare comprehensive ecosystem restoration plans for the Sacramento and San Joaquin rivers, 2) support scientific reviews, and 3) coordinate fish screen and fish passage projects with the AFRP, CVPIA, and other stakeholders to achieve CDFW fish passage goals.

The ERP has protected or restored more than 38,900 acres of habitat, most of which directly or indirectly benefits CV spring-run Chinook salmon. In 2014 the ERP released its updated Conservation Strategy to help guide the program's future work; which may result in habitat improvements for CV spring-run Chinook salmon.

California WaterFix and California EcoRestore. The purpose of the California WaterFix (CWF) is to modernize the state's aging water delivery system and provide additional opportunities to protect sensitive fish species. A proposed CWF water conveyance system would include new points of diversion in the north Delta in concert with improvements to the current through-Delta water export system in the south Delta. Actions under discussion include operation of a dual conveyance system and measures to reduce other stressors to the Delta ecosystem and sensitive species. CWF is in a developmental stage, its implementation is uncertain, and any new benefits or threats to CV spring-run Chinook salmon resulting from the plan would not occur for many years.

California EcoRestore is an initiative to help coordinate and advance habitat restoration in the Delta in the short term (next four years). The initial goal of California EcoRestore is to advance 30,000 acres of Delta habitat restoration. This restoration is unassociated with any habitat restoration that may be required as part of the construction and operation of any new Delta water conveyance (e.g., California WaterFix). The projects for California EcoRestore are still in developmental stages, so any new benefits or threats to CV spring-run Chinook salmon resulting from the plan would not occur for many years.

Flood Management. For the most part, levee maintenance actions continue to adversely simplify habitats and disconnect river systems from historic floodplains. Over the past five years, changes in levee maintenance practices have included "self-mitigating" features such as vegetative rock, constructing levee toe benches that allow for the planting of riparian vegetation, grading rock sizes to reduce piscivorous predator habitat and installing instream woody material to create shoreline refugia for emigrating juveniles. Physical habitat monitoring has shown the riparian mitigation is in itself successful; however, fishery monitoring has not demonstrated these features to be effective when compared to natural bank conditions. Additional monitoring and research is needed, as initial acoustic fish tracking studies have shown these designs may create a hydraulic effect that causes fish to migrate to the opposite side of the river channel.

Butte Creek. Recent conservation actions have improved habitat conditions for Butte Creek spring-run Chinook salmon. Completion of the Willow Slough Weir Project (new culverts and a new fish ladder) in 2010 improved fish passage through the Sutter Bypass. In addition, real-time coordinated operations of the DeSabla Centerville Federal Energy Regulatory Commission (FERC) Project No. 803 have been implemented in recent years to reduce the water temperature-related effects of the project on CV spring-run Chinook salmon adults during the summer.

Feather River – HEA/HEP and Oroville Dam FERC License Settlement. Through the Oroville FERC License Settlement, CDWR has committed to constructing a weir to segregate the spawning of CV spring-run and fall-run Chinook salmon, and implementing low-flow channel habitat improvements. Those habitat changes have yet to occur and there have been no major changes to CV spring-run Chinook salmon habitat in the Feather River in recent years. Additionally, through a parallel process, development of an HEA and HEP are underway, which is expected to enhance sufficient degraded habitat (or provide access to historical habitat) to accommodate an increase of 2,000 to 3,000 CV spring-run Chinook salmon in the Sacramento River Basin.

Battle Creek Restoration Project. As described above, the Restoration Project, when completed will restore nearly 50 miles of habitat available to CV spring-run Chinook salmon, however implementation has been delayed and not expected to be completed until at least 2020.

Lower Yuba River Habitat Restoration. The U.S. Army Corps of Engineers initiated a long-term gravel augmentation program in 2010 that is intended to improve spawning habitat in the uppermost reach of the lower Yuba River. Other lower Yuba River habitat restoration actions that are reasonably certain to occur in the next several years include implementation of a program to add woody material to the river in an effort to increase habitat complexity, and a side channel enhancement project intended to improve rearing habitat. Other fish passage and fish habitat improvement efforts for the lower Yuba River are currently in discussion and planning stages.

Emergency Drought Actions. NMFS and CDFW developed the Voluntary Drought Initiative to reduce the effects of the drought on priority salmon and steelhead populations in California during the 2014 and 2015 drought. It is a temporary, voluntary program that is only being implemented during State and Federal drought declarations or designations, with the goal of supporting agricultural activities while protecting the survival and recovery of ESA-listed salmon and steelhead. Agreements executed with water users during the drought provided a mechanism for ensuring minimum flow conditions for the survival and migration of adult and juvenile CV spring-run Chinook salmon in Mill, Deer and Antelope creeks.

Additionally, as part of the CVP/SWP biological opinion, the Delta Cross Channel (DCC) gates, which Reclamation uses to periodically send water to the interior Delta, includes requirements for closures of the DCC gates to protect outmigrating winter-run Chinook salmon from being directed to the interior Delta, rather than to the outer estuary and to sea. In 2014, Reclamation requested to open the DCC gates earlier than usual, due to the drought, which prompted new requirements to include protections for outmigrating CV spring-run Chinook salmon.

Summary

As discussed above, there are promising habitat restoration and fish passage programs and other projects being implemented and evaluated that, if successful, would greatly expand CV spring-run Chinook salmon spawning and rearing habitat. Likewise, there has been implementation of Recovery Actions with the potential for substantial habitat improvements. Although some key habitat improvement actions have begun, much work has yet to be implemented. Large scale fish passage and habitat restoration actions are needed for improving the CV spring-run Chinook salmon ESU viability.

While some conservation measures have been successful in improving habitat conditions for the CV spring-run Chinook salmon ESU since it was listed in 1999, fundamental problems with the quality of remaining habitat still remain (see Lindley et al. 2009, Cummins et al. 2008, and NMFS 2014). As such, the habitat supporting this ESU remains in a highly degraded state and it is unlikely that habitat quality has substantially changed since the last status review in 2010 (NMFS 2011). Overall, major habitat expansion and restoration for CV spring-run Chinook salmon has not occurred as of this review, and because of that, the loss of historical habitat and the degradation of remaining habitat continue to be major threats to the CV spring-run Chinook salmon ESU.

2.3.2.2 Overutilization for commercial, recreational, scientific, or educational purposes

The available information indicates that the fishery impacts on the CV spring-run Chinook salmon ESU have not changed appreciably since the 2010 status review (NMFS 2011). Attempts have been made (Grover et al. 2004) to estimate CV spring-run Chinook salmon ocean fishery exploitation rates using coded-wire tag recoveries from natural origin Butte Creek fish, but due to the low number of recoveries the uncertainty of these estimates is too high for them to be of value. CV spring-run Chinook salmon have a relatively broad ocean distribution from central California to Cape Falcon, Oregon, that is similar to that of Sacramento River fall-run Chinook salmon, thus trends in the fall chinook ocean harvest rate are thought to provide a reasonable proxy for trends in the CV spring-run Chinook salmon ocean harvest rate. While the fall-run Chinook salmon ocean harvest rate can provide information on trends in CV spring-run Chinook salmon fishing mortality, it is possible that CV spring-run Chinook salmon experience lower overall fishing mortality. If maturation rates are similar between CV spring-run and fall-run Chinook salmon, the ocean exploitation rate on CV spring-run Chinook salmon would be lower than fall-run Chinook salmon in the last year of life because CV spring-run Chinook salmon escape ocean fisheries in the spring, prior to the most extensive ocean salmon fisheries in summer.

The fall-run Chinook salmon ocean harvest rate index peaked in the late 1980s and early 1990s, but then declined (Figure 3). With the closure of nearly all Chinook ocean fisheries south of

Cape Falcon in 2008 and 2009, the index dropped to 6% and 1%, respectively. While ocean fisheries resumed in 2010, commercial fishing opportunity was severely constrained, particularly off California, resulting in a harvest rate index of 16%. Since 2011, ocean salmon fisheries in California and Oregon have had more typical levels of fishing opportunity. The average fall-run Chinook salmon ocean harvest rate between 2011 and 2014 is 45% which is generally similar to levels observed between the late 1990s and 2007. The CV spring-run Chinook salmon spawning migration largely concludes before the mid- to late-summer opening of freshwater salmon fisheries in the Sacramento Basin, and salmon fishing is prohibited altogether on Butte, Deer, and Mill creeks, suggesting in-river fishery impacts on CV spring-run Chinook salmon are relatively minor. Overall, it is highly unlikely that harvest resulted in overutilization of this ESU.

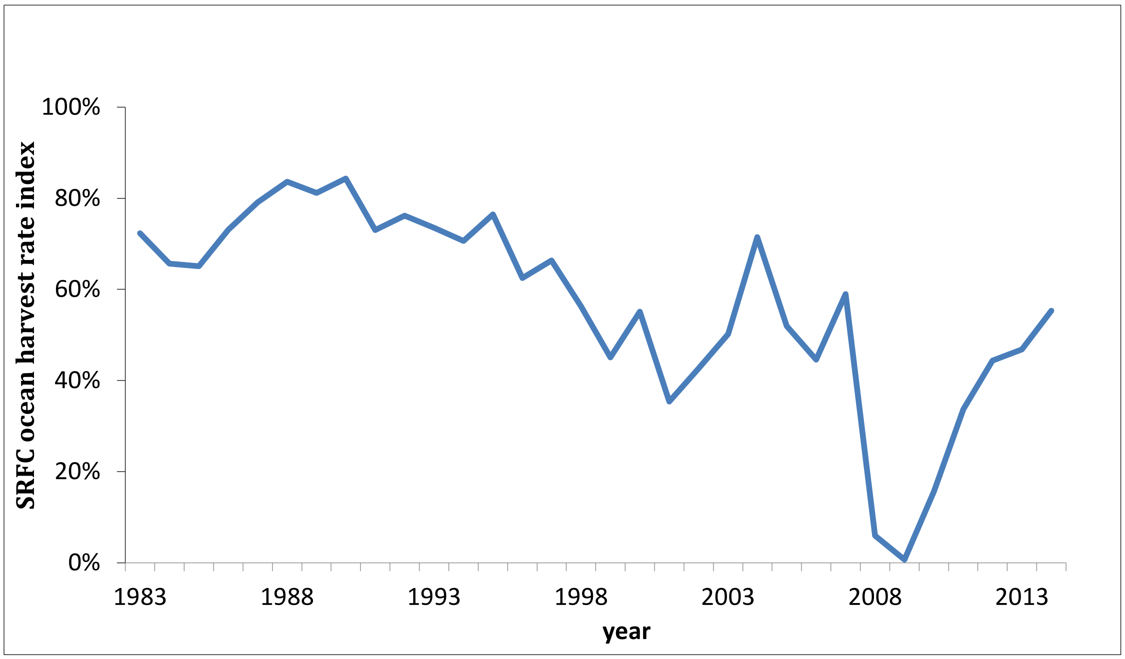

Figure 3. Sacramento River fall Chinook (SRFC) ocean harvest rate index for years 1983–2014 (taken from Appendix B, Table B-7, PFMC 2016).

2.3.2.3 Disease or predation

Naturally occurring pathogens may pose a threat to the CV spring-run Chinook salmon ESU because artificially propagated CV spring-run Chinook salmon are susceptible to disease outbreaks such as the Infectious Hematopoietic Necrosis Virus and Bacterial Kidney Disease. No disease outbreaks at the FRFH affecting CV spring-run Chinook salmon have occurred in the last five years.

Predation is a threat to CV spring-run Chinook salmon, especially in the lower Feather River, the Sacramento River, and in the Delta where there are high densities of non-native fish (e.g., striped bass, small-mouth bass and large-mouth bass) and native species (e.g., pikeminnow) that prey on outmigrating salmon juveniles. Survival studies of juvenile Chinook salmon migrating through the Delta have shown low survival/high predation rates (Williams et al. 2016). The presence of man-made structures in the environment that alter natural conditions likely also contributes to increased predation by altering the predator-prey dynamics often favoring predatory species. In the Sacramento River, removing the gates at the RBDD year-round since 2012 has minimized the impacts of predation at the dam. In the ocean, and even the Delta environment, salmon are common prey for harbor seals and sea lions, although the impacts on CV spring-chinook are unknown.

Disease and predation are persistent problems that can adversely affect CV spring-run Chinook salmon; however, no new information indicates that these threats have changed in severity since the 2005 listing determination or 2010/2011 status review. Although reducing predation at RBDD will benefit CV spring-run Chinook salmon at that location, it is unclear whether the reduction will substantially decrease the overall level of predation throughout the Sacramento River and Delta.

2.3.2.4 Inadequacy of existing regulatory mechanisms

Water Quality Regulation

Laws intended to protect California's water quality include the Federal Clean Water Act and Porter-Cologne Act (California Water Code). Agencies implementing these laws have directed considerable attention to salinity regulation in the Delta in order to ensure that freshwater is available for irrigating agricultural lands and for municipal and industrial uses. Poor water quality in the Delta resulting from agricultural and urban sources is a factor contributing to the ongoing collapse of the Delta ecosystem, which was detected when four pelagic fish species simultaneously and dramatically declined in abundance in 2002. Stronger implementation and enforcement of the Clean Water Act and the Porter-Cologne Act are needed in order to control agricultural (e.g., pesticides) and urban (e.g., ammonium) water pollution throughout the Central Valley.

Since the 2010/2011 status review, overall trends for water quality show improvements in water quality across the Central Valley. Many surface waters are polluted as water is discharged from agricultural operations, urban/suburban areas, and industrial sites. These discharges transport pollutants such as pesticides, sediment, nutrients, salts, pathogens, and metals into surface waters. Although conditions in most streams, rivers, and estuaries, throughout the State are much improved from 40 years ago, the rate of improvements have slowed overtime (SFEP 2015). Contaminants such as Polybrominated diphenyl ethers, and copper have declined over time, however many potentially harmful chemicals and contaminants of emerging concern (pharmaceuticals) have yet to be addressed. Legacy pollutants such as mercury and Polychlorinated biphenyls limit consumption of most fish, and directly and indirectly affect endangered fish populations, as well as their designated critical habitat.

In particular, urban storm water runoff is consistently toxic to fish and stream invertebrates (McIntyre et al. 2014, 2015). The array of toxicity is variously attributed to metals from motor vehicle brake pads; petroleum hydrocarbons from vehicle emissions of oil, grease, and exhaust; as well as residential pesticide use. Urban storm water toxicity has been linked to pre-spawn mortality of Coho salmon (Feist et al. 2011), and has been directly linked to effects at the population level (Spromberg and Scholz 2011, Spromberg et al. 2016). Emphasis on wastewater treatment plant upgrades and new legislative requirements (State Water Resource Control Board and Environmental Protection Agency), development and implementation of total maximum daily load programs (i.e., pathogens, selenium, pesticides, pyrethroids, methylmercury, heavy metals, salts, nutrients), and adoption of new water quality standards (i.e., Basin Plans), all aid in protecting beneficial uses for aquatic wildlife.

In California, approximately 9,493 miles of rivers/streams and some 513,130 acres of lakes/reservoirs are listed as impaired by irrigated agriculture through section 303(d) of the Clean Water Act. Of these, approximately 2800 miles, or approximately 28 percent, have been identified as impaired by pesticides. In recent years, NOAA scientists have investigated the direct and indirect effects of pesticides on individual ESA listed species, the foodwebs on which they depend, and at the population level (Baldwin et al. 2009b, Laetz et al. 2009, Macneale et al. 2010, Scholz et al. 2012).

Water quality pollution poses important challenges for the conservation and recovery of ESA-listed species and their habitat. Innovative and sustainable solutions such as green infrastructure and low-impact design (LID) are needed to manage pollutants as close to the source as possible. If these solutions can be applied at a broader scale, LID technology, policies, and watershed scale programs have the potential to maintain and/or restore hydrologic and ecological functions in a watershed (Spromberg et al. 2016), thereby improving water quality for ESA listed species and the ecosystem on which the species depend.

Species Identification for Regulatory Purposes

The Central Valley is home to four separate ESUs of Chinook salmon. Two of these ESUs are Federally protected (Sacramento River winter-run Chinook salmon and CV spring-run Chinook salmon) while two are not (fall-run & late fall-run Chinook salmon). Due to overlapping emigration time of juvenile CV spring-run and fall-run Chinook salmon, juvenile salmon that are captured at the State and Federal fish salvage facilities are often difficult to differentiate. Misidentification of CV spring-run Chinook salmon as fall-run Chinook salmon may lead to less timely Delta regulatory actions necessary to protect the listed species, which continue to delay and or hamper real-time efforts to protect the listed species.

Alternative identification methods under development include: a new genetic approach, which may be implemented in a near real-time framework; evaluation of fine-scale differences in morphological features between races; and analyses of multiple environmental variables in relation to daily salvage patterns of Chinook salmon juveniles to identify potential environmental cues predicting arrival of juvenile pulses at pumping facilities.

Whether as a direct tool in the form of real-time genetic assays of salvaged Chinook salmon juveniles, or as an indirect tool used to measure the accuracy of non-genetic alternative identification systems, genetic methods will clearly be integral in development of future take estimation procedures, and in the assessment of Central Valley Chinook salmon race population statuses in general.

2.3.2.5 Other natural or manmade factors affecting its continued existence

Feather River Fish Hatchery Spring-run Chinook Salmon Program

Recent genetic analysis on this stock (Garza and Pearse 2008) found subtle, but significant, differentiation between the FRFH spring- and fall-run Chinook salmon stocks. In addition, significant linkage disequilibrium in the population sample supported the hypothesis that it is a remnant of the ancestral Feather River spring-run Chinook salmon that has been heavily introgressed with fall-run Chinook salmon. A lack of close clustering relationships was also found between hatchery and naturally spawned population samples for the Feather River, although they were all still relatively closely related. However, the FRFH fall-run and "spring-run" Chinook salmon stocks did cluster together with relatively high bootstrap support, reflecting historic gene flow between them. In mean pairwise FST values, the FRFH stocks were as similar to other fall-run Chinook salmon populations (mean pairwise FST=0.005), indicating that they are not highly divergent from other Central Valley fall-run Chinook salmon (Garza and Pearse 2008).

In 2005, NMFS included the FRFH stock in the listed CV spring-run Chinook salmon ESU because: it represented the only remaining evolutionary legacy of the historic spring-run Chinook salmon population in the Feather River (upstream of Oroville Dam); its genetic linkage to the natural spawning population; it continues to exhibit a CV spring-run Chinook salmon migration timing; and for the potential to develop the hatchery program as a conservation hatchery. Since 2002, CDFW, CDWR, and NMFS have worked to reinforce the expression of a CV spring-run Chinook salmon life history at the FRFH by adopting new broodstock protocols designed to reduce or minimize the introgression of spring-run and fall-run Chinook salmon at the hatchery. A draft Hatchery and Genetics Management Plan has been developed that describes the new management protocols for the spring-run Chinook salmon hatchery program which includes in-river release of juveniles to reinforce homing of juveniles back to the Feather River and to minimize straying into other watersheds. The first 100 percent in-river release of spring-run Chinook salmon occurred in 2015, and is expected to continue in subsequent years. Overall, the adverse impacts of this program on naturally produced CV spring-run Chinook salmon are not likely to have changed substantially since the 2010/2011 review, but the new management efforts are expected to reduce impacts in the future.

Climate Change

Climate experts predict physical changes to ocean, river and stream environments along the West Coast that include: warmer atmospheric temperatures resulting in more precipitation falling as rain rather than snow; diminished snow pack resulting in altered stream flow volume and timing; increased winter flooding; lower late summer flows; a continued rise in stream temperatures; increased sea-surface temperatures; increased ocean acidity; sea-level rise; altered estuary dynamics; changes in the timing, duration and strength of nearshore upwelling; and altered marine and freshwater food-chain dynamics (see Williams et al. 2016 for a more detailed discussion of these and other projected long-term impacts due to climate change). These long-term climate, environmental and ecosystem changes are expected to in turn cause changes in salmon and steelhead distribution, behavior, growth, and survival. While an analysis of

ESU/DPS-specific vulnerabilities to climate change by life stage has not been completed, Williams et al. 2016 summarizes climate change impacts that will likely be shared among salmon and steelhead ESUs/DPSs. In summary, both freshwater and marine productivity and survival tend to be lower in warmer years for most salmon and steelhead populations considered in this assessment. These trends suggest that many populations might decline as mean temperature rises. However, the magnitude and timing of these and other changes, and specific effects on individual salmon and steelhead ESUs/DPSs, remain unclear.

Warmer temperatures associated with climate change reduce snowpack and alter the seasonality and volume of seasonal hydrograph patterns (Cohen et al. 2000). Central California has shown trends toward warmer winters since the 1940s (Dettinger and Cayan 1995). An altered seasonality results in runoff events occurring earlier in the year due to a shift in precipitation falling as rain rather than snow (Roos 1991, Dettinger et al. 2004). Specifically, the Sacramento River basin annual runoff amount for April-July has been decreasing since about 1950 (Roos 1991). Increased temperatures influence the timing and magnitude patterns of the hydrograph.

The magnitude of snowpack reductions is subject to annual variability in precipitation and air temperature. The large spring snow water equivalent (SWE) percentage changes, late in the snow season, are due to a variety of factors including reduction in winter precipitation and temperature increases that rapidly melt spring snowpack (VanRheenen et al. 2004). Factors modeled by VanRheenen et al. (2004) show that the melt season shifts to earlier in the year, leading to a large percent reduction of spring SWE (up to 100% in shallow snowpack areas). Additionally, an air temperature increase of 2.1°C (3.8°F) is expected to result in a loss of about half of the average April snowpack storage (VanRheenen et al. 2004). The decrease in spring SWE (as a percentage) would be greatest in the region of the Sacramento River watershed, at the north end of the Central Valley, where snowpack is typically shallower than in the San Joaquin River watersheds to the south.

Projected warming is expected to affect Central Valley Chinook salmon. Because the runs are restricted to low elevations as a result of impassable rim dams, if climate warms by 5°C (9°F), it is questionable whether any Central Valley Chinook salmon populations can persist (Williams 2006). Based on an analysis of an ensemble of climate models and emission scenarios and a reference temperature from 1951- 1980, the most plausible projection for warming over Northern California is 2.5°C (4.5°F) by 2050 and 5°C (9°F) by 2100, with a modest decrease in precipitation (Dettinger 2005). Chinook salmon in the Central Valley are at the southern limit of their range, and warming will shorten the period in which the low elevation habitats are thermally acceptable by naturally-producing Chinook salmon. This would particularly affect fish that emigrate as fingerlings, mainly in May and June.

CV spring-run Chinook salmon adults are vulnerable to climate change because they over-summer in freshwater streams before spawning in autumn (Thompson *et al*. 2011). CV spring-run Chinook salmon spawn primarily in the tributaries to the Sacramento River, and those tributaries without cold water refugia (usually input from springs) will be more susceptible to impacts of climate change. Even in tributaries with cool water springs, in years of extended drought and warming water temperatures, unsuitable conditions may occur. Additionally, juveniles often rear in the natal stream for one to two summers prior to emigrating, and would be susceptible to warming water temperatures. In Butte Creek, fish are limited to low elevation habitat that is currently thermally marginal, as demonstrated by high summer mortality of adults in 2002 and 2003, and will become intolerable within decades if the climate warms as expected. Ceasing water diversion for power production from the summer holding reach in Butte Creek resulted in cooler water temperatures, more adults surviving to spawn, and extended population survival time (Mosser *et al*. 2013).

Precipitation/Drought

The CV spring-run Chinook salmon ESU is highly vulnerable to drought conditions. During dry years, less cold water is available in the storage reservoirs such as Whiskeytown, Shasta, Oroville, and New Bullards Bar to control instream water temperatures downstream. The resulting increased in-river water temperature resulting from such drought conditions is likely to reduce the availability of suitable holding, spawning, and rearing conditions in Clear Creek, and in the Sacramento, Feather, and Yuba rivers. During dry years, the availability of thermally suitable habitats in CV spring-run Chinook salmon river systems without major storage reservoirs (e.g., Battle, Mill, Deer, and Butte creeks) would also be reduced. Multiple dry years in a row could potentially devastate this ESU. While CV spring-run Chinook salmon have historically been able to withstand droughts, the currently diminished abundance, spatial structure, and diversity of the ESU, and the increased frequency and duration of droughts predicted to occur as climate change progresses suggest that CV spring-run Chinook salmon are likely much more vulnerable to drought today than they were historically. Prolonged drought due to lower precipitation, shifts in snowmelt runoff, and greater climate extremes could easily render most existing CV spring-run Chinook salmon habitat unsuitable, either through temperature increases or lack of adequate flows. The previous drought, which occurred from 2007-2009, was likely a factor in the recent widespread decline of all Chinook salmon runs (including CV spring-run Chinook salmon) in the Central Valley (Williams et al. 2011). The period of consecutive dry years 2007-2009 ended with a relatively wet winter during water year 2010 (October 2009-September 2010), and 2011, with the Sierra Nevada Mountain snowpack at above average levels.

California has experienced well below average precipitation in each of the past 4 water years (2012, 2013, 2014 and 2015), record high surface air temperatures the past 2 water years (2014 and 2015), and record low snowpack in 2015. Some paleoclimate reconstructions suggest that the current 4-year drought is the most extreme in the past 500 or perhaps more than 1000 years. Anomalously high surface temperatures have made this a "hot drought", in which high surface temperatures substantially amplified annual water deficits during the period of below average precipitation.

California's 2014 Water Year, which ended September 30, 2014, was the third driest in 119 years of record. It also was the warmest year on record. On April 1, 2015, CDWR measured the statewide water content of Sierra snowpack at five percent of average for April 1st. These levels are lower than any year in records going back to 1950. Annual runoff, which is calculated from streamflow data, supplies many of our needs for water. Recent runoff estimates for California show measurements on par with 1930's and late 1970's droughts. Additionally, excessive groundwater pumping and aquifer depletion has resulted in land subsidence (sinking), which can cause permanent loss of groundwater storage in the aquifer system and infrastructure damage.

Finally, dry, hot and windy weather, combined with dry vegetation and a spark - either through human intent, accident or lightning - can start a wildfire. Drier-than-normal conditions can increase the intensity and severity of wildfires. According to CalFire (www.calfire.ca.gov), in 2014, fire crews responded to 4,266 fires which burned over 191,000 acres (which was similar to the year-to-date average of 4,508 wildfires on 109,888 acres burned), and in 2015, there have been 6,284 fires and over 307,595 acres burned. Wildfires often lead to high sedimentation and landslides into salmon bearing streams, and may burn riparian vegetation that would shade and cool the waterway.

The combination of low precipitation and high temperatures favored elevated stream temperatures, and these have been documented to be extreme in some watersheds. The lack of cold water stored behind Shasta Dam, in combination with water release decisions, led to a loss of stream temperature control below Shasta Dam in September 2014. Stream temperatures that exceeded the 13°C (56°F) target in Sacramento River Chinook salmon spawning areas are thought to have contributed to 95 percent mortality rates for eggs and fry produced by spawning winter-run and fall-run Chinook salmon in 2014. Concerns over a high potential for fish kills prompted emergency reservoir releases that were aimed at lowering downstream temperatures to alleviate those risks.

Ocean Conditions

Much of the northeast Pacific Ocean, including parts typically used by California salmon and steelhead, experienced exceptionally high upper surface ocean temperatures beginning early in 2014 and areas of extremely high ocean temperatures continue to cover most of the northeast Pacific Ocean. Additionally, a "warm blob" formed offshore of the Pacific Northwest region in fall 2013 (Bond et al. 2015). Off the coast of Southern and Baja California, upper surface ocean temperatures became unusually warm in the spring of 2014, and this warming spread to the Central California coast in July 2014. In the fall of 2014, a shift in wind and ocean current patterns caused the entire northeast Pacific domain to experience unusually warm upper surface ocean temperatures from the West Coast offshore for several hundred kilometers (km). In the spring of 2015, nearshore waters from Vancouver Island south to San Francisco mostly experienced strong and at times above average coastal upwelling that created a relatively narrow band (~50 to 100 km wide) of near normal upper surface ocean temperatures, while the exceptionally high temperature waters remained offshore and in coastal regions to the south and north.

Adult Chinook salmon maturing in 2015, 2016, 2017, and 2018 will likely be negatively impacted by poor stream and ocean conditions. The expected effects of the 2015/2016 tropical El Niño are likely to favor a more coastally-oriented warming of the Northeast Pacific this fall and winter that will persist into spring 2016. These ocean migrants will likely encounter an ocean strongly influenced by (if not dominated by) a subtropical food-web that favors poor early marine survival for Chinook salmon (Williams et al. 2016).

NOAA's Climate Prediction Center forecasts a 95 percent likelihood that the tropical El Niño event will persist through the winter of 2016, and they also predict a high likelihood for this event to alter North Pacific and Western US climate for the next few seasons. Because El Niño events favor fall/winter periods with an especially strong Aleutian Low pressure anomaly centered in the Gulf of Alaska, the “warm blob” of exceptionally warm upper ocean temperatures off the Pacific Northwest coast is expected to weaken considerably. In contrast exceptionally warm ocean temperatures between Central, Southern, and Baja California and Hawaii are expected to remain elevated for the next few seasons. El Niño-related changes in wind and related ocean current patterns are expected to cause a coast-wide warming of upper ocean temperatures from Alaska south to Mexico, but confined to a relatively narrow band within 100 miles off the coast.

The strong El Niño event is predicted to substantially reduce the odds for a repeat of the extreme warmth of the past two winters, extreme precipitation deficit experienced in California the past four winters, and the extreme warmth of the offshore waters of the Northeast Pacific Ocean that have persisted for most of the past two years. The past two years have also seen persistence in the warm phase PDO pattern of North Pacific Ocean temperatures, and the warm phase of the PDO is likely to continue for another year because of it strong tendency for persistence and the expected El Niño influences on the Aleutian Low and related ocean currents in the coming months.

2.4 Synthesis

The Central Valley technical recovery team delineated 18 or 19 independent populations of CV spring-run Chinook salmon that occurred historically, along with a number of smaller dependent populations, within four diversity groups (Lindley et al. 2004). Of these 18 or 19 populations, only three are extant (Mill, Deer, and Butte creeks) and they occur only in the Northern Sierra Nevada diversity group. In addition to these three extant populations, there are other tributaries with phenotypic CV spring-run Chinook salmon in them, but those populations all have fluctuating abundance reaching very low numbers, and/or are heavily influenced by hatchery origin spring-run Chinook salmon from the FRFH. Additionally there are current efforts underway to reintroduce CV spring-run Chinook salmon back into the San Joaquin River, as well as discussions for reintroduction into other Central Valley watersheds.

With a few exceptions, CV spring-run Chinook salmon populations have increased through 2014 returns since the last status review (2010/2011), which has moved the Mill and Deer creek populations from the high extinction risk category, to moderate, and Butte Creek has remained in the low risk of extinction category. Additionally, the Battle Creek and Clear Creek populations have continued to show stable or increasing numbers the last five years, putting them at moderate risk of extinction based on abundance. Overall, the SWFSC concluded in their viability report that the status of CV spring-run Chinook salmon (through 2014) has probably improved since the 2010/2011 status review and that the ESU’s extinction risk may have decreased, however the ESU is still facing significant extinction risk, and that risk is likely to increase over at least the next few years as the full effects of the recent drought are realized (Williams et al. 2016).

As discussed previously, there are potentially significant conservation measures to restore or expand habitat that are in early stages of implementation, such as the Battle Creek Salmon and Steelhead Restoration Project, actions required by NMFS’ CVP/SWP biological opinion, and the SJRRP. Other key actions for CV spring-run Chinook salmon are being formally discussed (e.g., Upper Yuba River reintroduction) or planned (e.g., EcoRestore). Some conservation measures are helping now, such as the removal of Wildcat Diversion Dam on Battle Creek, the removal of gate operations at Red Bluff Diversion Dam, and flow/export related actions in the Delta. However, some of the potential benefits from the aforementioned actions will not be realized for several years or more and the degree to which they will help benefit CV spring-run Chinook salmon and their habitat are uncertain.

The 2015 adult CV spring-run Chinook salmon returns were very low. Those that did return experienced high pre-spawn mortality. Juvenile survival during the 2012 to 2015 drought has likely been impacted, and will be fully realized over the next several years.

Summary descriptions of how the five ESA listing factors have changed since the 2010 status review are presented in Table 8 below. The only changes are related to improvements due to restoration activities, and impacts due to severe drought.

Table 8. Summary of whether and how each ESA listing factor for CV spring-run Chinook salmon has changed since the 2010/2011 status review. See section 2.3.2 for more detail.

LISTING FACTOR	CHANGE SINCE 2010/2011
Present or threatened destruction, modification, or curtailment of habitat or range	Limited habitat expansion. Some habitat restoration through CVP/SWP biological opinion, AFRP, B13, and ERP. Implementation of the San Joaquin spring-run Chinook salmon Reintroduction Plan has begun. Overall, no major change in this listing factor since 2010.
Overutilization for commercial, recreational, scientific, or educational purposes	Ocean harvest has not appreciably changed since 2010, as indicated by the Sacramento River fall Chinook harvest rate index. Restrictions in place in 2010 have continued the past 5 years.
Disease or predation	No evidence suggests that this listing factor has substantially changed since 2010.
Inadequacy of exiting regulatory mechanisms	No evidence suggests that the impact of this listing factor on CV spring-run Chinook salmon has substantially changed since 2010.
Other natural or manmade factors	Impacts of the Feather River Fish Hatchery likely did not substantially change since 2010. Drought conditions in 2012 to 2015 will likely reduce the abundance of those brood years, which would impact the abundance of returning adults in 2015 through 2018. Observations of this occurring has already begun, with very low returns in 2015.

3.0 RESULTS

3.1 Recommended Classification

Based on a review of the best available information, we recommend that the CV spring-run Chinook salmon ESU remain classified as a threatened species. It is important to note that the full effect of the ongoing severe drought on the ESU will be observed and measured over at least the next few years. In addition to the low adult returns observed in 2015, juveniles hatched in the drought years of 2013 through 2015 are expected to produce low adult returns in 2016 through 2018. Based on the severity of the drought and the low escapements as well as increased pre-spawn mortality in Butte, Mill, and Deer creeks in 2015, there is concern that these CV spring-run Chinook salmon strongholds will deteriorate into high extinction risk in the coming years based on the population size or rate of decline criteria. Monitoring environmental and biological conditions and management actions for these drought impacted year classes will be extremely important.

3.2 ESU Boundary and Hatchery Stocks

No change is recommended in the ESU boundary or hatchery membership status. NMFS will continue to monitor the spring-running Chinook salmon in the San Joaquin River tributaries and will assess whether a change to the ESU boundary is warranted in subsequent status reviews.

3.3 Experimental populations

When designating the San Joaquin River CV spring-run Chinook salmon experimental population, NMFS needed to determine whether the experimental population was essential to the continued existence of the species in the wild. The nonessential designation was based on the existence in the Sacramento River basin of four independent populations, one of which is supplemented by a hatchery, and several dependent or establishing populations that would be expected to persist should the San Joaquin River population not persist. The reintroduction is in its early phases, and the current condition of the Sacramento River populations are sufficient to support the survival of the species in the wild, thus there is no indication that a change from nonessential to essential would be warranted at this time.

We will continue to consider if a change to essential may be warranted in subsequent 5-year Status Reviews for this ESU as described in the 10(j) rule (78FR79622): "*We will assess the contribution of the NEP to the status of the species during the required 5 year status review of the CV spring-run Chinook salmon ESU. This information will be used by NMFS to determine if changes to the NEP designation may be warranted*."

4.0 RECOMMENDATIONS FOR FUTURE ACTIONS

Priority near-term drought actions:

- The CCVO, SWFSC, CDFW and other partners should closely monitor the status of this ESU and its response to the drought;
- The CCVO, SWFSC, CDFW and other partners should monitor environmental conditions and take protective measures to minimize the drought's impacts on CV spring-run Chinook salmon;
- NMFS should continue to work with partners to improve instream flows in Antelope, Deer, and Mill creeks; and
- NMFS should analyze whether the ESA consultation for the ocean salmon fishery with respect to its impacts on the CV spring-run Chinook salmon ESU should be reinitiated.

The status of this ESU may be severely impacted due to the extended drought, which may trigger reinitiation[2] of the ocean fishery consultation.

Priority actions for CV spring-run Chinook salmon recovery:

- Continue efforts to restore access to high elevation habitat in the Yuba River upstream of New Bullards Bar Dam and in the Sacramento River upstream of Shasta Dam;
- Battle Creek actions: Continue implementation of the Salmon and Steelhead Restoration Project; improve fish passage over natural barriers;
- Continue implementation of the San Joaquin River Restoration Program;
- Modernize fish passage facilities on Mill, Deer and Antelope creeks; increase spring, early summer, and fall instream flows for adult and juvenile fish passage through water acquisition, conjunctive use wells and storage, and water use efficiency plans and improvements;
- Develop and implement alternative water operations and conveyance systems, and restore Bay-Delta habitat and ecological flow characteristics to provide multiple and suitable salmonid rearing and migratory habitats for all Central Valley salmonids;
- Restore the ecological health of the Sacramento–San Joaquin River Delta and lower Sacramento River through significant changes in water, levee, and floodplain management, and reducing the abundance of non-native predatory fish;
- Implement ecologically based flows in the Sacramento River;
- Reduce the amount of CV spring-run Chinook salmon harvested in the commercial and recreational ocean salmon fishery;
- Butte Creek actions: Expand CV spring-run Chinook salmon monitoring program in to evaluate juvenile production and survival; implement temperature reduction at the DeSabla Forebay; modernize the fish passage facilities at Weir 1 in the Sutter Bypass;
- San Joaquin tributary actions: Continue the Scientific Evaluation Process to guide restoration of the Stanislaus, Tuolumne, and Merced rivers, and the San Joaquin basin as a whole to benefit CV spring-run Chinook salmon; continue to monitor spring-running Chinook salmon; and
- Feather River actions: Finalize and implement the HGMP for the FRFH; implement the Feather River Oroville Hydroelectric Facility's Fish Habitat Management Plan to reduce the interaction between hatchery and wild fish and between CV spring-run Chinook salmon and fall-run Chinook salmon in the Feather River; provide passage at Sunset Pumps weir.

[2] Section 7(a)(2) of the ESA and its implementing regulations (50 CFR 402.16) require Federal agencies to reinitiate consultation on previously reviewed actions if new information reveals effects of the action that may affect listed species or critical habitat in a manner or to an extent not previously considered.

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NATIONAL MARINE FISHERIES SERVICE
5-YEAR STATUS REVIEW
CALIFORNIA CENTRAL VALLEY DOMAIN
Central Valley Spring-run Chinook Salmon ESU

Current Classification: Threatened

Recommendation resulting from the 5-Year Status Review: Retain current ESA classification as threatened and current ESU boundary.

REGIONAL OFFICE APPROVAL:

Approve: Maria Rea Date: 4-13-16

Maria Rea
Assistant Regional Administrator
California Central Valley Office
West Coast Region

2015-2016 Chinook Salmon Dewatered Redd Monitoring on the Sacramento River

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Abstract

California's extensive water delivery system requires elevated Sacramento River flows during summer months and a reduction of flows starting in late summer to conserve storage for the following year. California's unprecedented drought has severely limited stored water in Shasta Reservoir, further emphasizing the importance of conserving stored water. As a result, Chinook salmon spawning downstream of Keswick Dam are subject to redd dewatering as flows are reduced. Overlapping winter-run incubation times and fall-run spawning periods allowed fall-run redds to be built before flows were reduced, increasing dewatering potential. Our monitoring effort marked and revisited redds which were deemed vulnerable to dewatering, re-measuring depth as flows out of Keswick Dam were reduced. Additionally, marked redds were categorized by the degree and duration of dewatering, indicating effect on juveniles. We observed 291 dewatered fall-run redds and one spring -run redd during the 2015-2016 survey period, a dewatering rate of 2.14%. Assuming a fecundity of 5,407 eggs per female (USFWS, 2012), 100% potential egg to fry survival, and 100% mortality, dewatering is theoretically responsible for a reduction in recruitment of 1,573,437 juvenile fall-run Chinook and 5,407 juvenile spring -run Chinook. It is unclear whether 100% mortality can be assumed, therefore additional research should be conducted to further clarify exactly what impact different degrees of dewatering have on Chinook redds in the Sacramento River.

Introduction

Since 2010, the California Department of Fish and Wildlife (CDFW), in partnership with Pacific States Marine Fisheries Commission (PSMFC), has conducted dewatered redd monitoring on the Sacramento River, between Tehama bridge (river mile 229) and Keswick Dam (river mile 302). The objective of this monitoring is to (1) determine the total number of redds dewatered and (2) provide real-time data for flow management purposes. Chinook salmon (*Oncorhynchus tshawytscha*) is the focal species in this monitoring effort.

Monitoring of dewatered redds is necessary on the Sacramento River to determine the impact of flow reductions from Keswick Dam. Flow is kept high throughout the summer to meet the demand of downstream water users. The agency that operates Keswick and Shasta Dams, the United States Bureau of Reclamation (Reclamation), reduces flows in the fall and early winter in order to maintain sufficient water storage for the following year. While this reduction in flow during 2015 did not negatively impact many redds below the first two major tributaries due to supplemental flow, the portion of the Sacramento River between Keswick Dam and Clear Creek (river mile 289) experienced significant redd dewatering as a result of these flow reductions. Negligible tributary flow during the fall-run Chinook salmon (fall-run) incubation period on this portion of river meant that any reduction in flow out of Keswick Dam was quickly evident as reduced water level.

Reclamation contracts with water users throughout the Central Valley, resulting in elevated Sacramento River flows in the summer for diversion out of the Sacramento-San Joaquin Delta through the Central Valley Project pumps. Since flows are elevated during the summer and early fall months, high quality spawning gravel that would otherwise be above the water line is made accessible to spawning Sacramento River winter-run Chinook salmon (winter-run). Due to the winter-run's endangered status under the federal and California Endangered Species Acts, Reclamation maintains high flows through October to provide winter-run alevins time to emerge. This presents a problem for the more numerous fall-run, which peak in spawning between late October and early November. The subsequent reduction(s) in flow for water conservation after winter-run alevins have emerged has the potential to dewater a large number of fall-run, spring-run, and potentially even late fall-run redds before alevins emerge.

Monitoring was conducted in an effort to document percent redds dewatered and provide fisheries and water resource managers with the data necessary to effectively manage the system for multiple beneficial uses. We were able to provide nearly real-time dewatering data to managers which allowed them to operate quickly, and is responsible for keeping at least 20 shallow winter-run redds from being dewatered.

It is important to note that the objective of this monitoring effort is to document the number of redds dewatered, not the overall abundance of redds. Determining dewatering percentage is possible because newly constructed shallow redds can be readily identified by their lack of algae and presence of fish, whereas deep water redds cannot be distinguished in river sections without annual bed mobilization.

Life History

The Sacramento River is unique in that it has four distinct spawning runs of Chinook salmon. These include winter-run, spring-run, fall-run, and late fall-run. Of these winter-run are state and federally listed as endangered, spring-run are state and federally listed as threatened, and late-fall and fall-run are federally listed as species of concern (NOAA, 2016).

Winter-run enter the river between December and August (CDFW, n.d.) in immature reproductive state (Reclamation, 2008), move up river quickly, and hold below Keswick Dam until spring and mid-summer. Due to water temperature requirements they then generally spawn in the 10 miles below Keswick Dam and the majority of redds emerge by mid to late October. Once emerged, fry hold in freshwater and estuaries for an additional five to nine months before moving in to the ocean (Reclamation, 2008).

Historically, winter-run spawned in the highest reaches of the Pitt, Sacramento, and McCloud Rivers as well as Hat Creek and Battle Creek (Reclamation, 2008). They would travel to these headwaters in order to spawn in creeks fed by cold-water springs, which contained the only water of suitable temperature for successful spawning during hot summer months. This is the source of the largest problem for winter-run spawning in the highly engineered Sacramento River system. Since winter-run cannot access their historic spawning grounds, sufficient cold water must be released out of Keswick Dam in order to allow for successful summer spawning. Winter-run are endemic to the Sacramento River system as well, further complicating and emphasizing the importance of conservation efforts.

Central Valley spring-run Chinook salmon (spring-run) are the next group to enter the river, between March and September. Like winter-run, spring-run enter in sexually immature form and hold for a period of several months before spawning. They are more commonly found in tributaries to the Sacramento River such as Butte, Deer, Mill, and Antelope creeks. Once in the tributaries they migrate to high elevations and hold through the summer in deep cold-water pools, before spawning in the fall, slightly ahead of fall-run. Spring-run juveniles exhibit inconsistent juvenile rearing and emigration strategies, functioning as either stream-type or ocean-type. The stream-type juveniles will generally rear in natal streams and emigrate as yearlings, whereas ocean-type juveniles will rear in the main channel and emigrate as sub-yearlings (NOAA, 2016).

Fall-run is the largest of the four runs and during 2015-2016 was the run most impacted by redd dewatering. Fall-run enter the Sacramento River as sexually mature adults between June and December and spawn between late September and December (CDFW, 2010). Juveniles emigrate within several months after hatching, although a small percentage may emigrate as yearlings. Because of its importance as a commercial and sport fish, the fall-run is also supported by numerous hatchery programs in the Central Valley. Approximately 32 million smolts are released from five central valley hatcheries annually (CDFW, n.d.).

Late-fall run Chinook have a similar life history to fall-run other than a run timing which is later and lower utilization of tributaries for spawning. Late-fall run enter the river between October and April and spawn between January and April (CDFW, 2010). They also enter the river as sexually mature adults and the majority of their juveniles exhibit an ocean-type emigration strategy. A portion of late-fall juveniles may be stream-type as well, remaining in the river until they emigrate as yearlings (CDFW, 2010).

Monitoring Area

The Sacramento River and its tributaries make up California's largest river system at a watershed size of approximately 27,000 square miles (69,930 square kilometers) and 31% of the state's total surface water runoff (Heiman and Lee Knecht, 2010). The Pit, McCloud, and Sacramento rivers all drain into Lake Shasta which is the state's largest reservoir at a capacity of 4.5 million acre-feet (Heiman and Lee Knecht, 2010). The Sacramento River flows out of Shasta Dam and in to Keswick reservoir, a forebay of Lake Shasta in place mainly for flood control and power generation purposes. Reclamation operates both Shasta and Keswick Dams and as such is responsible for flow related environmental impacts which may occur downstream.

Keswick Dam is the limit of anadromy on the Sacramento River and therefore is the northern edge of our monitoring area. From Keswick Dam the river flows another 302 miles (486 kilometers) to the Sacramento-San Joaquin Delta. For practical purposes we set the southern border of the monitoring area at the Tehama Bridge, a distance of approximately 73 miles (117 kilometers; See Figure 1). The area between Keswick and Tehama Bridge contains numerous habitat types, water velocities, and water quality values. Substrate types include mud/silt, sand, clay, hardpan, bedrock, gravel, cobble, and boulders. Because Chinook salmon have specific water quality and gravel size requirements for spawning, redds are often observed in predictable areas. These areas include gradually sloping gravel bars and laterals with 0.11 to 5.9 inch (0.3 to 15 centimeter) diameter gravel (California Department of Water Resources, 2003). Once these traits were identified it became easier to locate areas which had a high probability of containing new redds.

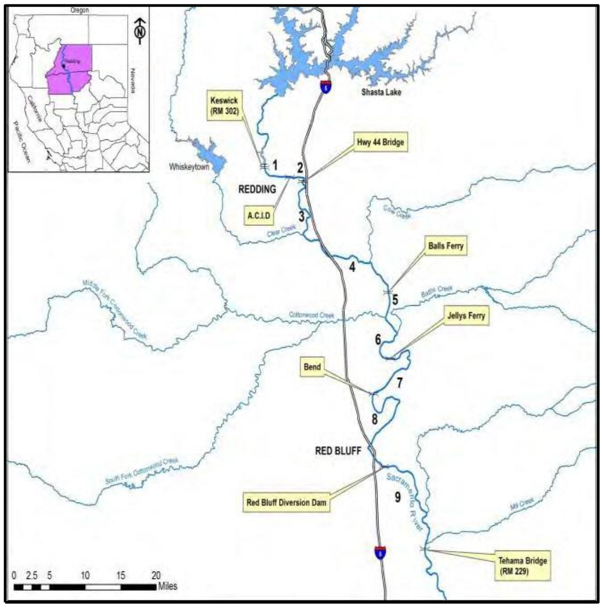

Figure 1.–Map of Upper Sacramento River Basin and study area including survey sections and major tributaries.

One major constraint on identifying redds in the Sacramento River is the lack of bed mobilization above Clear Creek. Since the river is dam operated and no major tributaries flow in between Keswick Dam and Clear Creek, flows only reach high enough levels to mobilize the river bed when Reclamation releases water for flood control or when Keswick Dam spills. Due to the severe California drought and the resulting low level of Shasta Reservoir, there has not been a spill or pulse flow event out of Keswick Dam since 2011 (California Department of Water Resources, 2015). A lack of bed mobilization means that redd morphology often remains intact between salmon runs and spawning years, requiring the surveyor to identify redds based off of algae growth and salmon presence. Below Clear Creek the river generally experiences flows high enough to mobilize bedload on a yearly basis, simplifying the monitoring effort.

Methods

The dewatered redd monitoring was conducted by jet boat and on foot. Survey crews consisted of at least two staff members from CDFW and/or PSMFC. Crews marked and collected data on underwater or dewatered redds. Redds were marked with a Trimble® Geo7x handheld unit and with physical markers (flagged and weighted disk tags). The Trimble® unit utilized a highly accurate global navigation satellite system (GNSS) which allowed redds to be pinpointed to an observed accuracy of nine to 32 inches (23 to 81 centimeters). A minimum of 15 points were taken at each redd and were then differentially corrected in Trimble's GPS Pathfinder Office® software. Differential correction corrects the handheld unit's points based off of a fixed and well surveyed station, further increasing accuracy. This high level of accuracy allowed us to differentiate individual redds upon revisiting sites and to accurately recognize redd superimposition. The Trimble® unit also contained a digital data sheet which allowed for analyzation of data in Microsoft® Access® and ESRI®'s suite of mapping software.

Pertinent data collected for each redd included date, water temperature, crew members, river section, water clarity, weather conditions, redd number, what time the redd was marked or updated, whether a salmon was present, dewatering status, and sampling action. In addition, pictures were taken of all redds throughout the winter-run, and part of the fall-run survey. Pictures were eliminated from sampling procedure part way through fall-run due to time constraints.

In order to standardize the depth measured at each redd, it was always measured at the shallowest point of the tailspill using a stadia rod and recorded to the nearest inch. Measuring shallow winter-run redds proved problematic. Since these redds were of such extreme concern, small changes in depth due to rock movement were deemed unacceptable. To mitigate this, we implemented standardized points of measurement by placing flat painted rocks on the top of each tailspill. This strategy proved successful, allowing us to relay accurate depth information during minor changes in flow.

Water temperature and clarity were sourced from the California Data Exchange Center (cdec.water.ca.gov) and carcass survey data, respectively. The carcass survey crew determined clarity with the use of a secchi disk mounted to a rigid graduated pole so as to reduce drift of the disk in the current. Measuring clarity allowed us to determine the effectiveness of redd surveys on individual days, as poor clarity made spotting redds difficult.

Redd number was determined by the unique disc tag number of the physical marker placed on the redd. Towards the end of the survey, redds were no longer physically marked as it was deemed unnecessary with the high accuracy and reliability of the Trimble® unit. At this point, redd numbers were assigned chronologically without the use of physical disc tags.

The next data point, whether or not a salmon was present, was recorded to indicate confidence in the validity of a given redd. Redds above Clear Creek were often hard to distinguish due to the carryover of redd morphology from previous runs and years, therefore a salmon nearby or actively digging increased confidence in the age of the redd.

The dewatering status included the options of not dewatered, top only, mostly, pot still wet, and pot dry. This was done in order to differentiate potential impact on the eggs and/or alevin in the redd.

Finally, the sampling action was taken to determine what actions were done at the site. The options used were “depth and photo” and “measured,” indicating whether or not a picture was taken. Previous years monitoring efforts utilized additional sampling actions, such as “redd modified,” however they were not used during the 2015-2016 monitoring effort.

In addition to the data collected for all redds, local water velocity was measured at winter-run redds as flows were reduced. Lower levels of velocity across redds is detrimental to juvenile development as it does not replenish dissolved oxygen or remove waste products as effectively (Bjornn, Reiser, 1991). Water velocity was measured using a SonTek® digital flow meter placed at a point upstream of the redd to reduce hydraulic influence caused by the shape of the redd. To further increase certainty that flow was being measured at the same point every time, painted rocks were once again deployed. Since flow was not reduced appreciably during the winter-run incubation period local water velocity did not significantly differ between measurements.

To locate new redds crews of two would drive specific sections of the river, with one crew member on the front of the boat looking for redds. We would frequent redd “hot spots” based on previous surveys and aerial redd survey results. Once identified, redds were checked for previous marking by using the map function on the Trimble® unit. If unmarked, data was taken and the redd was marked in the Trimble® unit.

Aerial redd surveys were also extensively utilized throughout the winter-run and part of the spring and fall-runs. During the winter-run spawning period the surveys were conducted once a week using a R44 four seat helicopter. The use of a helicopter allowed lower flying elevations, the ability to quickly return and hover over possible redds, and slower travel speeds. This proved effective for spotting potential winter-run redds which were marked on a map of the river and revisited via jet boat to confirm. Due to funding constraints, aerial redd surveys were transitioned to fixed wing flights once every two weeks for the spring and fall-run survey periods. The advantage gained by using the helicopter was not necessary for fall-run due to the high number of redds. These flights were only conducted a few times during the 2015 spring and fall-run spawning period due to environmental factors that required the survey to be cancelled.

At the beginning of the winter-run, spring-run, and fall-run redd dewatering survey all observed redds were marked regardless of depth due to unpredictable future flow reductions. Once flows were scheduled to reduce to the Biological Opinion minimum flow level of 3,250 cfs (USFWS, 2008; see Figure 2 for flow schedule) it became clear which redds were at risk of dewatering. At this point, redds were only marked if they were in two feet of water or less.

Redds were monitored until their projected emergence date. This date was calculated using accumulated thermal units (ATUs). Thermal units are accumulated based on water temperature, with warmer water contributing more ATUs per day than colder water. Chinook alevins will emerge from redds between 1,650 and 1,850 ATUs (Buccola, Rounds, Sullican, Risley, 2013), which takes approximately 72-90 days from the date of fertilization in the Sacramento River. In an effort to ensure emergence at the time of dewatering, the most conservative figure of 1850 ATUs was used.

Data was downloaded from the Trimble® and transferred into a Microsoft Access® and ArcGIS® database where it was used to develop maps and run queries. Queries proved useful in determining which redds were vulnerable to dewatering or had already been dewatered by altering the depth column requirements. This was especially important during the winter-run incubation period when Reclamation wanted to reduce flows and real time forecasting of dewatering was needed to inform management decisions. Thanks to our monitoring, we were able to provide accurate redd depth data that allowed management of flows to prevent dewatering.

Results

Reclamation started reducing flows out of Keswick Dam between September 15 and September 24, 2015, from 7,250 cfs to 6,850 cfs. This flow reduction had the potential to affect 49 active winter-run redds. Because of our monitoring efforts we were able to provide depth data to fisheries managers, avoiding any winter-run dewatering, although one fall-run redd was dewatered. The next flow reduction did not start until October 19, 2015, at which time there were four winter-run redds which had not yet emerged. These redds were once again monitored for depth, with information conveyed to managers which prevented

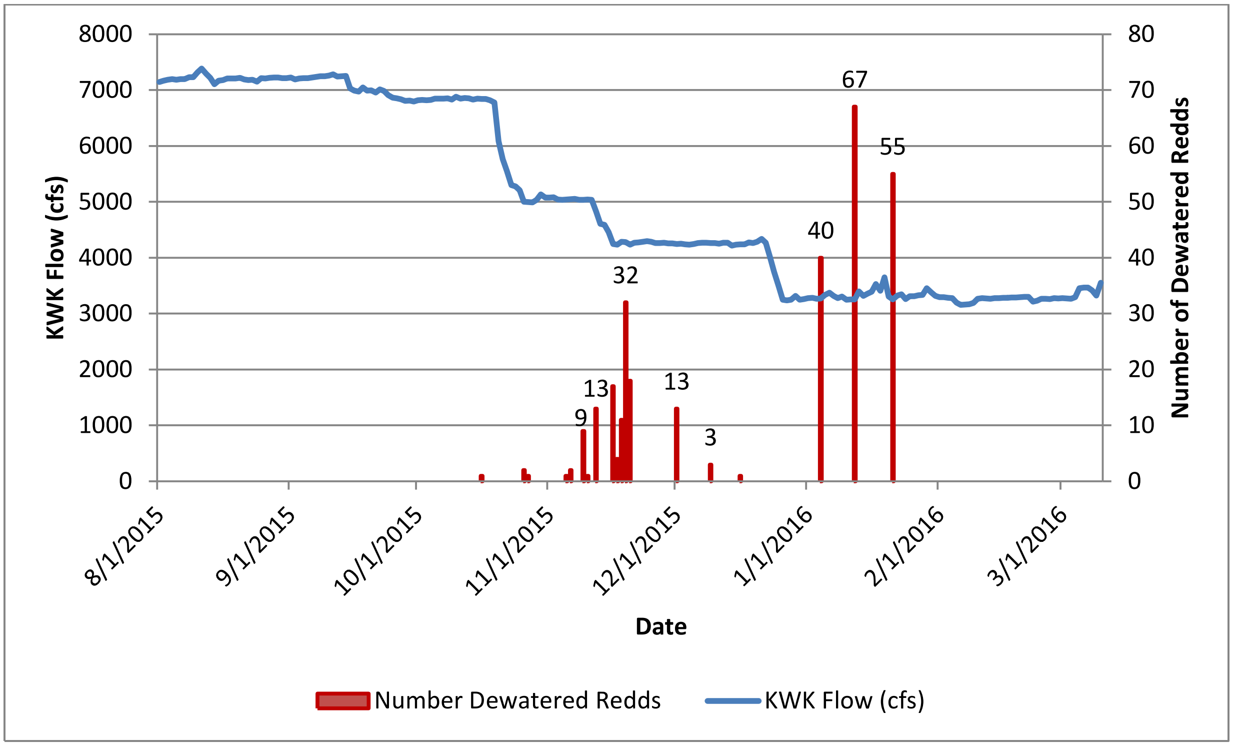

Figure 2.– Flow out of Keswick Dam (KWK) in cubic feet per second compared to the number of dewatered redds, by date observed.

dewatering.

The flow reduction which occurred between October 19 and October 26, 2015 reduced flows by approximately 1,850 cfs over an eight day period, stabilizing at 5,000 cfs. Surprisingly, this substantial flow event was only responsible for dewatering 16 fall-run redds. The next flow reduction to 4,250 cfs occurred between November 12 and November 16, 2015. This flow reduction had a more profound effect on dewatering than the previous reduction, presumably due to the increased abundance of fall-run redds. This flow reduction dewatered an additional 112 fall-run redds and one spring-run redd, bringing the overall dewatered redd count to 129.

The final flow reduction of 1,000 cfs occurred between December 23 and December 26, 2015 and brought the river down to its minimum level of 3,250 cfs (USFWS, 2008). This reduction in flow impacted many more redds than previous reductions, resulting in 162 additional dewatered fall-run redds (Figure 2).

Overall there were 291 observed dewatered redds during the 2015-2016 Chinook spawning season (May 2015 through April 2016). Of these redds, we believe that every one was a fall-run redd besides one which was built in September, and may have been a spring-run redd. Late-fall may have experienced dewatering as well, however due to environmental constraints, limited resources, and the priority of conducting stranding surveys and fish rescues, they were not surveyed. Turbid water and frequent storm events made marking late-fall redds problematic. As such, the observed number of dewatered redds is almost certainly lower than the actual number.

The majority of redd dewatering occurred between Clear Creek and Keswick Dam. Of the 291 dewatered redds observed, 248 were located at or above Clear Creek (Figure 3). The section of river between Clear Creek and the Highway 44 Bridge contained 135 dewatered redds, Highway 44 Bridge to Anderson-Cottonwood Irrigation District (ACID) diversion dam contained 106 dewatered redds, and ACID diversion dam to Keswick Dam contained seven dewatered redds. Of the remaining 43 dewatered redds below Clear Creek, 11 were located between Balls Ferry Bridge and Clear Creek, 17 were located between Bend District Bridge and Balls Ferry Bridge, two were located between Jellys Ferry Bridge and Bend District Bridge, and 13 were located between Red Bluff diversion dam and Jellys Ferry Bridge. No dewatered redds were observed south of Red Bluff diversion dam.

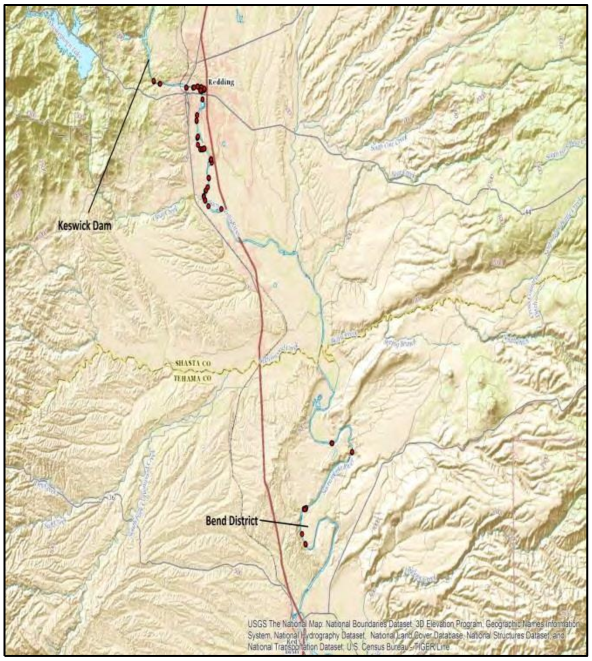

Figure 3.- Map of Sacramento River from Red Bluff to Keswick Dam (KWK). Red icons denote dewatered redds.

CDFW estimated 14,650 spawning spring and fall-run females in the Sacramento River during the 2015 spawning period. Of these females, 94% are thought to have spawned above Tehama Bridge (dewatered redd monitoring reach) and 1.4% did not spawn (Killam, 2015 Annual report – In progress)., The estimate for the number of spawning females in our monitoring reach is 13,578. Each spawning female counts for one redd, therefore the total number of redds is also estimated at 13,578. With this number we calculated the total dewatering percentage at 2.14%. Spring-run was included in the dewatered percentage due to a high degree of overlap and ambiguity between the two runs.

Assuming a fecundity of 5,407 eggs per female (USFWS, 2012), 100% potential egg to fry survival, and 100% mortality upon dewatering , dewatering is theoretically responsible for a reduction in recruitment of 1,573,437 juvenile fall-run Chinook and 5,407 juvenile spring -run Chinook.

When compared to the two previous years monitoring efforts, 2015-2016 saw more dewatering than 2014-2015, but less than 2013-2014 (Figure 4). 2014-2015 saw 47 dewatered redds and 2013-2014 saw 577 dewatered redds. Of the redds dewatered, one was from winter-run in 2014-2015, and five were winter-run in 2013-2014. Summer flows were significantly higher during 2013-2014 and 2014-2015, which may have contributed to the higher numbers of dewatered winter-run redds.

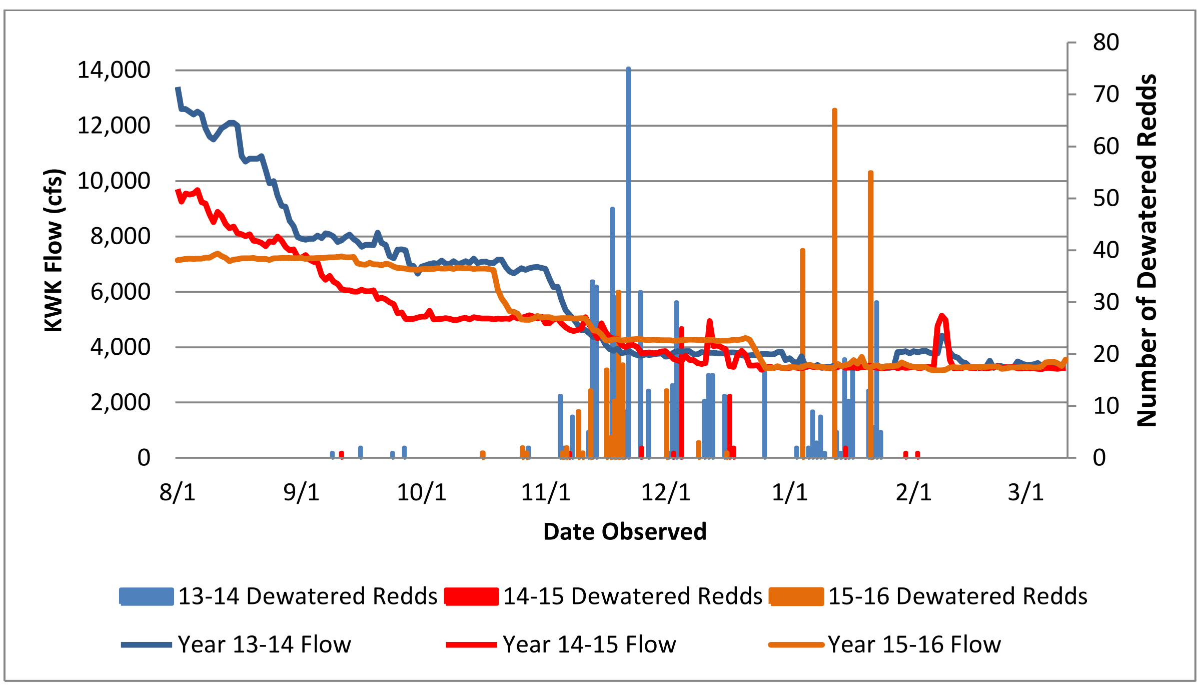

Figure 4. – Flow out of Keswick Dam (KWK) in cubic feet per second compared to the number of dewatered redds, by date observed. Figure compares water years 2013-2014, 2014-2015, and 2015-2016.

Discussion

This monitoring effort should be continued in the future to provide managers real-time data to help guide water management strategies that are protective of Chinook salmon populations. It is important to note that redd dewatering was not proportional to flow reductions. The largest flow reduction during the survey period (6,850 cfs to 5,000 cfs) resulted in 16 dewatered redds, while a much smaller reduction in flow (4,250 cfs to 3,250 cfs) dewatered 162 redds. While severe flow reductions can dewater channelized portions of the river, the majority of dewatering observed occurred on gradually sloping, shallow, gravel bars located next to the thalweg. These gravel bars remain inundated, yet shallow, at higher flows, allowing for extensive spawning.

The results of our dewatered redd monitoring between 4,250 cfs and 3,250 cfs should be considered when developing new management plans. If flows had been reduced to 4,250 cfs on November 1, 2015 and held constant, after all of the winter-run juveniles had emerged, a large percentage of dewatering would not have occurred. Had flows been held at 4,250 cfs the total fall-run and spring-run dewatered redd count would have been 129 redds, a reduction in redd dewatering of 56 percent. From a fall-run fisheries perspective, flows should have been lowered to 4,250 cfs immediately after winter-run emergence and held constant until Keswick releases increased for downstream water users. This should be considered in tandem with winter-run, spring-run, and late-fall run needs, as drought conditions may limit total water availability.

While every effort to mark all dewatered redds was made, it is almost certain that this monitoring effort produced an under-estimate of fall and late fall-run redd dewatering. For fall-run, time and staff constraints had the largest impact on the amount of redds that could be marked. Time had to be split between redd dewatering, water quality, and juvenile stranding monitoring. As such, it was not possible to monitor all productive spawning sites as often as necessary, lending to the probable under estimate of dewatering. Not visiting sites as often as necessary meant some redds were superimposed by other spawning females and previously fresh redds were given time to accumulate sediment and algae. This made identifying all unmarked redds extremely difficult. This issue could be alleviated by hiring additional staff. Late-fall monitoring was mainly limited by environmental constraints, as water clarity was poor for the majority of late-fall spawning.

For future consideration, more research regarding the effects of partial dewatering on Chinook juveniles in the Sacramento River Basin should be completed. It is unclear whether 100% mortality can be assumed for all degrees of dewatering, therefore a study on the effects of partial dewatering would increase confidence in the reduction in juvenile recruitment estimate.

Acknowledgements

We would like to thank CDFW, PSMFC, and USFWS personnel including Krystal Thomson, Virginia Evans, Matthew O'Neil, Patrick Jarrett, Tommy Steele, Michael Memeo, Zach Sigler, Darren Olson, Spencer Gutenberger, Byron Mache, Ryan Revnak, Stan Allen, and Tricia Parker-Hamelberg for their help with data collection, project coordination, and project administration. This monitoring effort was made possible through CDFW drought funding and USFWS Anadromous Fish Restoration Program funding FWS/F12AC00838.

Previous years reports can be found at:
http://www.calfish.org/ProgramsData/ConservationandManagement/CDFWUpperSacRiverBasinSalmonidMonitoring.aspx

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Obegi, Doug

From: Johnson, Matt@Wildlife <Matt.Johnson@wildlife.ca.gov>
Sent: Thursday, June 01, 2017 9:24 AM
To: Obegi, Doug
Cc: Roberts, Jason@Wildlife
Subject: FW: need more spring Sac outflow for baby salmon...
Attachments: Mill Creek Smolt Survival 2016.JPG; Cumulative Mill Cr Smolt Survival 2013-2016.JPG; Sac Flows Spring 2016.JPG; Sac Hydrology over time.JPG

Hi Doug. Matt from CDFW again. Jason asked me to forward a recent email to John M. from Golden Gate Salmon which summarizes some thoughts on Deer and Mill Creek wild spring-run Chinook and Sacramento River flow management. Matt

Matt Johnson
Environmental Scientist
California Dept. of Fish and Wildlife
1530 Schwab St. Red Bluff, CA
(530)-527-9490
Matt.Johnson@wildlife.ca.gov

From: Johnson, Matt@Wildlife
Sent: Tuesday, May 30, 2017 3:31 PM
To: 'john@goldengatesalmon.org' <john@goldengatesalmon.org>; Roberts, Jason@Wildlife <Jason.Roberts@wildlife.ca.gov>
Subject: RE: need more spring Sac outflow for baby salmon...

John,

I don't have data that estimates juvenile production of spring-run Chinook from Deer and Mill Creek, nor do I have data that would estimate total survival of these juveniles to the ocean, but based on recent acoustic tagging studies on Mill Creek, my familiarity with these populations and historical local agriculture practices, and observations of the hydrology of the Sacramento River, I do have some insight and opinions to share with you. I have attached some figures to help illustrate my points.

In a nutshell Deer and Mill Creek contain many miles of pristine spring-run Chinook habitat. These creeks could probably support 5K+ spring-run annually each, producing tons of juvenile salmon. Locally, trouble for the spring-run occurs in the lower 5-10 miles of the creeks where local irrigation dams and diversions occur. For good reason, much attention has been placed on improving fish passage and flows in lower Deer and Mill Creek. Fish ladders on these diversion dams are poorly designed (even absent in one case), leading to delayed fish passage and unnecessary stress. Pre-1914 waterrights are totally out of balance, allowing diverters to dry up the creeks. On good water years (like 2017) spring-run and agriculture can get along fine because there is enough water to go around. In dry years spring-run take a hit every time, when diversions result in not enough water left instream to allow late-migrating adults to access the creeks, and high predation rates on juveniles. Over time this has resulted in a winnowing of spring-run life history diversity and resiliency. Much progress is being made addressing the fish passage issues, and the Department has recently completed very robust and scientifically defensible flow studies for fish passage. However, IMHO, the gains from these efforts will likely be minimal if the hydrology of the Sacramento River is not concurrently addressed.

Since 2013 I have been assisting NOAA's Southwest Science Center with an acoustic survival study using Mill Creek smolts captured in a screw trap at river mile 5. I have attached a couple of figures depicting survival of these smolts from their release location (lower Mill Creek river mile 5) to the Golden Gate. While I have taken these figures from several public presentations given by the researcher, please keep these to yourself as they are part of this fellows unpublished graduate thesis (hopefully completed this summer). What we have learned from this study is that flow and temperature are highly correlated with survival (not surprising). What was surprising (to me) was where high mortality in the system is occurring, and just how poor survival is for wild smolts. Between 2013 and 2016 we have tagged a total of 304 smolts. One (1) smolt has been detected at a receiver at the Golden Gate, for an overall estimated survival rate of 0.3%. During the drought (2015 specifically) survival was poorest in Mill Creek under low, clear, and warm water conditions. However, survival has been extremely low in the reach of the Sacramento River from roughly below Woodson Bridge to Colusa across all study years (see Cumulative Mill Cr smolt survival 2013-2016). 2016 was a wet year for Northern CA and the Mill Creek watershed. Survival was very high in Mill Creek, and the first Sacramento River reach, but the fish never made it past Hwy 32 (Irvine Finch boat ramp) in 2016 (see Mill Creek smolt survival 2016).

Please see the figure titled "Sac Spring Flows 2016". I think this is very illustrative of the serious problem with Sac spring flows. Flows are great from Keswick to GCID in the spring. However, large diversions peel the water off going downstream, increasing water temperatures, slowing smolt movement, concentrating contaminants and pathogens, and increasing contact rates with predators. Adult spring-run face the same conditions travelling *upstream* in April and May, suffering unknown consequences from exposure to poor water quality in the Sac. 2016 was especially troubling year when Shasta Reservoir was near full pool and flows at Wilkins dropped to 2800 cfs in early May. Just brutal conditions for fish… Finally the figure titled "Sac Hydrology over time" really illustrates how Sac flow regimes have been altered due to water operations.

When considering the implications of the Mill Creek acoustic data please keep in mind that this study focused solely on late out-migrating spring-run smolts (due to minimum size requirements for acoustic tagging), a relatively small sub-sample. Mill Creek spring-run juveniles utilize a diverse life-history portfolio, with juveniles leaving Mill Creek October through June. However, I think a case could be made that the vast majority of Central Valley juvenile Chinook undertake a final migration in the spring months (April-May) to enter the Pacific when upwelling is occurring, and that flows in the middle and lower Sacramento River and delta are critical to the success of this out-migration. In summary, we have some very important "housekeeping" yet to accomplish on the spring-run tributaries, however, I think the biggest gains in recovery will come from increasing smolt survival. Higher, colder spring flows in the Sac are absolutely critical to achieve this increased survival. Please let me know if you have any questions. Matt

Matt Johnson
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(530)-527-9490
Matt.Johnson@wildlife.ca.gov

Save Our Water

SaveOurWater.com · Drought.CA.gov

From: john@goldengatesalmon.org [mailto:john@goldengatesalmon.org]
Sent: Tuesday, May 30, 2017 12:29 PM
To: Roberts, Jason@Wildlife <Jason.Roberts@wildlife.ca.gov>; Johnson, Matt@Wildlife <Matt.Johnson@wildlife.ca.gov>
Subject: RE: need more spring Sac outflow for baby salmon...

Hey guys

just touching bases... got any data, anecdotal or otherwise, I might use here? Thanks.

actually let me provide a friendly amendment..... I don't need to quote a specific person. Instead I might say something like, "I understand from fishery biologists that despite the improvements being made to spring run tributaries we're losing the benefits once these fish hit the mainstem as evidenced by data points X, Y and Z."

I will protect my sources.

John McManus
Executive Director
Golden Gate Salmon Association
650-218-8650

GoldenGate Salmon Association

> -------- Original Message --------
> Subject: Re: need more spring Sac outflow for baby salmon...
> From: "Roberts, Jason@Wildlife" <Jason.Roberts@wildlife.ca.gov>
> Date: Fri, May 26, 2017 4:42 pm
> To: "McManus, John @goldengatesalmon.org" <john@goldengatesalmon.org>,
> "Johnson, Matt@Wildlife" <Matt.Johnson@wildlife.ca.gov>

Hi John,

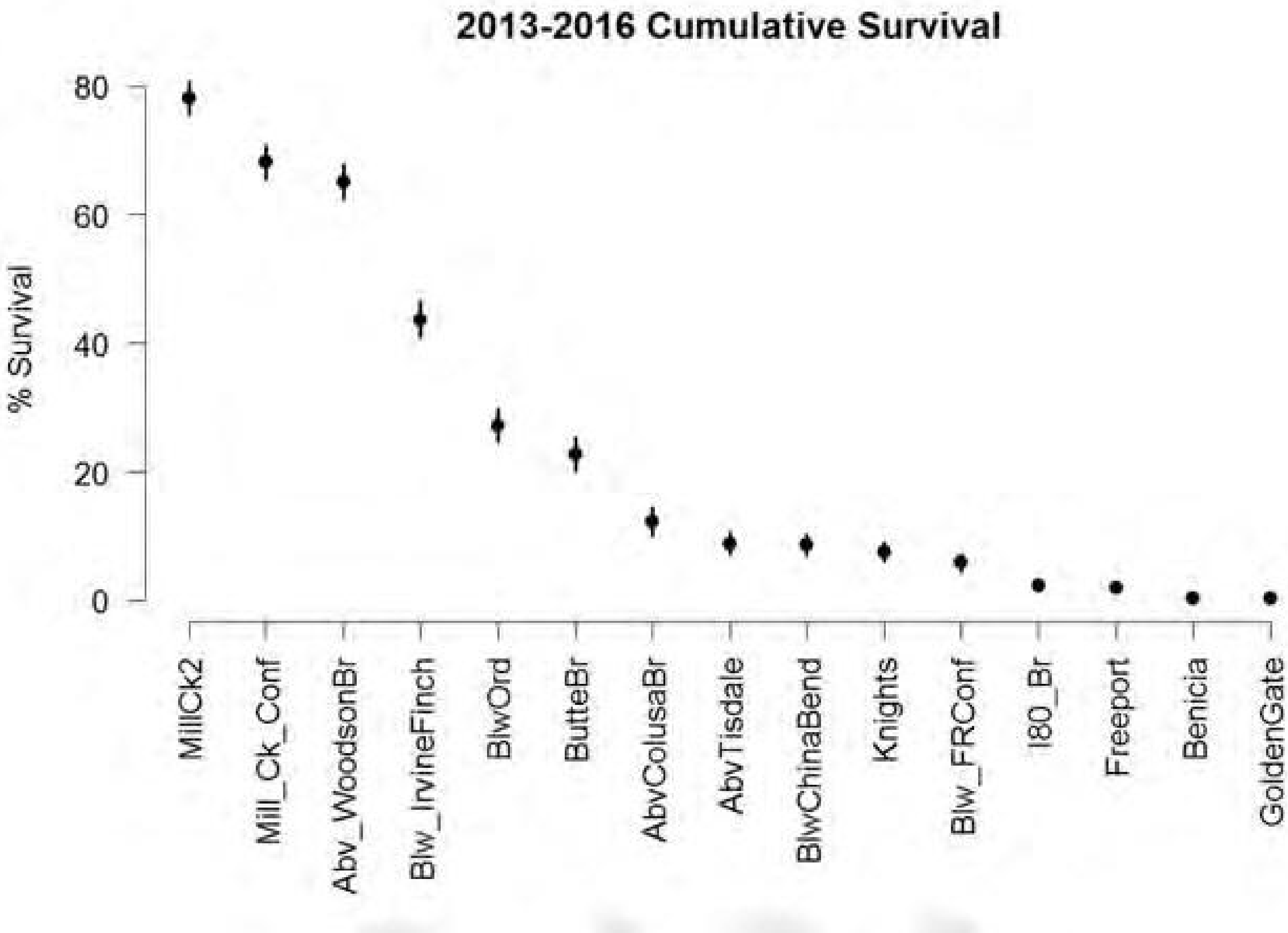
Matt can provide you something that is factual.

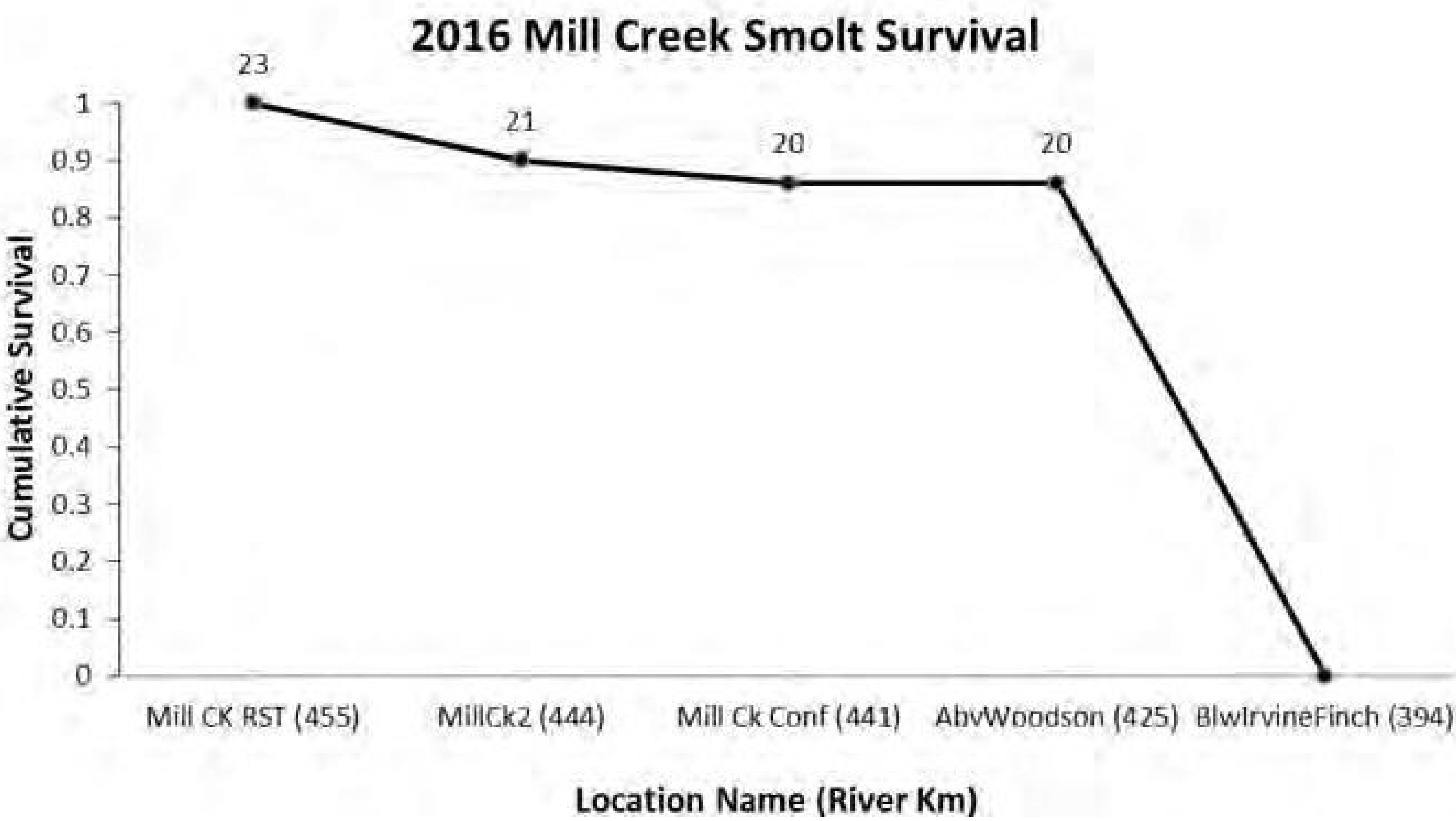
Matt, keep in mind that he wants to quote or cite you in testimony to the SWRCB.

Sent from my iPhone

On May 26, 2017, at 4:38 PM, "john@goldengatesalmon.org" <john@goldengatesalmon.org> wrote:

> Hi Jason
>
> Slide 12 in the attachment is the one we discussed before. I'm scheduled to present to the State Water Resources Control Board at the June 6th meeting. One request I'd like to lay on them is to consider spring pulse flows to aid juvenile salmon out migration in low water years.
>
> You had a great quote on that conference call we both attended. Can you recount that to me? It was along the lines of "we produce x xillion springers in the tribs but we loose them once they hit the mainstem..." What were those facts and figures? Thanks.
>
> John McManus
> Executive Director
> Golden Gate Salmon Association
> 650-218-8650
>
> <sigimg1>
>
> <2017-05-02 ShastaRPAMeetingSlides.pdf>


2013-2016 Cumulative Survival
% Survival
80
60
40
20
0
MillCk2
Mill_Ck_Conf
Abv_WoodsonBr
Blw_IrvineFinch
BlwOrd
ButteBr
AbvColusaBr
AbvTisdale
BlwChinaBend
Knights
Blw_FRConf
I80_Br
Freeport
Benicia
GoldenGate


2016 Mill Creek Smolt Survival
23
21
20
20
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Cumulative Survival
Mill CK RST (455)
MillCk2 (444)
Mill Ck Conf (441)
AbvWoodson (425)
BlwIrvineFinch (394)
Location Name (River Km)

File name: Mill-Deer Creek AT Fish Realtime Summary_20170531 2359.txt
Output on 01-Jun-2017 00:01:03
Acoustic tagged Chinook Salmon collect by RST at Mill and Deer Creeks
Summary statistics from real time receivers at
Sacramento I80/50 Bridge (rkm 170.7). Number of fish arriving.

Date yyyymmdd	Number Released	Detected at Sacramento Real time Daily #(%)	Cumulative #(%)
20170515	8	0 (0%)	0 (0%)
20170516	1	0 (0%)	0 (0%)
20170517	5	0 (0%)	0 (0%)
20170518	0	0 (0%)	0 (0%)
20170519	3	0 (0%)	0 (0%)
20170520	0	1 (3%)	1 (3%)
20170521	0	0 (0%)	1 (3%)
20170522	2	0 (0%)	1 (3%)
20170523	0	0 (0%)	1 (3%)
20170524	0	0 (0%)	1 (3%)
20170525	14	0 (0%)	1 (3%)
20170526	4	1 (3%)	2 (5%)
20170527	0	0 (0%)	2 (5%)
20170528	0	0 (0%)	2 (5%)
20170529	0	1 (3%)	3 (8%)
20170530	0	1 (3%)	4 (11%)

Individual fish statistics from real time receiver
at Sacramento I80/50 Bridge (rkm 170.7)
# of RL Detects = from River Left (East) receiver
# of RR Detects = from River Right (West) receiver

Location	TagID	Release Date	Release Location	Surg	First Detection (Date/time PST)	# of RL Detects	# of RR Detects	Travel (Days)	Speed Miles/day
Sacramento	0A6B	15-May-17 21:00	MillCk_RST_Rel	JN	20-May-17 12:13	0	6	4.6	37.5
Sacramento	0A6D	22-May-17 21:00	MillCk_RST_Rel	JN	26-May-17 22:33	7	12	4.1	42.8
Sacramento	0295	22-May-17 21:00	MillCk_RST_Rel	JN	29-May-17 15:30	8	0	6.8	25.7
Sacramento	0529	25-May-17 21:00	MillCk_RST_Rel	JN	30-May-17 06:22	0	3	4.4	39.6
Sacramento	096A	25-May-17 21:00	MillCk_RST_Rel	JN	31-May-17 09:46	17	4	5.5	31.4

DRAFT 12/15/2016
Sacramento River Spring Pulse Flow
To Evaluate CV Spring-run Chinook Salmon Survival

A study of spring pulse flows is being proposed by NMFS and CDFW to evaluate the survival of outmigrating spring run smolts. The proposed study is to implement and evaluate two spring pulse flows paired with JSAT tagged salmon releases. The study is being proposed for spring 2017.

Biological Objective/Rational: The biological objective is to improve survival rates of wild juvenile spring-run Chinook salmon during peak spring emigration periods. Existing data from previous studies show that survival in the upper and lower Sacramento River has been strongly correlated with flow but the exact relationship between flow and survival is less clear. This study will provide a basis to understand the relationship and provide information for potential management actions.

Investigators

PI: Dr. Flora Cordoleani (NMFS-SWFSC- UC Santa Cruz)
Co-PIs: Dr. Steve Lindley (NMFS-SWFSC-Santa Cruz),Cyril Michel (NMFS-SWFSC-Santa Cruz), Jeremy Notch (UC Santa Cruz), Arnold Ammann (NMFS-SWFSC-Santa Cruz), Howard Brown (NMFS-WCR-Central Valley Office), Jason Roberts (California Department of Fish and Wildlife)

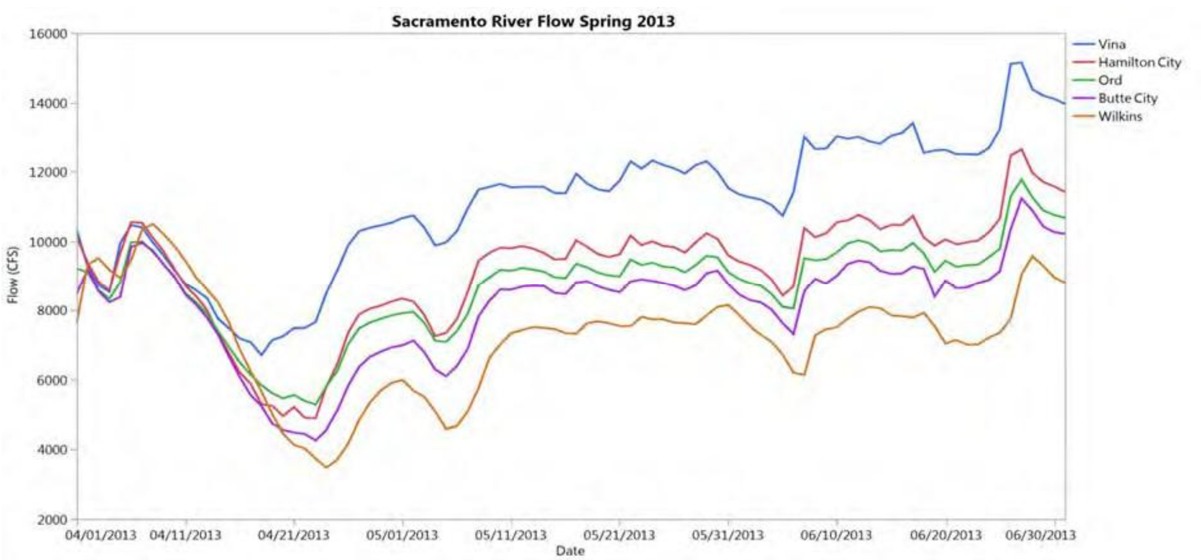
Spring Pulse Flow Proposal

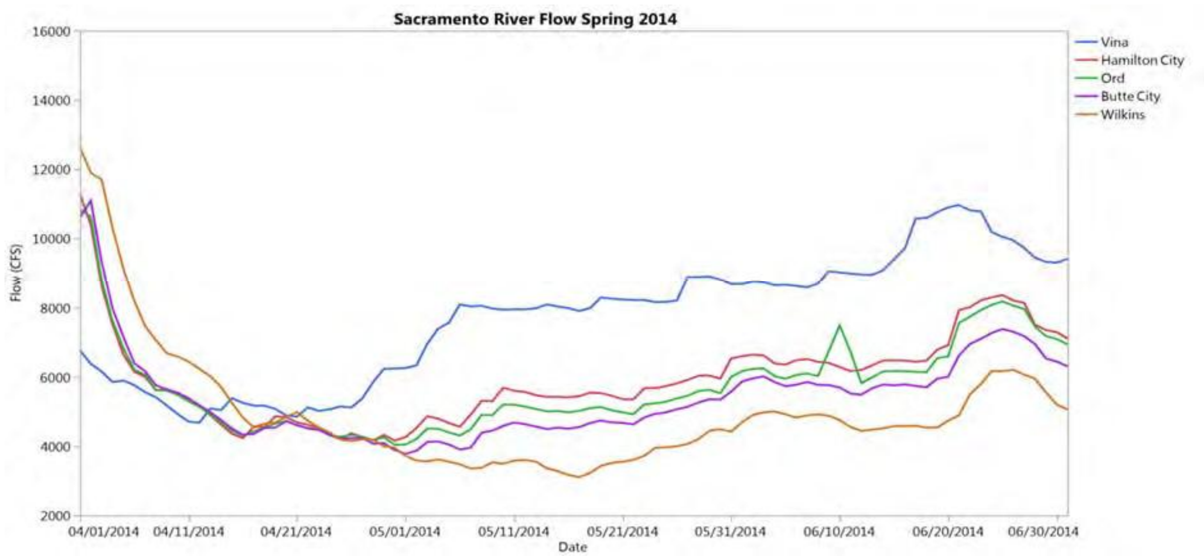
Two Sacramento River pulse flows that double the base flow for a short period of time between April 1 and May 15, 2017.

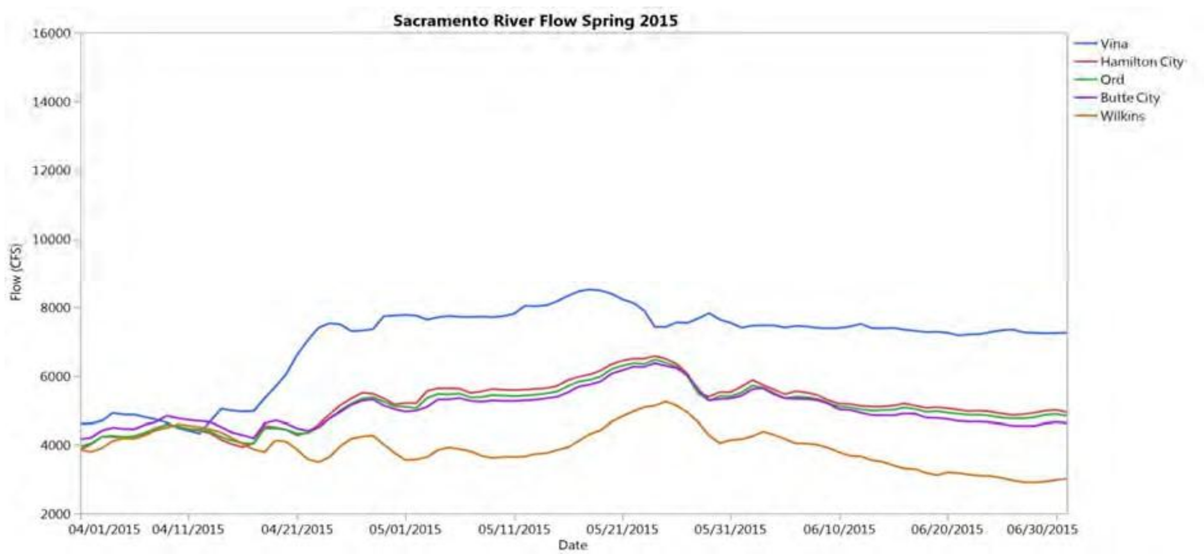
Pulse flow duration: 3 days per pulse, with the following 7 days ramping down to base flows
Pulse flow volume: 12,000 cubic feet per second (cfs) at Wilkins Slough gauge
Pulse flow target reach: Bend Bridge downstream to Wilkins Slough

In order to study the relationship between survival rates and increases in river flow for wild spring-run smolts, two pulse flows from Keswick Reservoir should be scheduled between April 1 and May 15 to coincide with the peak smolt outmigration from Mill and Deer Creek, according to 15 years of rotary screw trap (RST) data. The general concept is to capture as closely as possible the natural migration timing of wild spring-run smolts. Peak smolt outmigration from these tributaries typically occurs during snow melt events caused by warming air temperatures, which sends pulses of cold and turbid water downstream throughout the day. This seems to be a cue for smolts to leave the tributaries, and also triggers the outmigration of steelhead smolts, lamprey ammocoetes, and juvenile pikeminnow and hardhead.

While Deer and Mill Creek still have mostly natural, unmodified hydrographs, the hydrograph of the Sacramento River, into which those creeks flow, is mostly unnatural and managed. Therefore, there is often a mismatch between the conditions in the smolts' natal creeks and the conditions in the mainstem Sacramento River. In typical years, once these fish make it out of Mill and Deer Creeks, early spring flows in the Sacramento River can vary depending on the winter snowpack and the frequency of spring storms. Generally after April 15th water deliveries for agriculture increase and flows from Keswick Reservoir increase as a result. Flows in the upper Sacramento River upstream of Hamilton City see a pulse, but downstream of the Glenn Colusa Irrigation District (GCID) and other large diversions, flows in the Sacramento 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 gauge. The figures below represent the measured flows in the Sacramento River at various gauging stations, beginning upstream at Vina-Woodson Bridge and ending downstream at Wilkins Slough during the spring-run smolt outmigration period of 2013, 2014 and 2015.







The target population for this study is ESA-listed wild spring-run Chinook salmon, however, capture of taggable sized wild spring-run smolts is unpredictable and cannot solely be relied on to provide sufficient sample sizes for appropriate statistical power. Therefore, we are proposing using Coleman National Fish Hatchery fall-run Chinook salmon smolts as surrogates for wild spring-run smolts. Hatchery fall-run smolts are similar in size to the wild spring-run smolts that outmigrate in the spring, have overlapping outmigration timing, and migrate through the same migration corridor. The advantage of using hatchery fish is they are readily available in large numbers allowing for statistically appropriate release group sizes. We propose tagging a total of **500 hatchery fall-run smolts** with JSAT tags (125 per release group). Hereafter in the proposal, we will refer to the hatchery fall-run smolts as “surrogates”.

For this study, we will also opportunistically acoustic tag **200 wild spring-run salmon smolts** captured from the rotary screw traps located on Mill, Deer, Battle Creeks and/or Red Bluff Diversion Dam on the Sacramento River. Smolts will be held to the extent allowable by permits to allow for larger release groups during each pulse flow and base flow fish release. While we do not predict the sample sizes of wild smolts to be sufficient alone to accept or refute the hypotheses, we view the results of the wild spring-run smolts as potentially corroborative to the hatchery fall-run tagging results.

Hypothesis of Study

The null hypothesis for this study is that flow does not influence survival of outmigrating smolts. We have four alternative hypotheses for this study, all of which can be tested through a Cormack Jolly-Seber mark-recapture model.

A1: Survival increases throughout the river and regardless of season with increases in flow
A2: Survival increases in only specific regions but regardless of season with increases in flow
A3: Survival increases throughout the river but only during certain time periods, with increases in flow
A4: Survival increases only in specific reach x time period combinations, with increases in flow

With the wide range of flow values that the tagged smolts will experience, we can model how the relationship between flow and survival varies throughout the study period and throughout the pulses and troughs in flow. Furthermore, we will collect other water quality variables (such as turbidity, water velocity and temperature) to see how these relate to changes in survival as well. While previous tagging studies have shown strong support for increased flows correlating with increases in survival, the exact mechanisms that lead to flow influencing survival are unclear. This is in large part because these increases in flow were due to storm events, during which many covariates change in synchrony. With a pulse-flow, only a subset of the variables are likely to change drastically, which may lead us to decouple relationships and better understand exact mechanisms behind the flow-survival relationship. Of particular interest, increased turbidity and increased water velocities are typical during storm events, and are both thought to lead to increased outmigrant survival, but most studies are not able to decouple the effects of these variables.

Desired Pulse Flow and Fish Release Schedule

Depending on the water conditions that we are faced with in spring of 2017, we have two plans for the pulse flow experiment: One for a dry/normal winter and one for a wet winter. The plans are:

Plan A, Dry/Normal Winter:
Plan A is enacted if the mean flow at Wilkins Slough from April 1-10th is lower than 10,000 cfs. This would be our criteria for deciding if current base flows are representative of a dry spring.

- We request the release of the first pulse flow from Keswick on April 15th, high enough that it would result in a 3-day sustained 12,000 cfs flow at Wilkins Slough gauge.
- We will then release our tagged Coleman fish hatchery fall-run “surrogates” from Red Bluff as soon as the water pulse arrives to Red Bluff. We will also release any tagged wild spring-run smolts from the trapping locations on Mill and Deer Creeks with appropriate lead time to allow these fish to take advantage of pulse flows on the mainstem Sacramento River.
- Coleman could release one of their production releases a day after our Red Bluff release (coordination with Coleman National Fish Hatchery still pending). Given the one day difference, and the Red Bluff head start, we believe the pulse flow tagged fish should stay ahead. This would ensure that our surrogates don't benefit from any potential predator swamping that occurs due to the Coleman production releases, so as to ensure any survival gains can be attributed to higher flows only.
- We will then release the first non-pulse flow surrogate release from Red Bluff 2 weeks after, at which point Sacramento River flows should have dropped back to base flows. If flows are for some reason still higher than 8,000 cfs at Wilkins Slough gauge, we will delay until flows drop under this threshold. We will also release any available tagged wild spring-run smolts at this time.
- We request a second identical Keswick pulse flow 2 weeks after the base flow fish release, likely sometime around May 15th. We will again release surrogate smolts at Red Bluff once the water pulse arrives. We will also release any available tagged wild spring-run smolts at this time.
- We will then release our 2nd non-pulse flow surrogate release 2 weeks later at Red Bluff, likely around end of May. We will also release any available tagged wild spring-run smolts at this time. By that time, flows will likely be low at Wilkins Slough, and therefore there is probably no need for a threshold flow to allow for a fish release.

Plan B, Wet Winter:
Plan B is enacted if mean flow at Wilkins Slough for April 1-10th is above 10,000 cfs, and if flow forecasts predict that it will stay roughly the same through April 15th. This would be our criteria for deciding if current flows are representative of an average or a "wet" spring.

- For the first fish release, no need for a pulse flow out of Keswick, but take advantage of the existing natural high flows. We will release surrogate fish on April 15th at Red Bluff. Coleman may or may not elect to do the same, but if so, we will coordinate with them so that our fish get released 1 day before theirs. Coleman usually releases some of their production in mid-April. We will also release any available tagged wild spring-run smolts at this time.
- We will then wait until the flows at Wilkins Slough gauge drop by 50% from the flows when the first fish release went out. At this point, we will release the 1st low-flow surrogate release. We will also release any available tagged wild spring-run smolts at this time. If flows at Wilkins *haven't* dropped by 50% by May 15th, we may elect to cancel the remaining fish releases. There wouldn't be enough time to get the other releases in before June, at which point fish releases lose their biological meaningfulness.

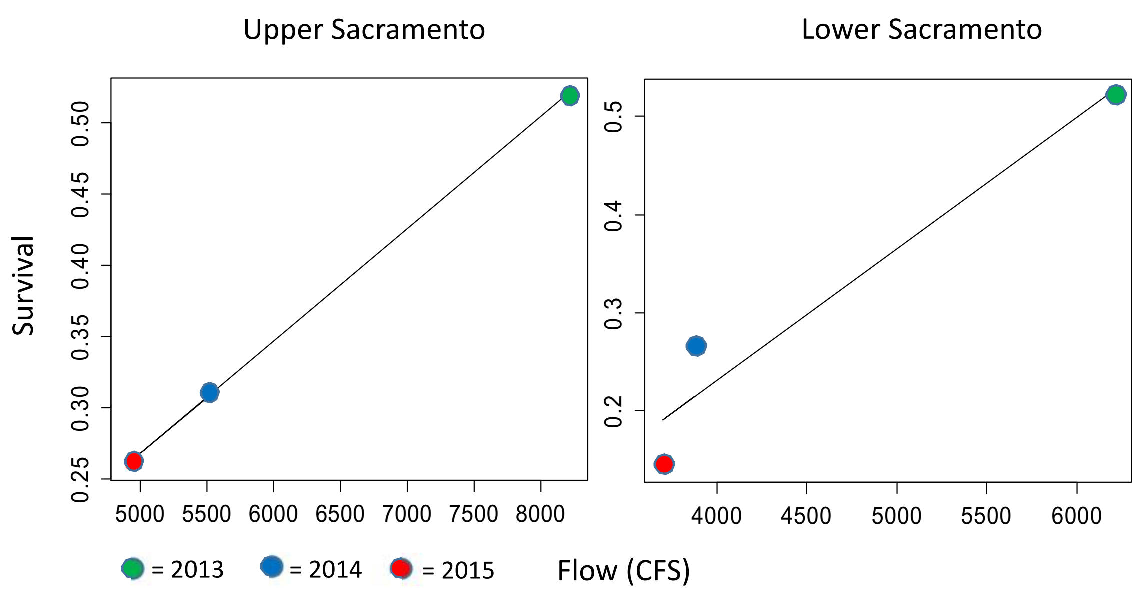
- Then, 2 weeks after the first low-flow fish release, we request a Keswick pulse flow as described in Plan A, i.e. resulting in 3-day sustained flows of 12,000 cfs at Wilkins Slough. When the pulse arrives to Red Bluff, we will release the surrogates at Red Bluff. We will also release any available tagged wild spring-run smolts at this time.
- Finally, 2 weeks later, we will release the final release of surrogates from Red Bluff, at which point the flows in the Sacramento River should be near to base flows. We will also release any available tagged wild spring-run smolts at this time.

<u>Scientific Justification</u>

We have seen strong evidence that higher flows result in higher survival of outmigrating Chinook salmon smolts in the Sacramento River. This evidence comes from two separate studies, one on tagged late fall-run smolts from 2007-2011, and one on tagged wild spring-run smolts from 2013-2015.

Wild spring-run smolt tagging study

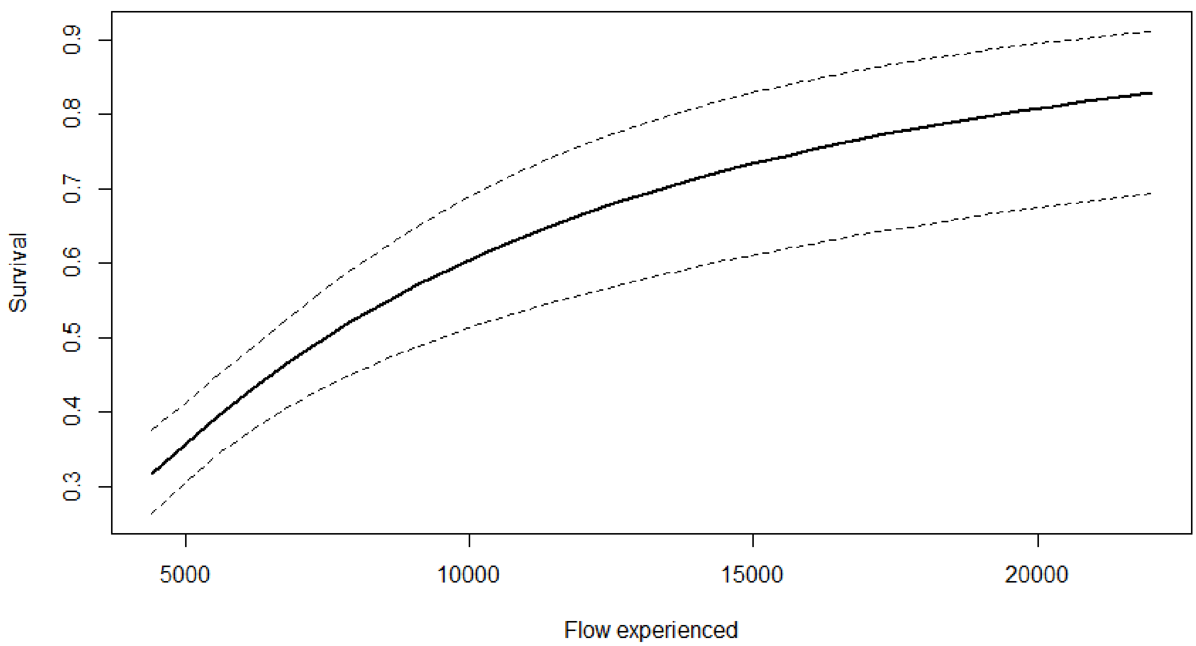
According to three years of survival data from JSAT acoustic tagged smolts from Mill Creek, survival in the upper and lower Sacramento River has been strongly correlated with flow, as seen in the figure below. For this study, the Upper Sacramento River is designated from the confluence of Mill Creek downstream to Butte City, and the lower Sacramento River is designated from Butte City downstream to Knights Landing. The flow value for each year is the average flow that all tagged smolts experienced while going through those regions during the study period, and the survival rate is the proportion of smolts that survived that region. The sample size for the lower Sacramento River is small due to the fact that not many smolts survive downstream through that region on any given year.



Hatchery late fall-run smolt tagging study

From the acoustic tagging work done with late-fall run Chinook smolts, it does seem clear that outmigration survival increases drastically with larger flows, and has been shown in countless other studies throughout the Pacific coast. However, the exact relationship between flow and survival is the harder part to pin down, and can have a serious influence on how effective pulse flows are at increasing survival.

The SWFSC has been using the existing late-fall run Chinook acoustic tagging data to look at relationships between different environmental factors and survival. They used flow, temperature, and turbidity in both the river and in the delta (i.e. 6 different distinct models) to see which had the strongest correlation with survival. The model using flow in the mainstem of the Sacramento River as a covariate had the strongest support, and by a large margin. The next step SWFSC took was to then look at different relationships between survival and Sacramento River flow as measured at Bend Bridge. In particular, is the relationship between the two a simple linear, logarithmic, or quadratic relationship? They tried testing these and other different hypotheses, and the logarithmic model seemed to fit the best. The log(flow) correlated the best with survival during outmigration. They then used the coefficient estimate for the effect of flow to make a covariate prediction plot based on the known extremes in daily flow at Bend Bridge during the study period (4400 to 22000 cfs). The figure below demonstrates that plot.



The logarithmic relationship indicates that there are diminishing returns as flow gets higher, but this shouldn't be too much of a surprise since survival can only be as good as 1, and we presume that even in the wettest years some fish will die during outmigration. However, what this figure demonstrates is there does seem to be a point around 10,000 – 12,000 cfs where the "returns" start to considerably diminish.

A few caveats here, these are late fall-run, so it's unclear how strong this relationship is for wild spring-run. Also, these analyses are using Bend Bridge as the gauging station, but our current hypothesis is focused on low flows near Wilkins Slough.

When these late fall smolts are headed out to sea, if flows at Bend Bridge are 12,000 cfs, it typically means there's a winter storm, meaning runoff, which implies that flows at Wilkins Slough are substantially higher than at Bend Bridge (due to the high runoff inputs from tributaries between Bend Bridge and Wilkins Slough. However, in the spring, if there's 12,000 cfs at Bend Bridge, it's typically due to Keswick releases and much of that water is being diverted along the course of the river, therefore flows at Wilkins Slough would typically be lower than 12,000 cfs. So the question for the proposed study is how much flow at Wilkins do we believe will be sufficient to see measurable gains in survival, and are we comfortable using flow recommendations for the upper river in the lower river? From a quick look at the Bend Bridge in comparison to Wilkins Slough hydrograph, it does seem that flows during smaller winter storms tend to be somewhat similar between the two stations, except that the Wilkins Slough pulse of water tends to be 1-2 days later, and a few thousand cfs higher. So, if we reran the above analyses with Wilkins Slough flow rather than Bend Bridge flow, we would probably see a similar relationship with late-fall run survival. Therefore, we believe 12,000 cfs is a reasonable estimate for how flows need to be in the Wilkins Slough region to potentially cause a measurable increase in outmigration survival.

Funding options for tags and labor

CDFW Funding has already committed to funding the purchase of tags for this project:
$149,000 for about 769 tags (~700 tags for fish releases, ~69 for tag life side-study)

As for labor, we are seeking funds. We hope to secure NMFS Phase III funding:
Labor: $180,206
Equipment: $14,340
Note: NMFS phase III funding is regionally competitive source and is not assured. If this does not come through, additional funding support options need to be pursued to maintain study viability.

Other tagging study considerations

To increase the total number of wild spring-run smolts tagged during this study, there are four potential locations we can utilize:

Mill Creek – A RST will be operated and checked by CDFW and NMFS personnel daily for spring-run smolts to tag. Spring of 2017 will likely offer low numbers of spring-run smolts due to only 46 redds being observed in the fall of 2016 in Mill Creek.

Deer Creek – No RST is in place, but options are available to install and operate a RST by CDFW and NMFS personnel daily. A total of 267 adult spring-run were observed holding in

Deer Creek summer of 2016, so there is more potential to tag outmigrating smolts from this system compared to Mill Creek.

Battle Creek – a RST is operated and checked daily by USFWS every spring on Battle Creek. There is potential for USFWS to hold smolts >80mm captured in the RST each day and for NMFS personnel to tag them on site. The 2016 spring-run estimate for Battle Creek has not been calculated, but there seems to be a comparable number of spawners to Mill and Deer. In the past 10 years there has been a strong resurgence of spring-run Chinook in Battle Creek, probably due to restoration efforts and improved summer flows.

Red Bluff Diversion Dam (RBDD) – this would be the best option to capture and tag relatively larger groups of wild smolts, although it will be difficult to know if tagged wild fish are spring or fall run due to the time required for genetic stock assignments. There are 3-4 RSTs checked daily at RBDD, and outmigrating smolts could potentially be caught and held for 1-2 days prior to tagging in order to obtain a larger sample size. This option would definitely be feasible if there is a natural spring pulse flow that triggers the movement of wild smolts upstream of RBDD.

Estimated Water Cost Per Pulse Flow

Day #	Base[1] (cfs)	Study[2] (cfs)	Water cost (cfs)	Water cost (TAF)	Notes
1	5,000	12000	7,000	14.00	
2	5,000	12000	7,000	14.00	
3	5,000	12000	7,000	14.00	
4	5,000	10200	5,200	10.40	[4]Ramping rates apply
5	5,000	8670	3,670	7.34	
6	5,000	7370	2,370	4.74	
7	5,000	6264	1,264	2.53	
8	5,000	5324	324	0.65	[5]Ramping rates apply
9	5,000	5125	125	0.25	
10	5,000	5000	0	0.00	
		Water cost per pulse:		**67.91**	

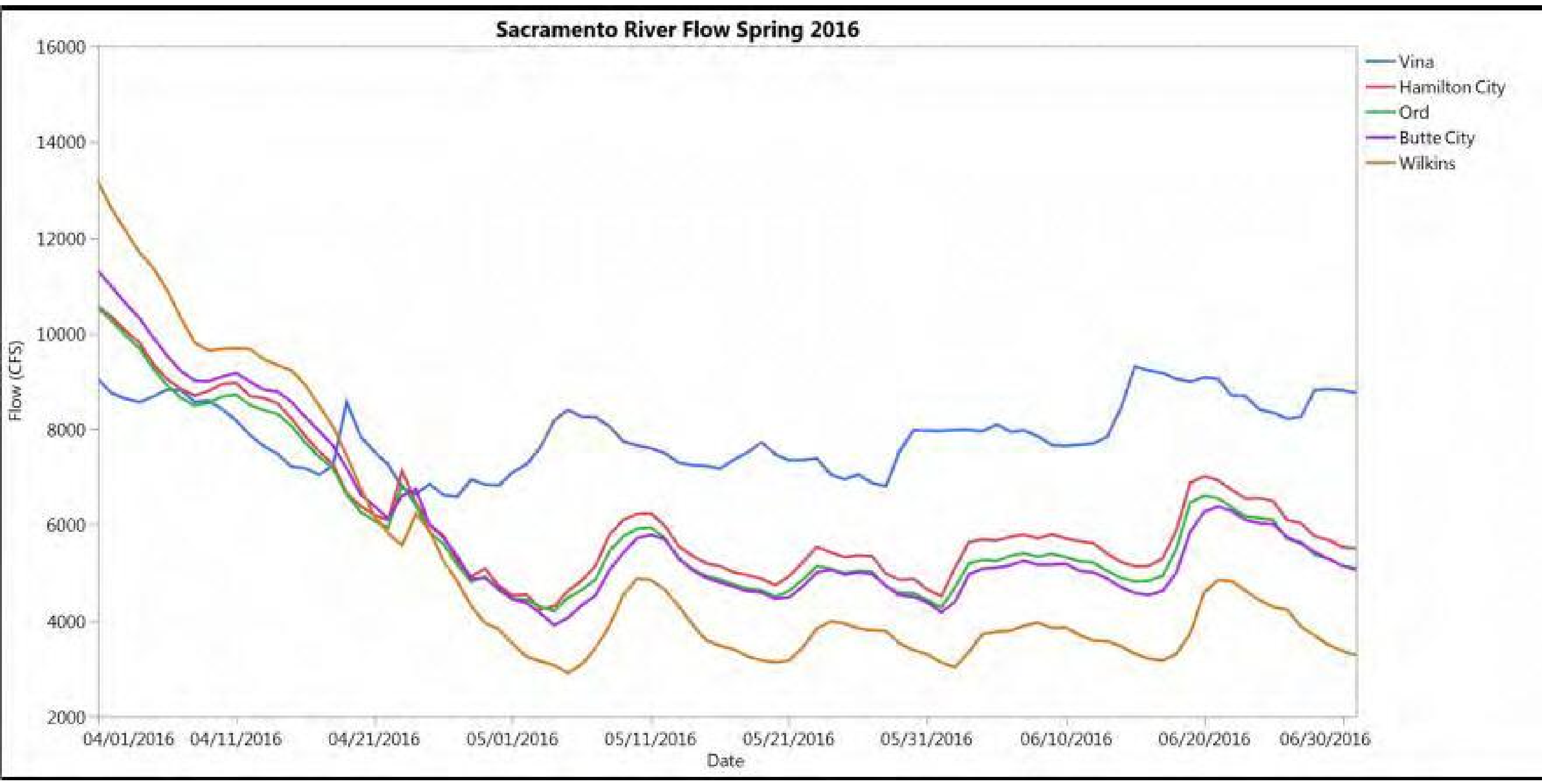
[1] Base is the assumed base flow at Wilkins Slough, simplified for the calculation of water cost

[2] Study includes the pulse flow to 12,000 cfs for 3 days, plus required ramp down rates per Reclamation's 2008 CVP/SWP BA

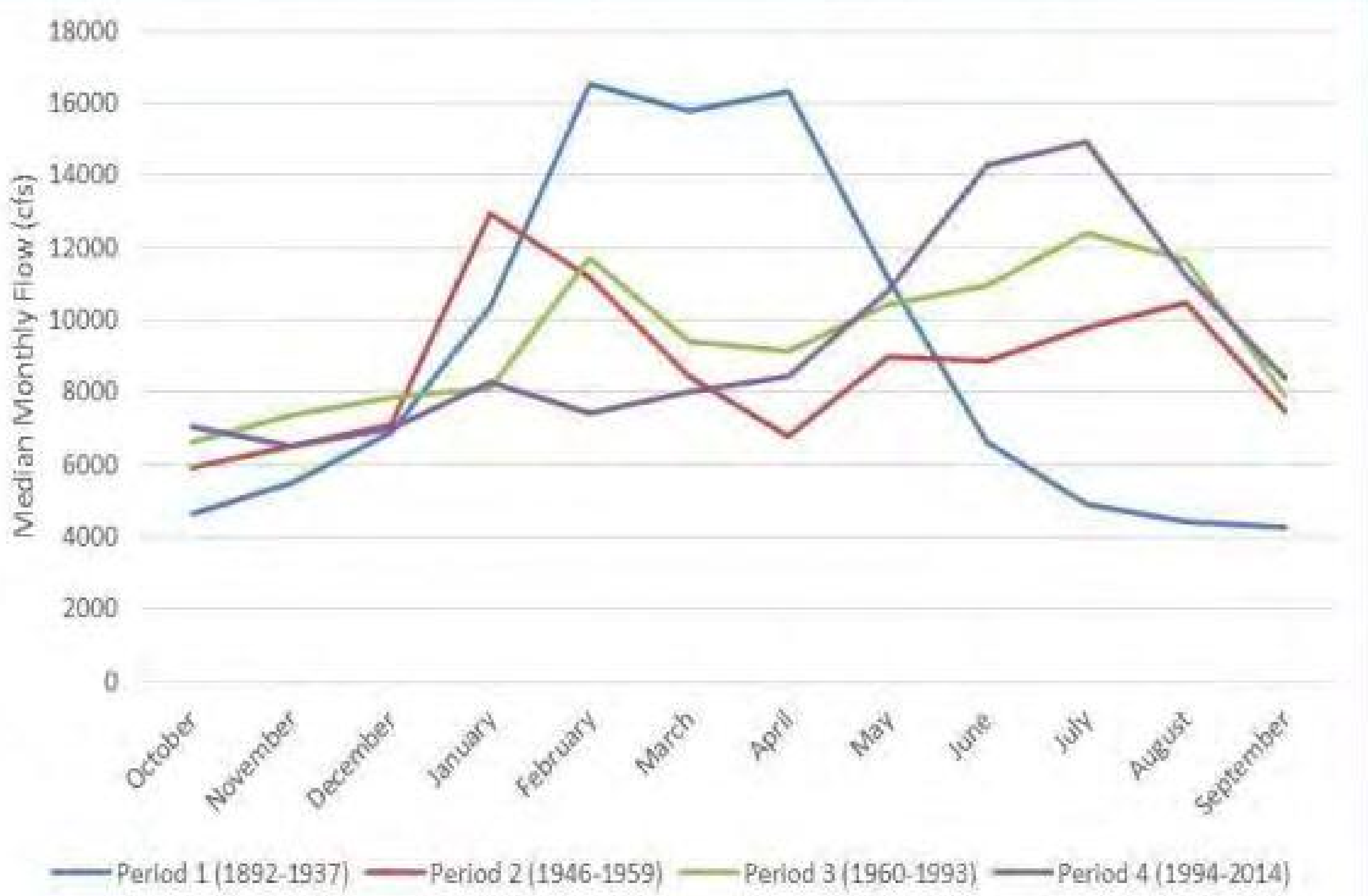
[3]Assumes a Keswick increase of 7,000 cfs for the pulse will make it all the way down to Wilkins Slough, with no accreations or depletions (or that both cancel each other out)

[4]CVP/SWP 2008 BA: When Keswick releases are 6,000 cfs or greater, decreases may not exceed 15 percent per night. Decreases also may not exceed 2.5 percent in one hour.

[5]CVP/SWP BA: For Keswick releases between 4,000 and 5,999 cfs, decreases may not exceed 200 cfs per night. Decreases also may not exceed 100 cfs per hour.


Sacramento River Flow Spring 2016
16000
14000
12000
10000
8000
6000
4000
2000
Flow (CFS)
04/01/2016
04/11/2016
04/21/2016
05/01/2016
05/11/2016
05/21/2016
05/31/2016
06/10/2016
06/20/2016
06/30/2016
Date
Vina
Hamilton City
Ord
Butte City
Wilkins

Sac Flow Alteration



Ecological Applications, 0(0), 2019, e01880

Warm, dry winters truncate timing and size distribution of seaward-migrating salmon across a large, regulated watershed

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Abstract. Ecologists are pressed to understand how climate constrains the timings of annual biological events (phenology). Climate influences on phenology are likely significant in estuarine watersheds because many watersheds provide seasonal fish nurseries where juvenile presence is synched with favorable conditions. While ecologists have long recognized that estuaries are generally important to juvenile fish, we incompletely understand the specific ecosystem dynamics that contribute to their nursery habitat value, limiting our ability to identify and protect vital habitat components. Here we examined the annual timing of juvenile coldwater fish migrating through a seasonally warm, hydrologically managed watershed. Our goal was to (1) understand how climate constrained the seasonal timing of water conditions necessary for juvenile fish to use nursery habitats and (2) inform management decisions about (a) mitigating climate-mediated stress on nursery habitat function and (b) conserving heat-constrained species in warming environments. Cool, wet winters deposited snow and cold water into mountains and reservoirs, which kept the lower watershed adequately cool for juveniles through the spring despite the region approaching its hot, dry summers. For every 1°C waters in April were colder, the juvenile fish population (1) inhabited the watershed 4–7 d longer and (2) entered marine waters, where survival is size selective, at maximum sizes 2.1 mm larger. Climate therefore appeared to constrain the nursery functions of this system by determining seasonal windows of tolerable rearing conditions, and cold water appeared to be a vital ecosystem component that promoted juvenile rearing. Fish in this system inhabit the southernmost extent of their range and already rear during the coolest part of the year, suggesting that a warming climate will truncate rather than shift their annual presence. Our findings are concerning for coldwater diadromous species in general because warming climates may constrain watershed use and diminish viability of life histories (e.g., late springtime rearing) and associated portfolio benefits over the long term. Lower watershed nurseries for coldwater fish in warming climates may be enhanced through allocating coldwater reservoir releases to prolong juvenile rearing periods downstream or restorations that facilitate colder conditions.

Key words: dams; drought; flow; migration; nursery; phenology; reservoirs; salmonids; snow; temperature mitigation; thermal tolerance.

Introduction

Many taxa migrate to track favorable conditions that vary in time and space. Reproduction is often timed in migratory life histories so that juveniles can exploit conditions that promote growth and survival (e.g., Van Der Jeugd et al. 2009). Anadromy is an example of this strategy, whereby juveniles can rear initially in watersheds and grow before migrating to sea where growth potential is higher, but predation risk is also high and dependent on size (Quinn 2005). Lower watershed components such as estuaries are often important habitats for migratory fish because they offer high densities of small prey to fuel growth and migration (Kjelson et al.

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1982, Beck et al. 2001). The conditions of riverine and estuarine watershed components vary among seasons and some anadromous life histories exploit springtime conditions of watersheds to rear when, typically, prey availability is high, predation risks are comparatively low, habitats are inundated and flowing, and temperatures facilitate metabolism conducive to growth (Quinn 2005). This allows fish to emigrate over the spring and summer to marine environments, where prey are also seasonally abundant, and rapid early growth promotes marine survival (Woodson et al. 2013). Thus, anadromy benefits fish by synchronizing juvenile phases with optimal seasonal conditions.

The condition of regional environments can influence migration timing. For example, warmer springs can advance the arrival of migratory birds on nesting grounds (Bradley et al. 1999), and early wet seasons and high soil moisture during dry seasons can advance migrations of butterflies (Srygley et al. 2010). Similar dynamics occur for anadromous species. Warmer summer temperatures can advance summer migrations of anadromous adults into fresh waters (Quinn and Adams 1996) and high river flows can force or induce juvenile migrations downstream en route to the ocean. (Kjelson et al. 1982). Such phenologies are of conservation interest because the timings of many ecological events are responding to long-term changes in environmental conditions (e.g., Bradley et al. 1999).

Anthropogenic changes in the timing of natural processes have substantial potential to alter migration timing. In many watersheds, snowpack is a natural reservoir that disperses cool, snow-fed runoff throughout the landscape in the spring and summer (e.g., Knowles and Cayan 2002). In addition, dams and artificial reservoirs have proliferated globally and, by retaining waters, altered the timing and magnitude of downstream flow and temperature (Olden and Naiman 2009, Couto and Olden 2018). In some watersheds, managers can control the amount and temperature (by sourcing water from portions of thermoclines) of waters released from reservoirs to facilitate favorable conditions for fish downstream (e.g., Danner et al. 2012). The water temperatures stored by reservoirs and thus available for release depend on factors such as recent air temperature and precipitation (Nickel et al. 2004). However, in many regions, air temperatures are rising (Knowles and Cayan 2002, Barnett et al. 2005), springtime snowpacks are decreasing (Mote et al. 2018), and lake and reservoir temperatures are rising (O'Reilly et al. 2015). Thus, the timing and persistence of water conditions favorable for cold-water migratory species are potentially governed by changing climates and hydrologic modifications.

Climate may mediate the nursery value of watersheds by constraining migration timing of juvenile fish. Ecologists are recognizing that the value of nursery habitats should be measured by their ability to support population dynamics including ontogenetic migrations that allow fish to access appropriate environments given their developmental stage (Sheaves et al. 2015). Coldwater anadromous fish rear inland within a diversity of climates, including areas that approach thermal limits (Kjelson et al. 1982, Quinn 2005, Richter and Kolmes 2005), and climate-driven variation in watershed conditions (e.g., flow, temperature) among years can determine the survival of juvenile anadromous fish (Crozier and Zabel 2006). It remains less clear, however, how climate may constrain the timing of ontogenetic migrations by determining annual windows within which juveniles can access rearing habitats. This issue is especially relevant to cold-water fish in warmer regions, which may not be able to shift their timing in response to changes in climate conditions, but rather compress their timing during critical juvenile stages (sensu Mantua et al. 2015). The extent of seasonal time windows that support appropriate habitat conditions is significant because the anadromous life history template (i.e., migration between fresh and marine waters) includes variants characterized by differences in their timing and residencies among habitat types. For example, some life histories rear in watersheds late in the spring, provided that the watershed remains inhabitable. A diversity of life history variants is beneficial because it disperses fish and integrates stochastic habitat experiences across time and space, minimizing competition (Greene et al. 2010) and spreading risk (Schindler et al. 2010). By understanding how climate, hydrology, and managed water infrastructure determine when juvenile fish can exploit rearing habitats, we can better appreciate how these factors influence nursery habitat value in individual years and constrain the viability of life history diversity over many years.

Here we quantified relationships among regional winter weather, springtime snowpack and reservoir conditions, springtime stream temperature and flow, and annual outmigration timing and maximum sizes of juvenile anadromous fish in a lower watershed. These fish begin using the watershed in the winter but are sensitive to warm waters that occurred as precipitation declined and temperatures rose regionally in the summer. We hypothesized that cold, wet winters would store an abundance of snowpack in the mountains and cold water in reservoirs, which would prolong the presence of cold, high-flowing waters downstream in the spring. We further hypothesized that these cool, flowing conditions persisting into the spring would allow juvenile fish to inhabit the watershed later in the year and emigrate to sea at larger sizes. We can expect air temperatures to rise and snowpack to decline in many systems (e.g., Barnett et al. 2005) and conservation of fish nurseries must be improved by understanding when and why juveniles use nursery habitats (Sheaves et al. 2015). Accordingly, our goal was to use field-based observations to understand how regional climates, hydrologic infrastructure, and physiological limits of fish can determine the timing of limiting habitat conditions and, by implication, the nursery functions of these habitats.

Methods

Study system

The Sacramento and San Joaquin Rivers meet in the Central Valley of California (Fig. 1). Water flows from Coast Range and Sierra Nevada headwaters into the rivers, through an extensive, now channelized, tidal Delta, and then into San Francisco Bay. Our study examined the lower Sacramento River and the Delta where water temperatures vary seasonally from 5°C to 25°C, and salinity levels are 0–0.5 ppt in the Sacramento River and 0–5 ppt in the Delta. This system experiences a Mediterranean climate, which is characterized by cool, wet winters and warm, dry summers. The Sacramento–San Joaquin watershed receives $\approx$ 30–40 km^3 of rain and snow, and $\approx$ 40% of this annual amount is released after 1 April as snowmelt (Knowles and Cayan 2002). This water is managed via some of the world's most extensive and integrated dams, reservoirs, aqueducts, and canals to support competing interests of people (e.g., agriculture) and fish. A major component of this system's infrastructure is Shasta Dam and its reservoir, Shasta Lake, located in the Northern Sacramento Valley. Shasta Dam is by far the largest reservoir in the state and is fed by rain and snowmelt runoff. In the spring, a thermocline forms and managers release warmer waters from higher elevations of the reservoir. This allows them to preserve a deeper "cold pool" that they can later use to provide cold water during warmer months (July–October) to maintain downstream temperatures appropriate for fish spawning and rearing habitat (Danner et al. 2012). Waters are then diverted to meet intense demands of agricultural, municipal, and industrial purposes. Thus, watershed conditions are ultimately constrained by water stored in mountain snowpack and artificial reservoirs, and the water quality experienced by fish in the lower watershed is now a product of intensive hydroregulation.

We examined the phenology of juvenile Chinook salmon (*Oncorhynchus tshawytscha*), an anadromous species that rears in steams, floodplains, and estuaries of the Pacific Rim (Quinn 2005). The Sacramento River is inhabited by the Central Valley fall and late fall run, Central Valley spring run, and Sacramento winter run evolutionarily significant units, which are classified under the U.S. Endangered Species Act as species of concern, threatened, and endangered, respectively. Spring and winter run life histories in the Central Valley have declined precipitously as dams prevented fish from spawning and rearing in elevated, cooler waters (Myers et al. 1998, Yoshiyama et al. 1998). Hatcheries contribute substantially to Chinook salmon in this system, specifically to fry before 1999 and fry and smolts throughout the study window (Huber and Carlson 2015). We were initially concerned that hatchery practices (e.g., timing and size of fish released) may create artificial trends of fish responses in relation to springtime conditions, but we found little evidence that hatchery practices varied with springtime conditions (Appendix S1). Hatchery fish, however, were certainly among those observed. Chinook salmon in the Central Valley inhabit the southernmost extent of their species' range and prefer water temperatures of 12°–15°C, but temperatures often exceed 22°C. In this system, juvenile rearing peaks February–March and outmigration peaks April–June, which is two to three months earlier than in more northern estuaries (Kjelson et al. 1982). Additionally, while other populations often include life histories that rear in fresh waters over the summer, the overwhelming majority of juveniles in the Central Valley migrate to sea as subyearlings, and often as fry, apparently to avoid warmer waters (Myers et al. 1998). Indeed, that fish are restricted by dams to lower, warmer portions of the watershed has probably decreased the expression of life history types that rear for a year before migrating to sea, and we may therefore expect that effects of temperature on phenology are especially evident in the current population compared to the historical, undeveloped system. In addition, the construction of Shasta Lake and its effect of thermal inertia on water stored from winter has cooled downstream conditions in the springtime (Boles et al. 1988); thus, historical conditions in the lower watershed, to which fish are now restricted, were probably more severe than they are currently and were always a major constraint to habitat use. Overall, summertime water temperatures constrain habitat use in our focal species and effects of temperature on the Chinook salmon population may be especially apparent in the system's current state (Kjelson et al. 1982, Myers et al. 1998).

We quantified environmental conditions and juvenile salmon responses separately across two regions and habitat types (Fig. 1). This allowed us to examine habitat use across a major portion of the region's lower watershed and compartmentalize analyses within places where the environment and fish timing were likely to be similar. We focused on two regions: the Sacramento River and the Delta. Within each region, we examined two habitat types: shoreline and mid-channel waters. We described the timing of juvenile salmon separately for each habitat type and region because fish must encounter the river before the delta, and they often use deeper, mid-channel waters later in the year as they grow (sensu Munsch et al. 2016). Finally, we examined the size of fish captured adjacent to Chipps Island in the mid-channel of the Delta because this is where juvenile salmon entered the marine waters of San Francisco Bay and the Pacific Ocean beyond. That is, juvenile salmon captured at this location provide our best estimate of salmon outmigration sizes.

Data collection

We assembled data to examine relationships among winter weather and springtime conditions of reservoirs, fish habitats, and fish responses (Fig. 1).

Data describing monthly mean air temperatures and precipitation were provided by a NOAA weather station

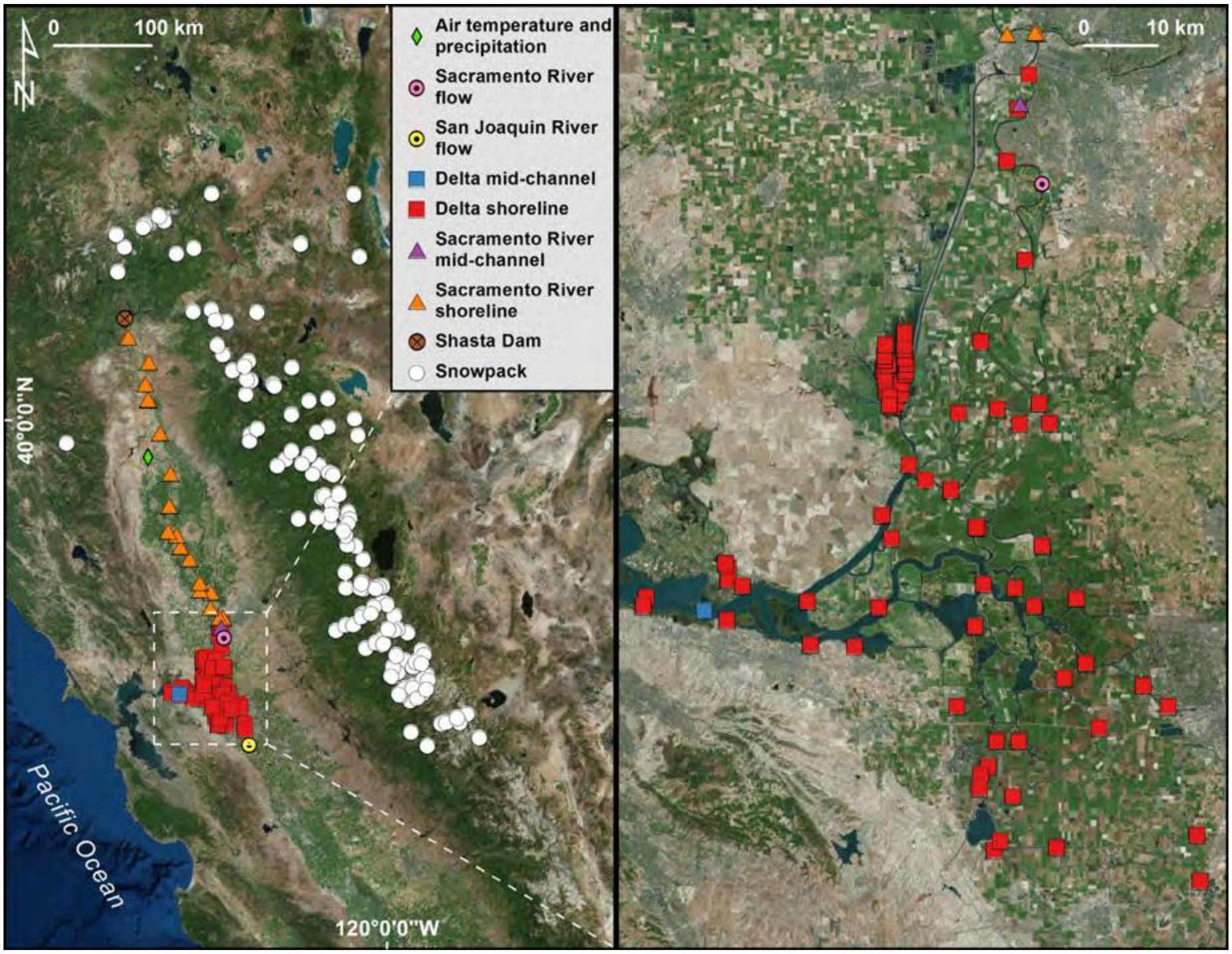

FIG. 1. Locations within the Sacramento–San Joaquin region (California, USA) where fish presence, water temperature, air temperature, and snowpack were measured, and where Shasta Dam is located. Fish presence and water temperature were measured on-site at near and offshore locations.

near the Sacramento River (data *available online*).[6] We used data describing annual snowpack archived by the California Department of Water Resources within the boundaries of the Sacramento–San Joaquin ecoregion (Abell et al. 2008) and above 36.78° N to quantify the amount of snow available to melt into the watershed (data *available online*).[7] Snow was described by the conventional metric 1 April snow water equivalent, which is the quantity of liquid water in the snow and representative of the previous winter's snowfall because, typically, further snowfall and prior snowmelt that year are minimized.

Data describing water temperature profiles in Shasta Lake were provided by the U.S. Bureau of Reclamation. These measurements are collected at incremental depths to create a depth profile of water temperature. Because there were gaps among years in data describing temperature profiles of Shasta Lake, but these data as well as weather and snow data were often collected concurrently as far back as 1946, we used all available data describing Shasta Lake temperatures, snow, and weather dating back to 1946 to increase our power in detecting relationships among these variables.

Data describing daily water flow were provided by U.S. Geological Survey gages on the Sacramento and San Joaquin Rivers to quantify the magnitude of annual high flow events (data *available online*).[8,9] We summed daily flow values from the two rivers to estimate flow into the Delta.

Data describing fish habitat temperature and fish presence were provided by the U.S. Fish and Wildlife Service. The Service concurrently monitors water temperatures and juvenile salmon throughout the Sacramento River and Delta via point measurements (data *available online*).[10] That is, researchers visit many sites where they

[6] www.ncdc.noaa.gov/cdo-web/datasets/GSOM/stations/GHCN-D:USC00046506/detail

[7] cdec.water.ca.gov/snow/current/snow/

[8] https://waterdata.usgs.gov/usa/nwis/uv?site_no=11447650

[9] https://waterdata.usgs.gov/nwis/uv?site_no=11303500

[10] https://www.fws.gov/lodi/juvenile_fish_monitoring_program/jfmp_index.htm

concurrently sample fish and measure water temperature. The Service repeatedly samples shorelines in many locations whereas they sample mid-channel surface waters in two locations, each at the downstream boundary of their respective regions (Sacramento River and Delta). Along shorelines, a net is deployed parallel to shore and pulled landward to catch juvenile salmon close to shore (Brandes and McLain 2001). In the mid-channel, a net is deployed in the channel of a flowing river to catch juvenile salmon in the middle of the river. During each netting event, researchers also measure water temperature on-site. Shorelines are primarily inhabited by salmon fry, a life stage that occurs shortly after fish hatch and are 40–55 mm in length. Channel areas are primarily inhabited by smolts, a life stage that occurs at larger sizes as fish physiologically prepared to enter the ocean. On average, the U.S. Fish and Wildlife Service conducted 541 beach seines in the Sacramento River, 1,128 beach seines in the Delta, 1,484 trawls in the Sacramento river, and 1,806 trawls in the Delta distributed approximately evenly across every year. We examined 1992–2016 and 1995–2016 for shoreline and mid-channel waters, respectively, because during these time periods concurrent data for all variables were available.

Analysis

We quantified relationships among regional winter weather conditions, springtime snow and reservoir conditions, springtime habitat conditions, and annual fish responses (Fig. 2). Our approach was to use statistical models to convert rich data sets of environmental conditions into annual indices and then compare these indices to annual timing and maximum sizes of fish. We described model parameters used to calculate indices in the text below and listed them in Table 1 for clarity. Our analyses examined (1) water conditions in April because preliminary explorations suggested that during this month, (a) flow and temperature varied substantially among years and (b) juveniles often left the system, and (2) weather conditions during the preceding October–March because this coincided with the wet, cold season when snowpack and waters in artificial reservoirs accumulate. For brevity, we refer to October–March as winter.

We used weather station data to quantify an annual index of air temperature and precipitation from October to March (Models 1 and 2, Table 1). In these models, the response variable was monthly temperature or precipitation and the explanatory variables were the year parameterized as a categorical variable to generate an index value and month parameterized as a random walk of the second order to account for nonlinear trends in weather as years progressed from October to March. These and all subsequent models that generated annual indices were fit to Gaussian likelihood distributions using a Bayesian approach and vague priors.

We used snowpack data to quantify an index for water content of snow in regional mountains (Model 3, Table 1). In this model, the response variable was snowpack, which was log-transformed to normalize its distribution, and the explanatory variables were year parameterized as a categorical variable to generate an index value, elevation to account for the premise that snow is deeper at higher elevations, station (i.e., a unique sampling location) parameterized as an independent and identically distributed variable to account for non-

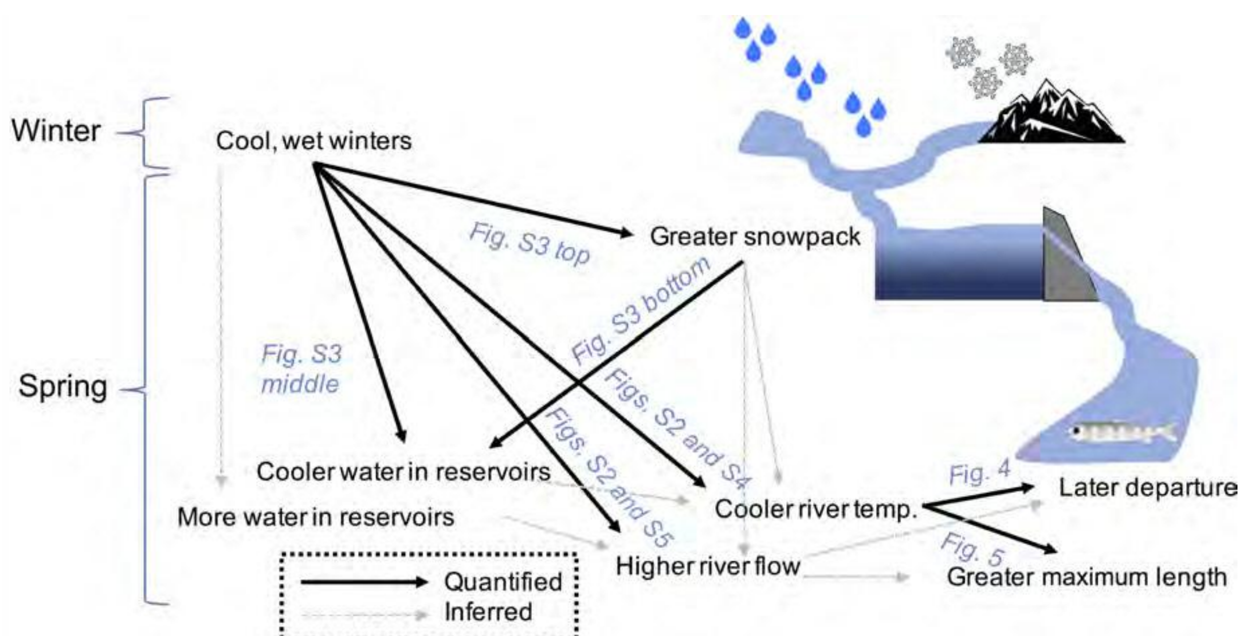

Fig. 2. Conceptual description of our analyses. Water quantities and temperatures are deposited into reservoirs and made available downstream in the springtime according to winter precipitation and air temperature. Fish downstream respond to water conditions. Arrows indicate the influence of one factor on another factor. Supplemental figures citations refer to Appendix S2.

Table 1. Parameters used in models to calculate annual indices of winter and springtime conditions.

Model no.	Response	Parameters	Parameter types	Notes
1	Oct–Mar air temperature	Year + Month	Year, categorical; Month, random walk of order 2	"Year" is the annual index of winter air temperature. That is, the temperature of a given winter relative to other winters while accounting for nonlinear seasonality from Oct to Mar in temperature
2	Oct–Mar precipitation	Year + Month	Year, categorical; Month, random walk of order 2	"Year" is the annual index of winter precipitation. That is, the precipitation during a given winter relative to other winters while accounting for nonlinear seasonality from Oct to Mar in precipitation
3	$\log_{10}$(Snowpack + 1)	Year + Elevation + Station + Space	Year, categorical; Elevation, linear; Station, independent and identically distributed; Space, Gaussian Markov Random Field (Rue et al. 2009)	"Year" is the annual index of springtime snowpack. That is, the amount of snow in the mountains for a given year relative to other years while accounting for greater snowpack at higher elevations and the premise that snowpack values will be similar among observations repeated over time at the same stations and in spatially proximate stations
4	Shasta Lake surface water temperature (i.e., top 20% of water column)	Year + Depth	Year, categorical; Depth, linear	"Year" is the annual index of springtime Shasta Lake surface water temperature. That is, the temperature of surface waters for a given year relative to other years while accounting for cooler waters occurring deeper due to the thermocline
5	April water temperature (Sacramento River shoreline)	Year + Day of Year + Station	Year, categorical; Day of Year, linear; Station, independent and identically distributed	"Year" is the annual index of April water temperature. That is, the temperature of waters in April for a given year relative to other years while accounting for rising temperatures as dates approach summer and the premise that temperature values will be similar among observations repeated at the same stations over time
6	April water temperature (Delta shoreline)	Year + Day of Year + Distance to Sacramento River Main stem + Distance from San Francisco Bay + Station	Year, categorical; Day of Year, linear; Distance to Sacramento River Main stem, linear; Distance from San Francisco Bay, linear; Station, independent and identically distributed	"Year" is the annual index of April water temperature. That is, the temperature of waters in April for a given year relative to other years while accounting for rising temperatures as dates approach summer, cooler waters on the river's main stem and upstream, and the premise that temperature values will be similar among observations repeated at the same stations over time
7 and 8	April water temperature (Sacramento River and Delta mid-channels)	Year + Day of Year	Year, categorical; Day of Year, linear	"Year" is the annual index of April water temperature. That is, the temperature of waters in April for a given year relative to other years while accounting for rising temperatures as dates approach summer

independence of measurements repeated at the same locations attributable to factors not explicitly included in our model, and a spatial field describing the proximity of locations to one another, which accounted for our expectation that proximate measurements will be similar due to factors not explicitly addressed by our model.

We used temperature profile data to quantify an index for each water year of temperature of waters at the surface of Shasta Lake (Model 4, Table 1). We were interested in surface water temperatures because managers release these warmers waters during the early spring so that they can conserve the cooler, deeper waters for releases during warmer portions of the year (Bartholow et al. 2001). We defined surface waters as those in the top 20% of the water column. For each year, we summarized the temperature profile at Shasta Lake by taking the median of temperatures collected at various elevations during the time period one week before and after April 1 to coincide measurements with those of snowpack and the annual time period when fish appeared to begin responding to temperature downstream. In this model, the response variable was water temperature and the explanatory variables were year parameterized as a categorical variable to generate an index value and depth to account for the premise that deeper waters will be cooler.

We used flow gauge data to quantify water flows during April for each water year. We described flow simply as the log-transformed median daily flow for that month. This was appropriate because there were no consistent trends among years between flow in April and day of year (i.e., flow could be increasing or decreasing through April depending on the year), and we applied a log-transformation to normalize the distribution of these data.

We used temperature data collected during beach seining and trawling to quantify for each water year indexes of temperatures during April in the Sacramento River and Sacramento–San Joaquin Delta (Models 5–8, Table 1). In these models, the response variable was water temperature and the explanatory variables were year parameterized as a categorical variable to generate an index value, day of year to account for increasing temperatures as days progressed in April and, for data collected at many stations along shorelines, station parameterized as an independent and identically distributed variable to account for non-independence of measurements repeated at the same locations attributable to factors not explicitly included in our model. For the model describing water in the Delta, we also included variables describing the distance of measurements from the Sacramento River main stem and San Francisco Bay because preliminary data explorations suggested that waters were cooler farther upstream and on the main stem, consistent with the Sacramento River delivering cool water to the Delta. We compared indexes describing snow, weather, and water conditions via linear models to examine whether we could detect an influence of winter precipitation and temperature, as measured by the weather station, on regional snowpack (Model 9, Table 2), water temperatures near the surface of Shasta Lake (Model 10, Table 2), flow in the Sacramento River and Delta (Models 11 and 12, Table 2), and April water temperature in the shoreline and mid-channel waters of the Sacramento River and Delta (Models 13–16, Table 2).

Next, we described the annual timing of juvenile salmon so that we could relate timing to environmental conditions. For juvenile salmon along the shoreline, we defined annual arrivals and departures as the 5th and 95th percentile days of the year that juvenile salmon were observed for that water year. For fish in the mid-channel, we used the same definition for arrivals, but defined departures as the 75th percentile days of the year that fish were observed. This was because annual observation dates of these fish were right-skewed and thus percentiles describing the tail end of annual distributions (e.g., 95th percentile) were often heavily influenced by smaller numbers of migrants observed late in the summer. We combined all measurements taken alongshore of each region (i.e., the Sacramento River or Delta) whereas these conditions in mid-channel waters were described at one location; thus, habitat conditions and fish responses along shorelines were summarized from spatially aggregated data describing a region and in mid-channel waters they described a single station where fish were presumably leaving these regions.

In models describing the effect of springtime conditions on departure timing, the response variable was departure date and the explanatory variable was April water temperature index (Models 17–20, Table 2). We initially considered relating juvenile salmon responses to temperature *and* water flow, but these variables confounded models because they were correlated ($r^2 = 0.73$ [Sacramento River (Sac. R.) shore], 0.70 [Delta shore], 0.70 [Sac. R. mid-channel], 0.38 [Delta mid-channel]). We therefore modeled juvenile salmon responses to temperature alone, as temperature is particularly well known to impact salmon in this system (e.g., Kjelson et al. 1982), and acknowledged that flow is also an important habitat attribute and that fish likely responded to both flow and temperature.

Finally, we described the effect of springtime conditions on maximum size of juvenile salmon entering marine waters (Model 21, Table 2). In this model, we examined the size of the largest salmon observed daily at the Delta mid-channel station (i.e., adjacent to Chipps Island) between April and August. We excluded data from days where fewer than 10 fish were observed and rare (0.22%) observations of fish above 20 cm that were probably of older age classes. During the summer, the maximum size of emigrating juveniles decreases, presumably because life histories that are timed later in the calendar year provide juveniles with less time to rear before temperatures exceed tolerances, and we therefore accounted for day of year when describing maximum size. We used a mixed effects model to describe effects of springtime conditions on maximum size (Bates et al. 2015). In this model, the response variable was the

TABLE 2. Parameter estimates of linear models comparing winter conditions, springtime conditions, and fish responses.

Model number, response, and parameter	Estimate	SE	P	Random effect SD
9, Springtime snowpack index				
Intercept	0.469	0.062	<0.001	
Winter precipitation index	0.002	0.000	<0.001	
Winter air temperature index	−0.029	0.005	<0.001	
10, Springtime Shasta Lake surface water temperature				
Intercept	2.330	2.555	0.369	
Winter precipitation index	−0.028	0.013	0.031	
Winter air temperature index	0.323	0.219	0.152	
11, $\log_{10}$(median Apr water flow; Sac. R.)				
Intercept	0.173	0.023	<0.001	
Winter precipitation index	0.000	0.000	0.051	
Winter air temperature index	−0.005	0.002	0.016	
12, $\log_{10}$(median Apr. water flow; Delta)				
Intercept	0.182	0.024	<0.001	
Winter precipitation index	0.000	0.000	0.041	
Winter air temperature index	−0.005	0.002	0.011	
13, Apr water temp index (Sac. R. shoreline)				
Intercept	−7.267	4.241	0.101	
Winter precipitation index	−0.029	0.016	0.090	
Winter air temperature index	1.171	0.340	0.002	
14, Apr water temp index (Delta shoreline)				
Intercept	−6.076	3.473	0.094	
Winter precipitation index	−0.019	0.013	0.160	
Winter air temperature index	1.046	0.278	0.001	
15, Apr water temperature index (Sac. R. mid- channel)				
Intercept	−10.886	4.738	0.033	
Winter precipitation index	−0.022	0.019	0.255	
Winter air temperature index	1.430	0.377	0.001	
16, Apr water temp index (Delta mid-channel)				
Intercept	−6.337	2.664	0.028	
Winter precipitation index	0.000	0.011	0.963	
Winter air temperature index	1.022	0.212	<0.001	
17, Departure (Sac. R. shoreline)				
Intercept	167.508	9.426	<0.001	
Apr water temperature index	−7.278	1.554	<0.001	
18, Departure (Delta shoreline)				
Intercept	172.553	8.832	<0.001	
Apr water temperature index	−6.469	1.483	<0.001	
19, Departure (Sac. R. mid-channel)				
Intercept	142.255	5.573	<0.001	
Apr water temperature index	−4.131	0.950	<0.001	
20, Departure (Delta mid-channel)				
Intercept	177.274	11.702	<0.001	
Apr water temperature index	−6.341	1.939	0.004	
21, Daily max. length entering marine waters (cm)				
Intercept	12.564	0.563	<0.001	
Apr. water temp index	−0.214	0.082	0.016	
Day of year	−0.017	0.002	<0.001	
Year				0.354
log10 (Daily no. salmon measured)	(offset = 1)			

Note: Sac. R., Sacramento River.

largest fish observed daily, and we parametrized (1) April water temperature index and (2) day of year as fixed effects, (3) year as a random effect to account for the premise that salmon lengths were similar within years, and (4) log-transformed number of fish observed daily as an offset to account for the premise that larger fish were more likely to be observed on days when more total fish were observed.

We ran analyses in R version 3.3.3 (R Core Team 2019) using the packages INLA (Rue et al. 2009), lme4 (Bates et al. 2015), and ppcor (Kim 2015). We used the Bayesian package INLA to calculate indices because it allowed us to incorporate all requisite model parameters (e.g., spatial fields that accounted for spatial autocorrelation in snowpack measurements), and we used frequentist approaches to quantify linear relationships (e.g., departure timing) so we could report correlations, partial correlations, and *P* values.

Results

Chinook salmon arrived in shoreline and mid-channel waters of the Sacramento River and the Delta between November and February (Fig. 3). During their early residence in the winter, fish generally experienced cool, flowing waters (Appendix S2: Figs. S1, S2).

As winters progressed to spring, flows dropped, temperatures rose, and fish along shore increasingly occupied the coolest available waters (Appendix S2: Figs. S1, S2). Along both the upper Sacramento River and Delta shorelines, fish began using disproportionately cool waters after average temperatures of all waters (occupied and unoccupied by juvenile salmon) exceeded approximately 15°C. Across all years, this tended to occur in April.

The springtime environment experienced by fish varied substantially among years and depended on winter weather. Years with cool, wet winters left deep springtime snowpack reservoirs in the mountains (Appendix S2: Fig. S3, top) and years with wet winters produced cool springtime surface waters at Shasta Lake (Appendix S2: Fig. S3, middle). In addition, years that produced greater mountain snowpack also produced cooler surface waters at Shasta Lake (Appendix S2: Fig. S3, bottom). Cool waters in the Sacramento River and Delta persisted longer into spring if the winter was also cool (Appendix S2: Fig. S4, right). Depending on the region and habitat type, springtime waters were 3.75°–7.0°C cooler in the coolest years compared to the warmest years. While springtime waters tended to be cooler in years with greater winter precipitation, this relationship was not statistically significant (Appendix S2: Fig. S4, left). In years with cool, wet winters, springtime flows in the Sacramento River and Delta were higher (Appendix S2: Fig. S5).

Warm springs advanced juvenile salmon departures and reduced their maximum sizes entering the ocean. Fish departed earlier when April water temperatures were higher (Fig. 4). Models indicated that, depending on region and habitat type, a 1°C increase in April water temperatures corresponded to fish departing four–seven days earlier (Models 17–20, Table 2). Given the range of springtime water temperatures and respective effects of water temperatures on departure, this corresponded to salmon departing the Sacramento River shoreline, Delta shoreline, Sacramento River mid-channel, and Delta mid-channel waters 51, 36, 28, and 24 d earlier, respectively, in the warmest years compared to the coolest years. Salmon did not depart earlier in years that they arrived earlier (correlations between arrival vs. departure date: $P > 0.19$; $r^2 = 0.06, 0.08, 0.05, 0.01$; Sac. R. nearshore, Delta nearshore, Sac. R. mid-channel, Delta mid-channel, respectively). There was a frontier of maximum lengths in salmon emigrating to sea given the date, and this frontier contracted to exclude larger fish in years with warmer springtime waters (Fig. 5). Maximum emigration sizes, given the date, decreased 0.214 cm for

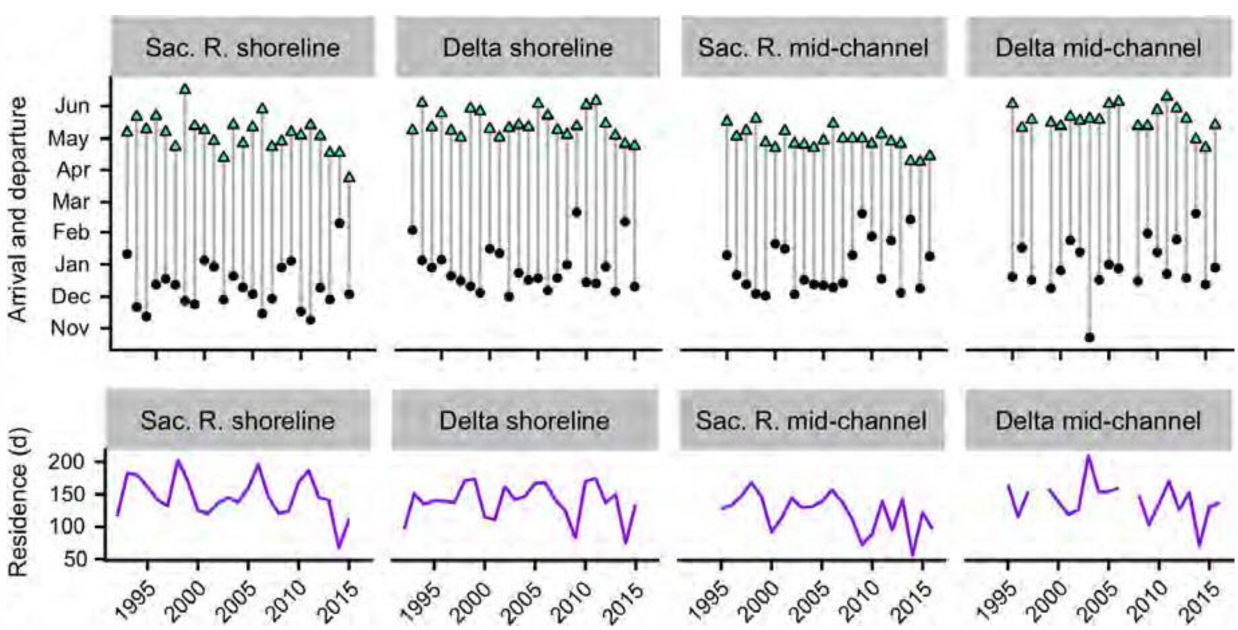

Fig. 3. Time series of arrival (black points) and departure (cyan points) dates and total residence periods (purple lines). Residence periods are calculated by subtracting arrival dates from departure dates. Sac. R., Sacramento River.

every 1°C increase in springtime water temperature (Fig. 5, Model 21, Table 2). This corresponded to salmon outmigrating at 0.801 cm smaller maximum sizes in the warmest years compared to the coolest years.

Discussion

Cool, wet winters deposited cold water and snow into natural and artificial reservoirs. These sources supplied the lower watershed with cool water as the region warmed and dried in the Mediterranean spring. The extent of cool air and precipitation during the winter determined the persistence of cool, high-flowing waters into the spring. Fish populations known to require cool temperatures and benefit from flowing waters inhabited the watershed if waters remained cool. When cool waters allowed fish populations to inhabit the watershed longer into the spring, individuals emigrated to sea at larger maximum sizes. We detected effects on timing in nearshore and mid-channel waters of the lower Sacramento River and the Sacramento-San Joaquin Delta, suggesting that fish responses were occurring across a major portion of the watershed. That arrival and departure timing were not correlated and that maximum sizes were smaller in years with warmer, drier winters suggests that, unlike the observations of other studies examining climate-driven phenologies (e.g., Bradley et al. 1999), these fish truncated rather than shifted their timing in response to variable conditions. Overall, (1) winter air temperature and precipitation appeared to constrain springtime windows in which migratory fish could use their nursery habitats and (2) longer residence windows provided by cold, wet winters appeared to benefit fish by enabling growth opportunities before migrating to sea where survival is size selective (e.g., Sogard 1997, Woodson et al. 2013). More broadly, our findings contribute to an increasingly global recognition that climate can influence phenology, raising management concerns for species that alter their timing in response to changing climates (Stenseth and Mysterud 2002).

Early departures due to unfavorably warm waters in the spring suggest impaired fish habitats. First, fish in warm, dry years may experience immediate stress or mortality (Richter and Kolmes 2005). Smolts in the Sacramento River experience greater mortality when water temperatures are high and flows are low (Kjelson et al. 1982), and potentially premature migrations to sea arising from higher temperatures may further diminish the benefits of migration by disrupting tradeoffs related to predation risk. The hypothesized purpose of migration in anadromous fish is to trade off the relative predation risk and foraging opportunities of marine and fresh waters: fresh waters are relatively unproductive but offer safety from predators, the converse is true for marine environments, and estuaries appear to be intermediate (Quinn 2005). In theory, smaller fish gain more from predator refuge because they are more vulnerable (Sogard 1997). Furthermore, there appears to be a seasonal window for juveniles to enter the ocean to experience conditions conducive to fitness (e.g., high prey availability), which varies by date among years (Satterthwaite et al. 2014). Constraints on outmigration timing may therefore induce premature migrations when fish are small and vulnerable or before ocean conditions are favorable that year. Indeed, that predator life histories may no longer be synchronized with ephemeral prey (i.e., the match-mismatch hypothesis) is a major management concern for species shifting their phenologies in response to changing climates: predators may feed suboptimally (sensu Satterthwaite et al. 2014) or engage in novel trophic interactions via shifting to alternative prey (Deacy et al. 2017). In addition, there are many nonnative, warm-water predators of Chinook salmon in Central California (e.g., Demertras et al. 2017), and cool waters may diminish the presence of predators in juvenile salmon habitats or lower their metabolic rates and thus predation rates. Cool water therefore appears to benefit juvenile salmon in the spring by promoting extended growth and reduced predation risk, the very factors driving anadromy and estuarine residence. More generally, by expanding when juveniles could occupy certain habitats, cold waters potentially promoted fundamental nursery functions, including the ability to support optimally timed ontogenetic migrations, seasonal occurrence of necessary physical conditions, and the ability to optimize food/predation tradeoffs associated with migrations to sea (Sheaves et al. 2015).

Long annual extents of tolerable conditions may support life history diversity and be imperiled by a warming climate. Chinook salmon and many related species exhibit a diversity of life histories where their timing among habitats spanning rivers, lakes, estuaries, and oceans varies among individuals and populations (Quinn 2005). This benefits fish and people because salmon stabilize their composite populations by spreading their risk among many habitat experiences (Schindler et al. 2010) and minimize competition by spreading their density over time and space (Greene et al. 2010). However, life history variants that use the lower Sacramento River and Delta are constrained by the requirement to outmigrate before temperatures exceed thresholds, typically around April. This is concerning because California's winter temperatures are expected to increase by 1.7°–3.4°C and snowpack is expected to decrease by 29–89% by the end of the century (Hayhoe et al. 2004, Cayan et al. 2008). Our models suggest that an increase of 1.7°–3.4°C in winter air temperatures corresponds to a 1.97°C and 3.95°C increase in April temperature index, which corresponds to advancing departures by 8–29 d (depending on the region and habitat type) and decreasing maximum sizes given the date by 0.42–0.85 cm. As noted by Niels Bohr, "prediction is very difficult, especially about the future"; likewise, these numbers should be interpreted cautiously and to provide context, not as literal predictions of the future. Overall, in the future, waters may exceed tolerable conditions earlier in the year, life histories may be further

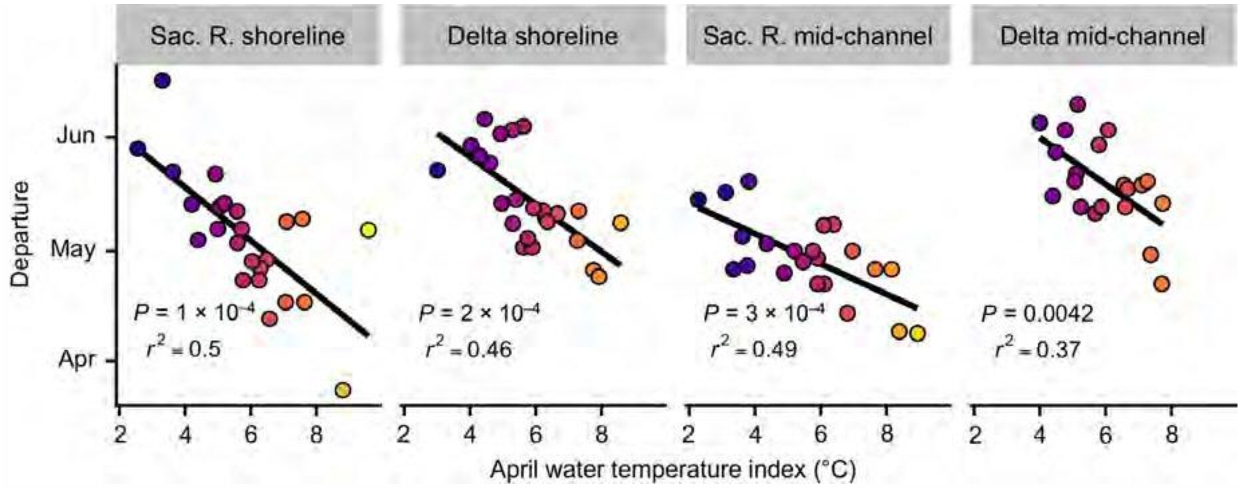

FIG. 4. Juvenile salmon departure timing compared to April water temperature. Lines indicate relationships predicted by linear models for variables shown on the x- and y-axes. Point colors correspond to April water temperature. We report correlations and P-values for relationships between departure timing and April water temperature.

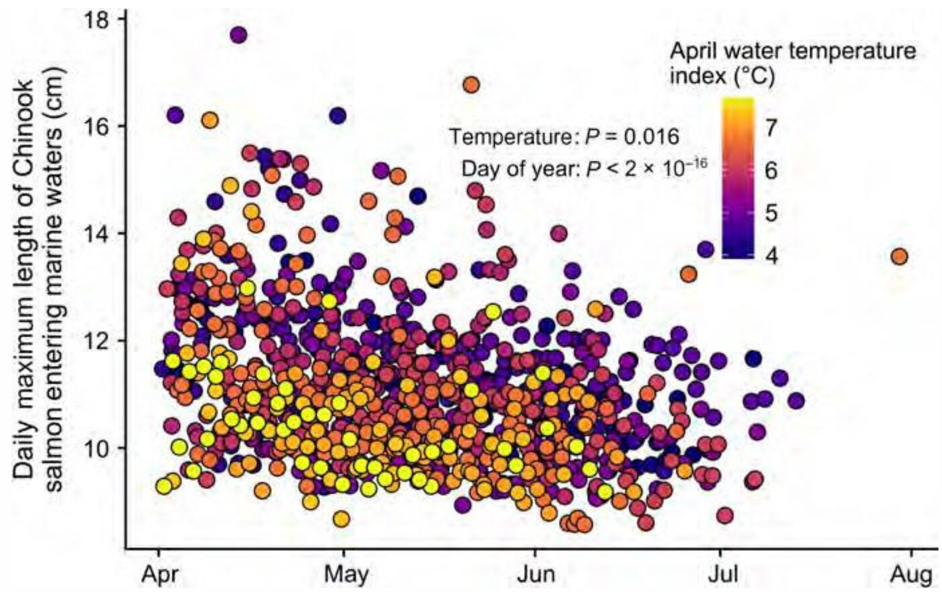

FIG. 5. Daily maximum size of juvenile salmon entering marine waters from April to August colored by April water temperature. We report P values for the relationship of daily maximum size with April water temperature and date.

constrained by requirements to depart the system earlier, and portfolio benefits derived from a diversity of life histories may be subsequently lost.

Managers may consider prolonging cool temperatures into springtime to allow juvenile salmon to use habitats more extensively. Recent advances in modeling allow managers to predictably alter downstream temperatures in the Sacramento River and other systems by releasing certain amounts and temperatures of water from reservoirs such as Shasta Lake (Danner et al. 2012, Pike et al. 2013, Caldwell et al. 2014). These efforts have largely focused on facilitating appropriate temperatures in the 100-km reach below Keswick Dam for winter-run Chinook salmon that spawn in late spring and early summer, and the incubation of their eggs in summer and early fall. Our results suggest that juvenile Chinook salmon rearing in the lower Sacramento River may also benefit from allocating cool waters at the onset of spring (cold water attributable to releases from dams equilibrate to the environment before waters reach the delta). This is in addition to studies that suggest greater flows promote juvenile fish outmigration survival by as much as fivefold in this system (Kjelson et al. 1982, Michel et al. 2015). Water allocations from dams in this region must meet many management targets related to people and fish, and the benefits of cooling waters in the spring for juveniles would need to be considered in this fuller context that considers the importance of human uses and other life history stages of salmon that are management priorities. Other methods that may reduce temperatures include re-plumbing channelized systems to alter the distribution of cool water and planting riparian vegetation that blocks solar radiation (Beschta 1997).

Our study provides further evidence that climate constrains watershed use by Pacific salmon across many phases of its life cycle (reviewed by Crozier et al. 2008). Salmon embryos develop faster at warmer temperatures (Beacham and Murray 1990), but can perish in exceedingly warm or low-flowing waters (Martin et al. 2017). Following emergence, juvenile survival can decrease in warm and low-flowing conditions (Kjelson et al. 1982, Crozier and Zabel 2006). Notably, positive effects of warming climates may occur in cold-constrained systems (e.g., southwestern Alaska); for example, if higher temperatures advance the timing of spring ice breakup and promote growth through increased prey availability and, potentially, metabolism (Schindler et al. 2005). In addition, the timing of juvenile downstream migrations can shift to earlier dates in warmer years (Achord et al. 2007). Related to these findings, our results suggest that (1) temperature can set upper limits on time windows in which populations can inhabit watersheds and (2) these smaller time windows prevent life histories that use the system later in the year from reaching larger sizes before heading to sea. Later, adults returning to spawn are also stressed by excessively warm conditions, and can advance the timing of their migrations upriver in response to long-term changes in river temperature to avoid the lower, warmer portions of watersheds during the warmest part of the year (Quinn and Adams 1996). Finally, adults time their spawning according to stream temperature, presumably to synchronize the emergence of their juveniles with optimal rearing conditions (Beer and Anderson 2001). Salmon have some capacity to buffer climate-driven stressors through plastic or evolutionary responses that include phenology, but this capacity is limited because adaptive timing in one habitat often competes with adaptive timing in another (Crozier et al. 2008). In our case, earlier migrations to sea may increase survival in the watershed but decrease survival in the ocean if seasonal prey are not yet abundant (Satterthwaite et al. 2014) or if earlier outmigrants are smaller and therefore at greater risk of predation (Sogard 1997). Overall, our findings and those of others suggest that climate often constrains when salmon use certain habitats and why, and it will be important to monitor how phenological responses across the life cycle translate ultimately to demographic responses (e.g., cohort survival).

Complexities should be considered in the interpretation of our results. First, we examined population-level constraints rather than the experiences of individuals. For instance, individuals naturally predisposed (e.g., life history variants) to enter marine waters in the winter would presumably be less impacted by warm springs. Secondly, we chose broad-scale metrics to describe our study system. Fish experienced a more nuanced, dynamic environment beyond what we could measure that depended on finer-scale habitat conditions and fish movements. An example of this supported by our data is that fish may use shoreline waters until they exceed tolerable levels and then retreat to cooler mid-channel waters before leaving the system entirely. In addition, metrics that described environmental conditions in certain months were probably correlated with those of proximate months and our models are probably measuring their response to both. However, that our model understanding of the environment correlated well with fish responses suggests that we have parsimoniously captured the phenomenon: cold, wet winters keep waters cool and flowing high longer, allowing fish to depart to sea later and larger. Finally, we may expect that, compared to more natural systems, our system's lack of juvenile age structure (e.g., age 1+ fish that rear at higher elevations before migrating to sea) and habitat complexity (e.g., extensive stream networks with coldwater refugia) may contribute to an especially apparent, population-level phenological response of fish to temperature.

Our study would also be enhanced by a greater understanding of habitat use in mid-channel waters and outcomes (e.g., mortality sources) of populations that departed earlier and smaller. In contrast to measurements of habitat use along shore, fish observations in mid-channel waters only occurred in two locations. This likely limited our understanding of the temperatures that fish select for because temperatures are likely to vary substantially among locations in the watershed and may explain why, in contrast to habitat use in shoreline waters, we did not detect fish in mid-channel waters using cooler than average temperatures in the spring. Understanding the demographic consequences (e.g., fry to adult survival) of reductions in outmigration windows and maximum outmigration sizes would further improve the application of this work for identifying the relative benefits of water management. For example, departure timing may reflect mortality as well as higher and earlier emigration rates in warm years and it would be informative to quantify relationships between fish size at emigration and survival or reproductive success at later life stages (sensu Woodson et al. 2013). It would be especially informative to determine how watershed habitat conditions may interact (e.g., synergistically, additively, antagonistically) with conditions experienced during nearshore and marine life stages to determine overall survival.

Migration enables many taxa to be in the right place at the right time. For juvenile Chinook salmon in the Sacramento River and Delta, the “right time” appears to be when waters are cool and flowing high. In this region, precipitation occurs mostly in winter, but mountain snowpack and artificial reservoirs store water that is released in the spring. This delays the onset of intolerably warm aquatic environments despite warming weather and increases the time window in which migratory fish can use their freshwater and estuarine habitats. The extent of habitat use for coldwater species in watershed ecosystems may therefore depend on cool, wet winters. We studied a species where it was especially responsive to low stream flows and high water temperatures, but snowmelt and air temperature are fundamental to fish habitat conditions in spring for many aquatic ecosystems. We should therefore consider that, in systems fed by snowmelt or artificial reservoirs, warm, dry winters (e.g., recent drought in California) may portend poor nursery habitat conditions for fish that year. This is significant because many species rely on freshwater and estuarine waters during critical juvenile phases (Beck et al. 2001), these fish often develop to support essential functions in marine ecosystems (Sheaves et al. 2015), and snowpack and air temperature conditions are changing worldwide (Barnett et al. 2005). Indeed, in recent years with warm, dry winters, juvenile Chinook salmon inhabited Central California briefly, which is concerning if it foreshadows warming winters and threats to life histories that migrate through the system later in the spring.

However, ecologists and managers are developing more sophisticated and nuanced approaches to water regulation in conservation contexts (Danner et al. 2012). Within constraints set by climate, regulation strategies can mitigate periods that are stressful to fish if we quantitatively understand the impacts of flow and temperature on fish performance (e.g., egg survival; Martin et al. 2017). Concerted research efforts may therefore seek to understand critical ontogenetic and annual periods when flow and temperature matter most to fish, which may allow us to develop regulatory strategies that optimize for human water needs and conservation impacts.

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Supporting Information

Additional supporting information may be found online at: http://onlinelibrary.wiley.com/doi/10.1002/eap.1880/full

Juvenile salmon growth, movement, and survival in Butte Creek and the Sutter Bypass- A look at the past and present tagging studies

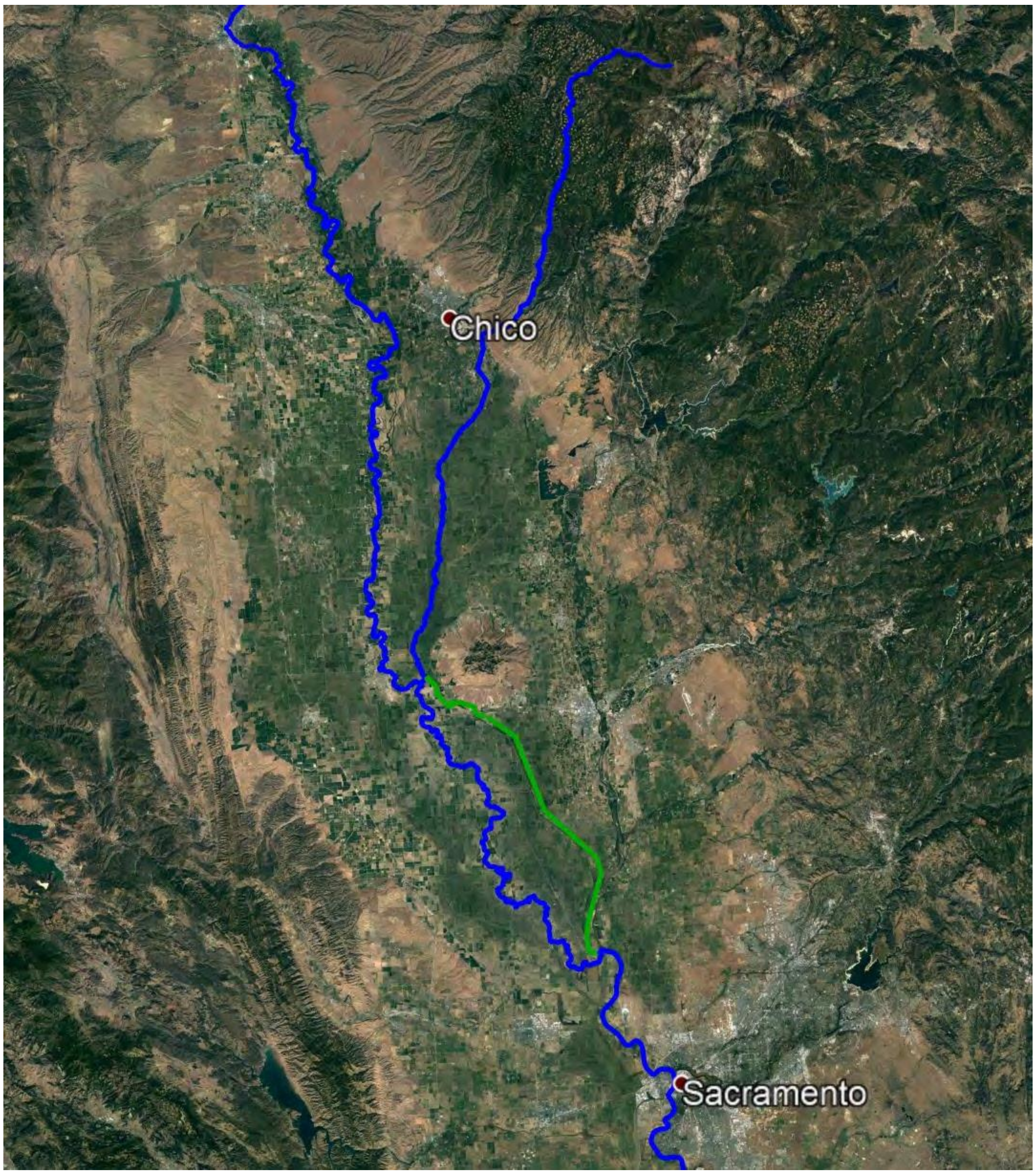
Jeremy Notch, Flora Cordoleani, Alex McHuron, Clint Garman, Tracy McReynolds

NOAA FISHERIES | Southwest Fisheries Science Center
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
UNIVERSITY OF CALIFORNIA SANTA CRUZ

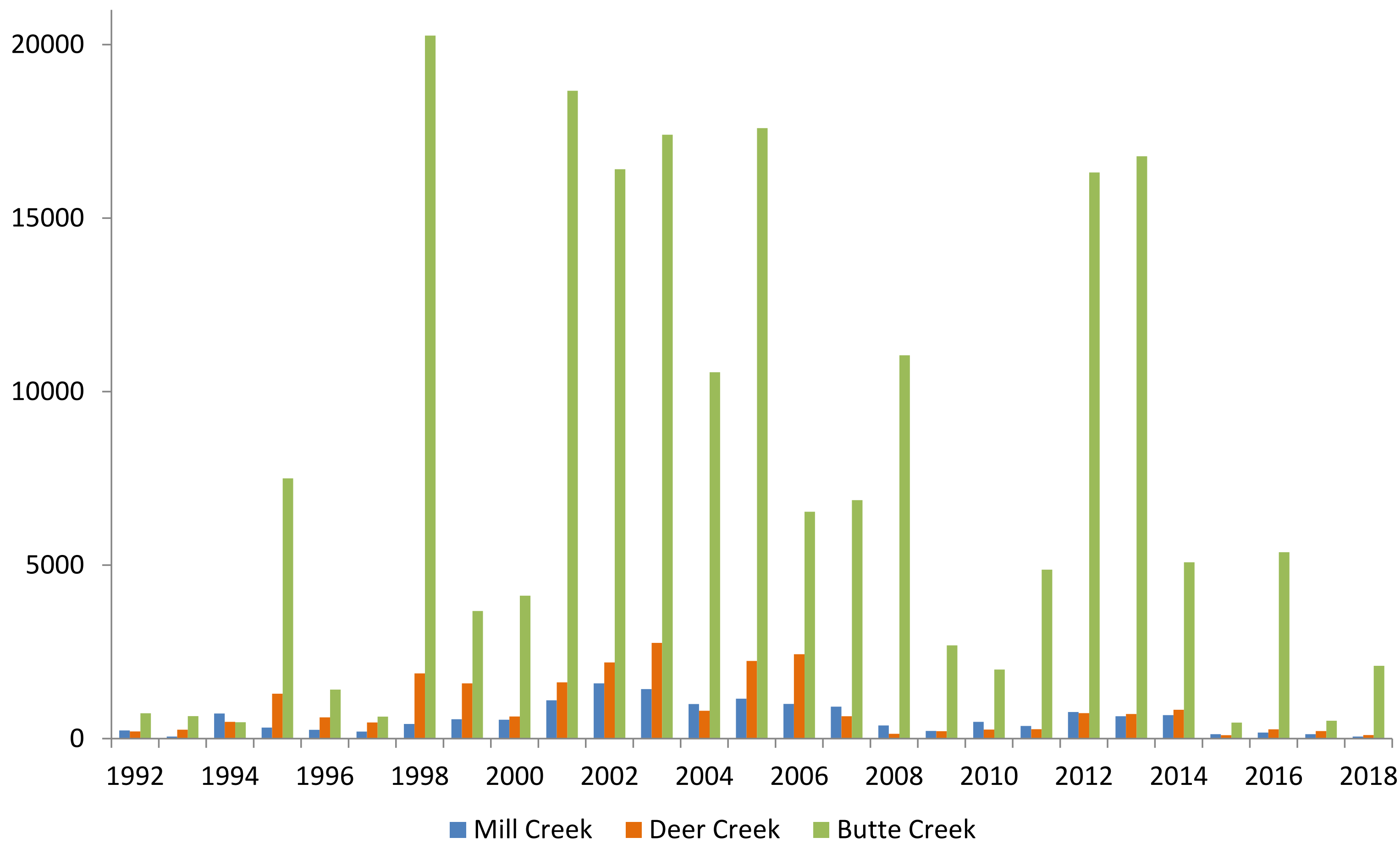
Study Objectives

Part 1:
-What is the growth and residence time of spring-run juveniles rearing in Butte Creek and the Sutter Bypass? (CDFW CWT Study, 1996 - 2004)

Part 2:
-What are the survival and movement rates of smolts out-migrating from the Sutter Bypass? (NOAA Acoustic Tagging Study, 2015 - 2017)


Chico
Sacramento

Mill, Deer, Butte Creek Spring-Run Escapement 1992 - 2018

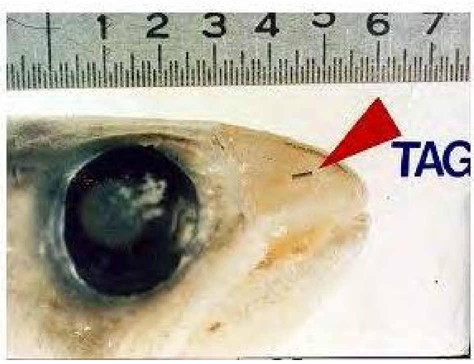


Part 1
CDFW Coded Wire Tagging (CWT) Study – 1996-2004

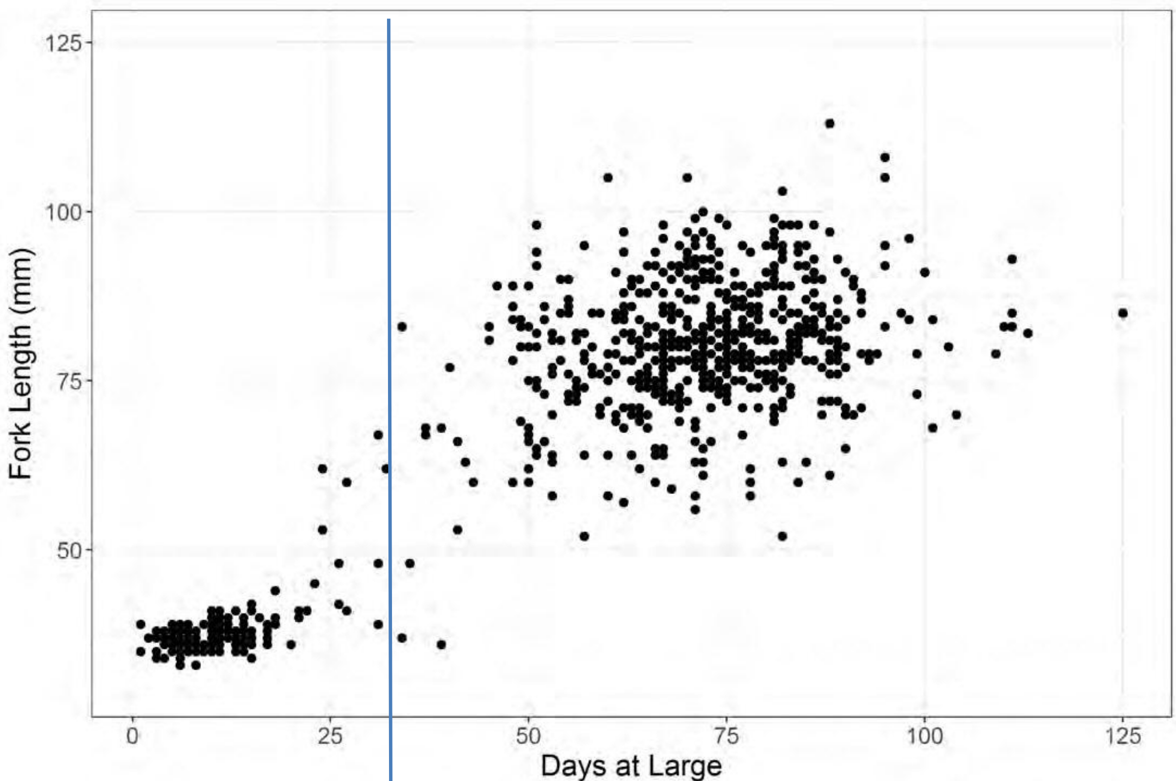
- ~750,000 spring-run juveniles (30-40mm) CWT tagged between 1996 – 2004 near spawning grounds in late January – early February

- 769 recaptured ~70 miles downstream in the Sutter Bypass

- Unique ID on CWT allows for analysis of group movement and growth rates



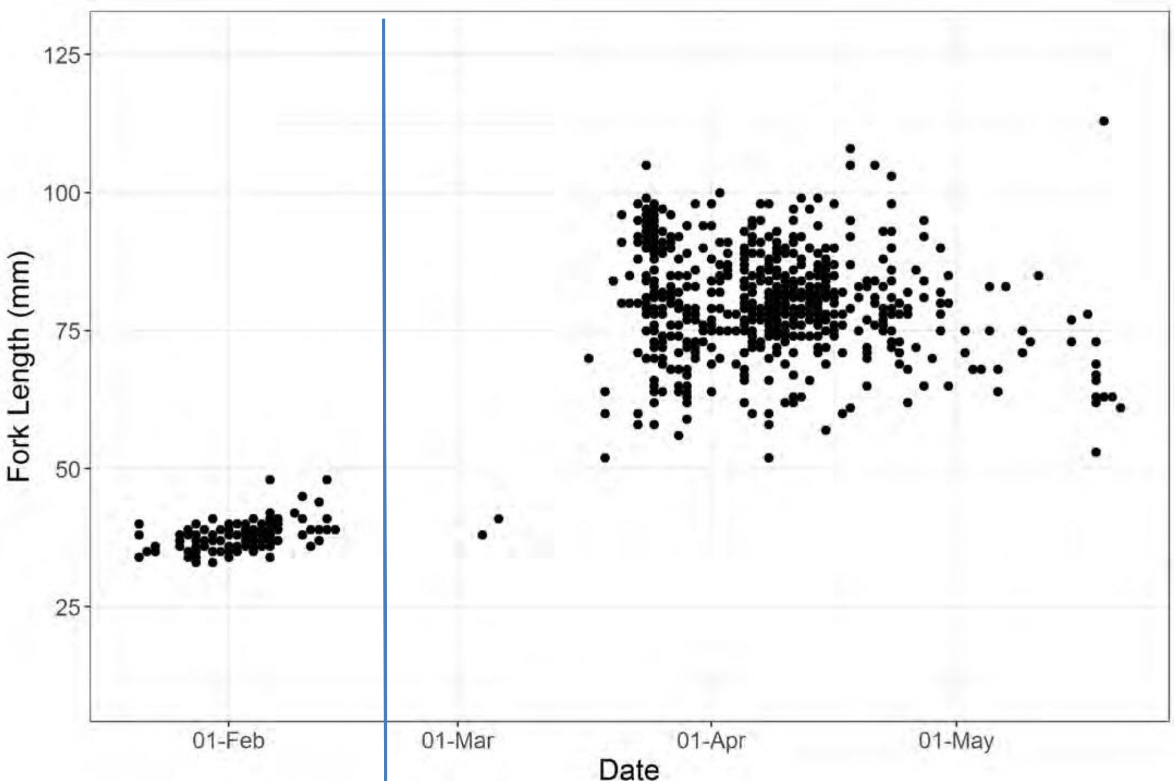
1996 – 2004 CWT Recaptures in Sutter Bypass



Runners
n = 137 (17%)
Av. residency = 11 days (± 5.6)
Av. growth = 3mm (0.27mm/day)
Av. length = 38mm (± 4mm)

Walkers
n = 628 (83%)
Av. residency = 72 days (± 13.5)
Av. growth = 44mm (0.62mm/day)
Av. length = 80mm (± 10mm)

1996 – 2004 CWT Recaptures in Sutter Bypass



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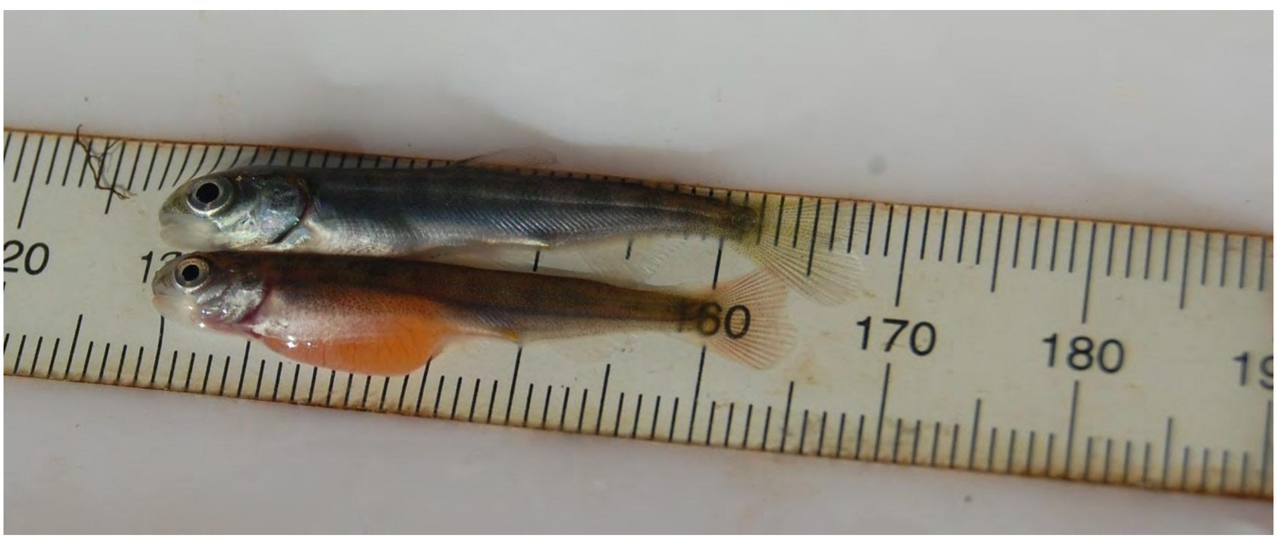
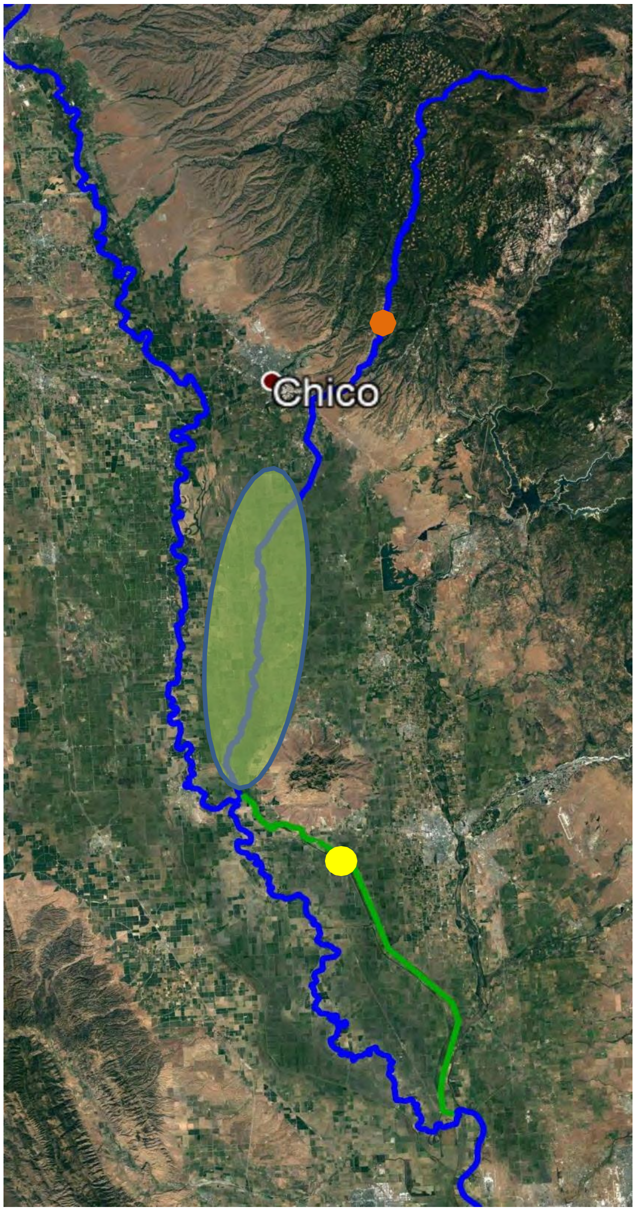
Av. residency = 72 days (± 13.5)
Av. growth = 44mm (0.62mm/day)
Av. length = 80mm (± 10mm)

Walker

Runners

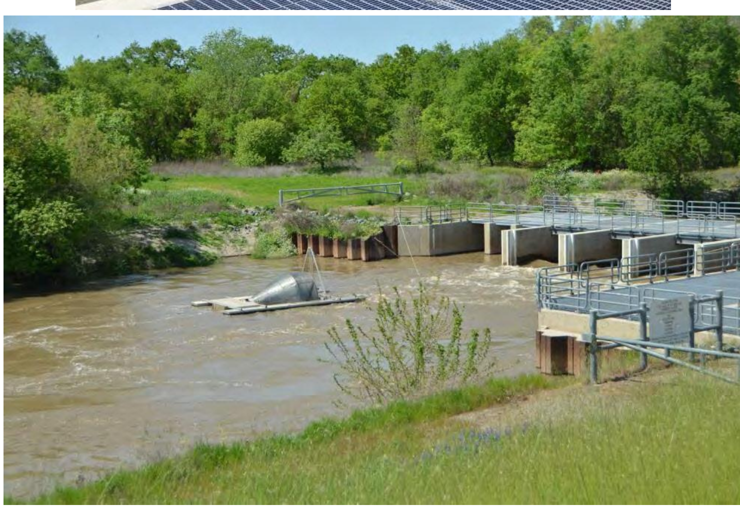


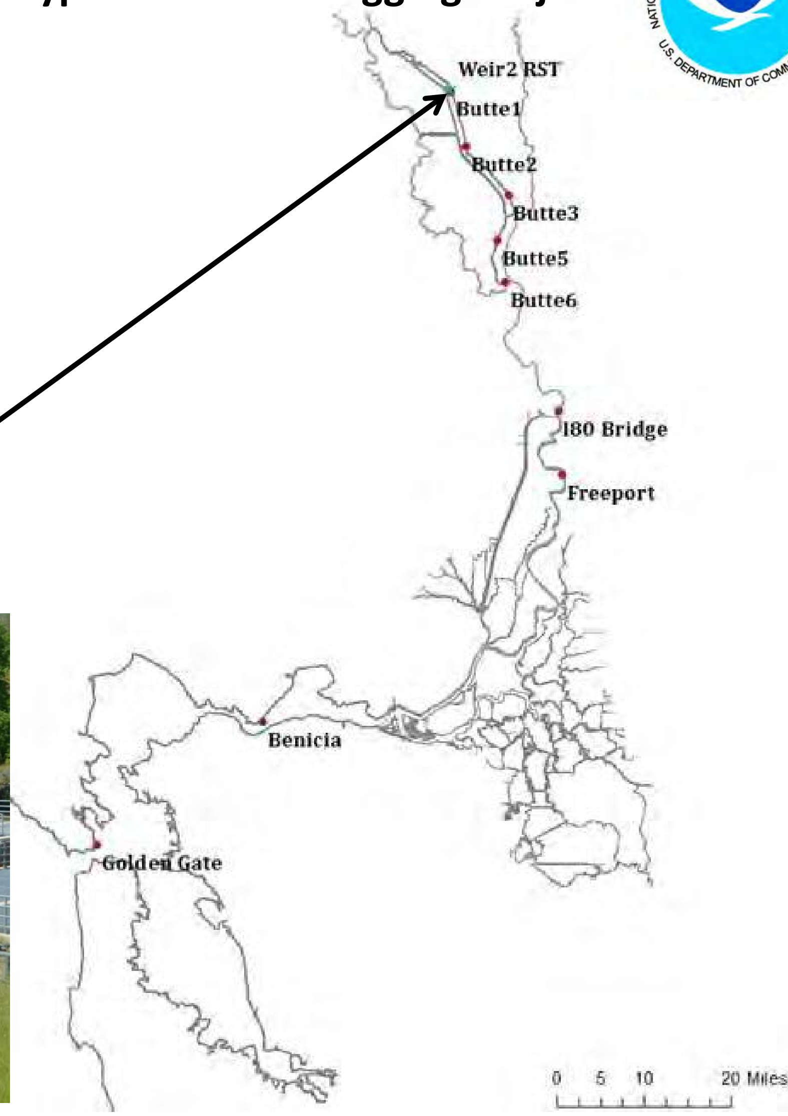


Butte Basin

- Largest contiguous wetland habitat in the Sacramento Valley
- Butte Sink managed by USFWS as a wildlife refuge
- Mostly comprised of private land with 32 conservation easements

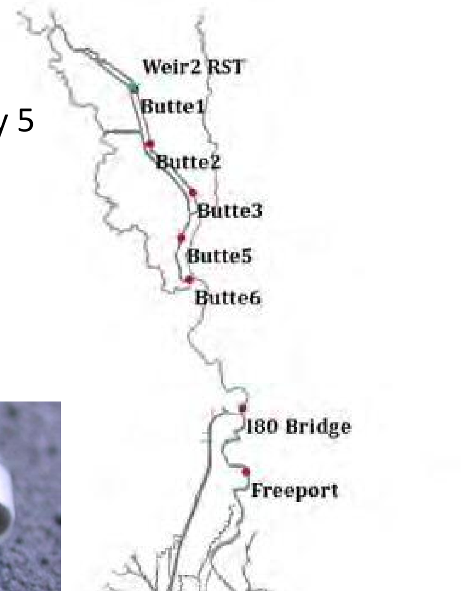
Part 2
2015 – 2017 Sutter Bypass Acoustic Tagging Project

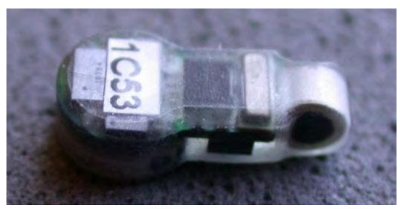




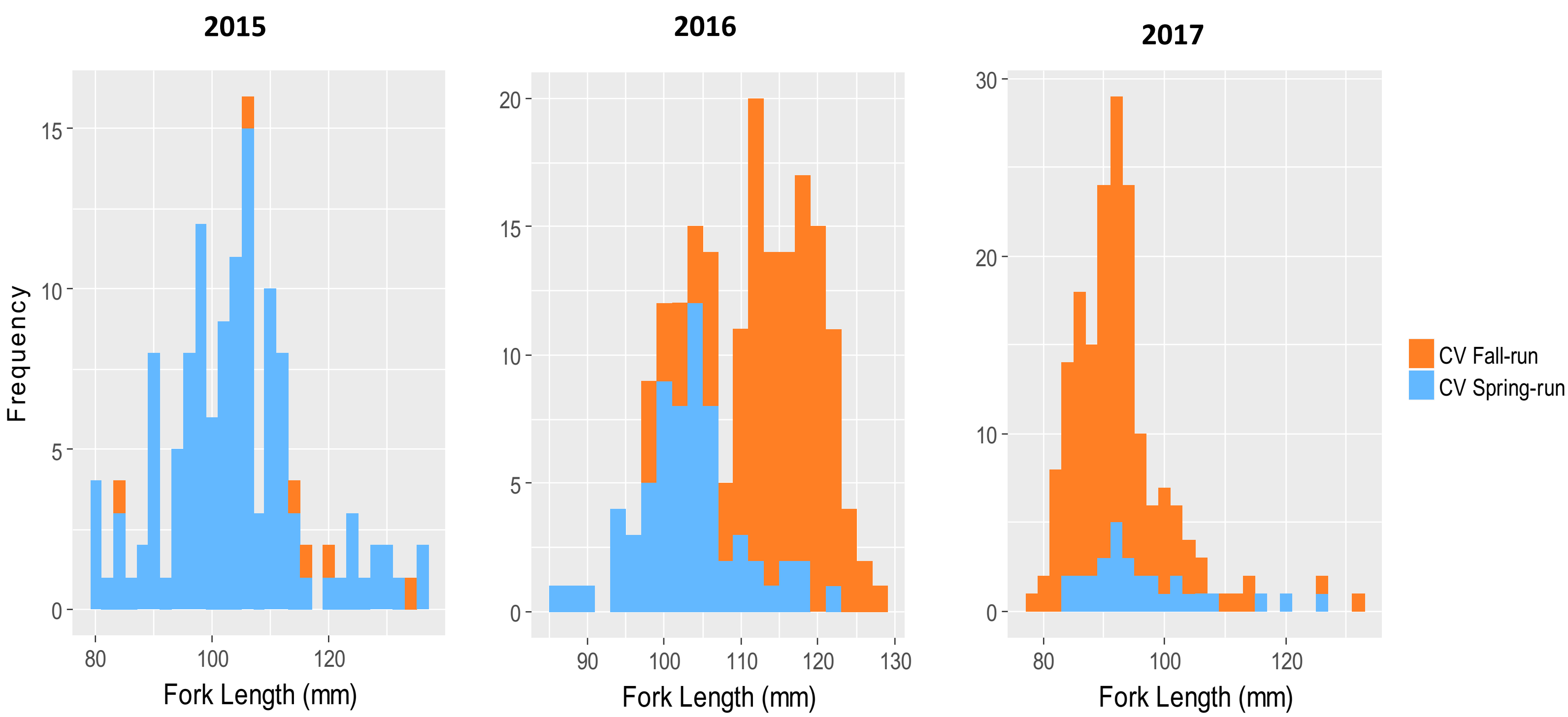
JSATS – Juvenile Salmon Acoustic Telemetry System

- Minimum fish size > 80mm, 6.0 g
- Unique ID for each tag, pings every 5 seconds for 30 days
- Fish released at 9pm to allow for recovery



Genetics By Year

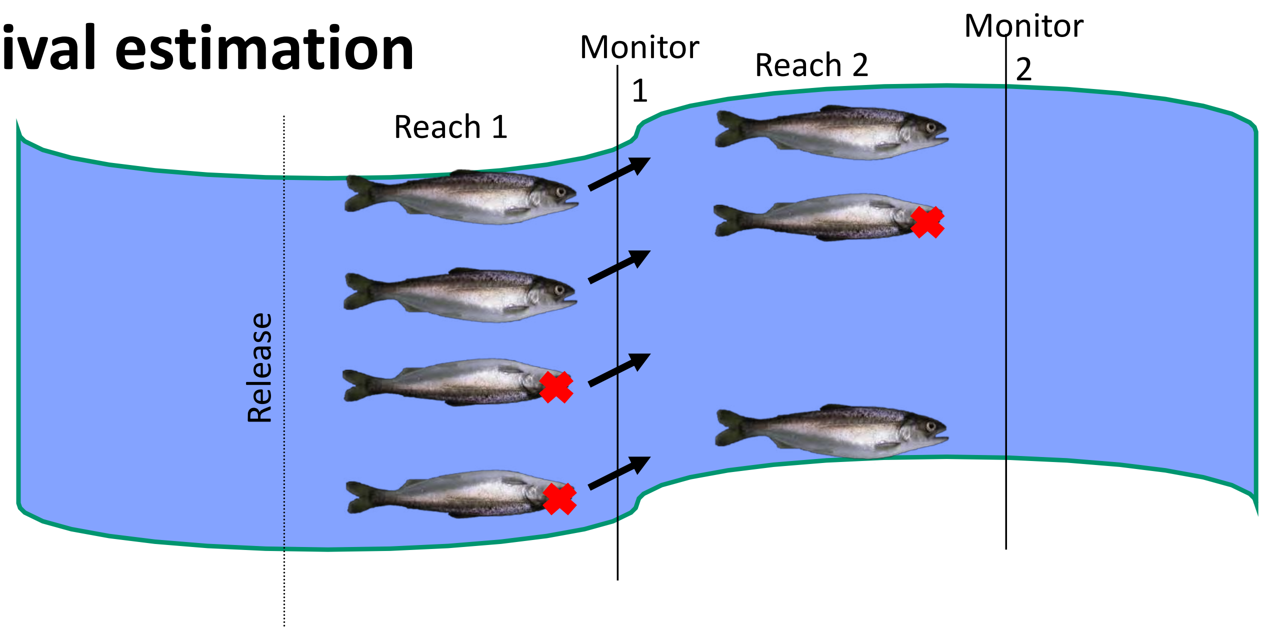


n = 141
Av. length = 105 mm

n = 200
Av. length = 110 mm

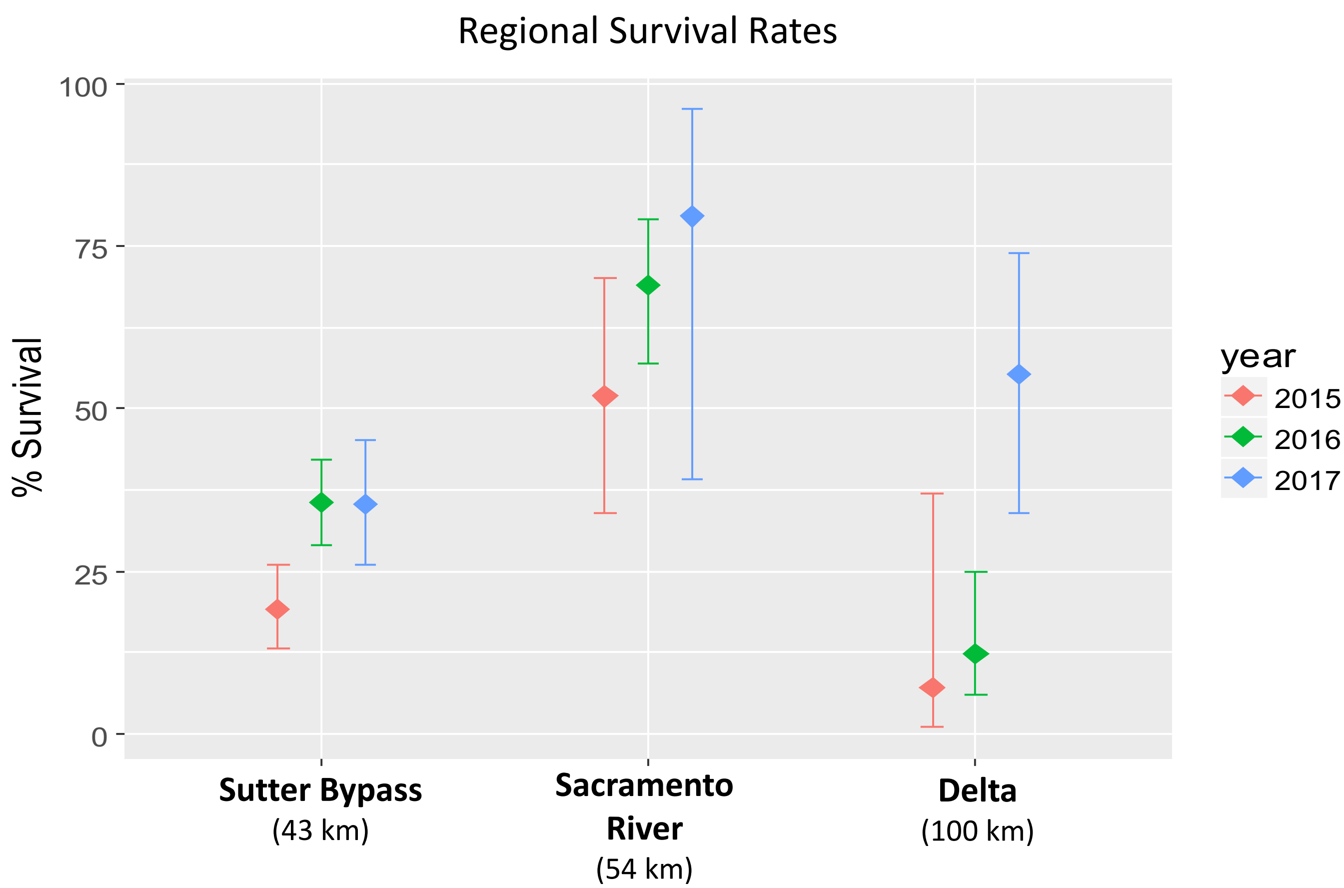
n = 190
Av. length = 93 mm

Survival estimation



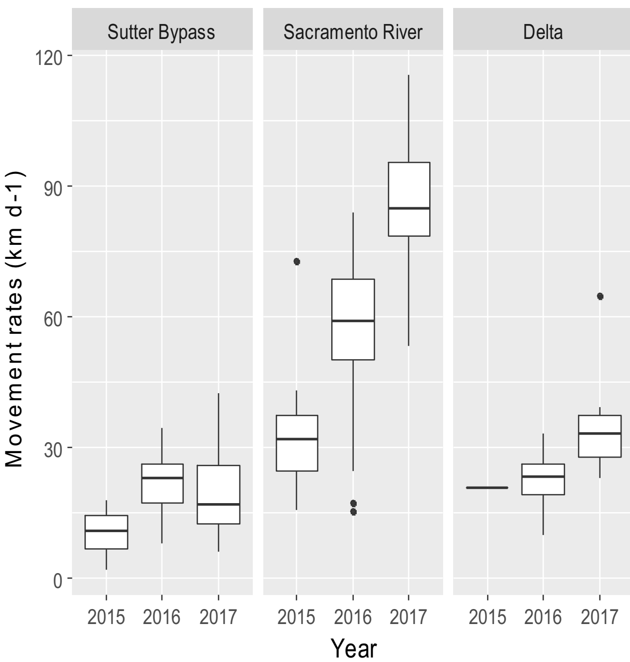
- Covariates: fish length, fish condition factor, temperature at release, flow at release, travel rate

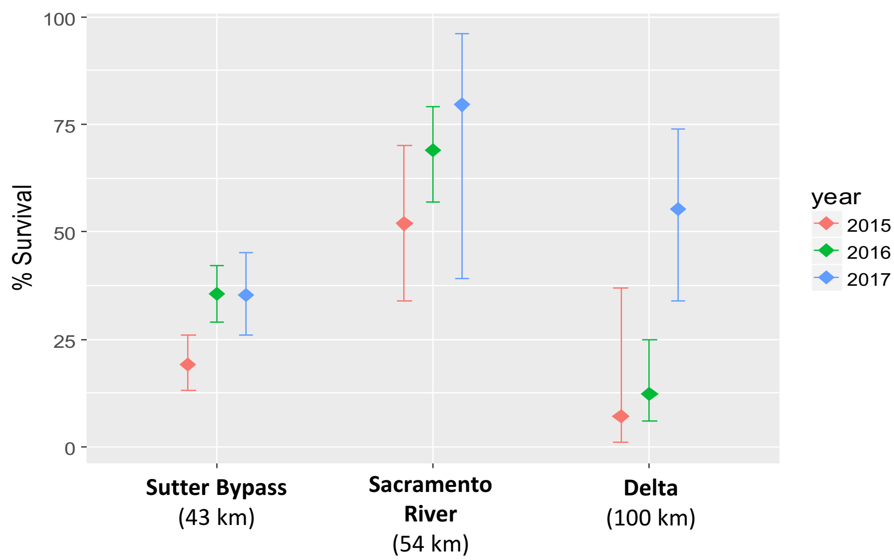
Model	# Parameters	Delta AICc
Reach + Year	18	0
Reach + Travel Rate (Sutter, Sac, Delta, Bay)	20	0.7
Reach + Flow at Release	17	8.34
Reach + Temp at Release	17	8.67



Regional Survival Rates
% Survival
100
75
50
25
0
Sutter Bypass
(43 km)
Sacramento
River
(54 km)
Delta
(100 km)
year
2015
2016
2017

Movement Rates vs. Survival





Conclusions

- Juveniles tend to walk (72 days, 83%) vs run (11 days, 17%) through Butte Creek and the Sutter Bypass
- Growth rates averaged 44mm (0.6mm/day) for walkers
- Low smolt survival rates through the Sutter Bypass and Delta in recent years
- Smolt survival appears to be correlated with movement speed: faster movement speeds lead to higher survival rates

Thank you

Flora Cordoleani

Alex McHuron

- Clint Garman
- Tracy McReynolds
- Paul Ward


Questions ?

science for a changing world

Prepared in cooperation with National Atmospheric and Oceanic Administration, National Marine Fisheries Service

Effects of the Proposed California WaterFix North Delta Diversion on Flow Reversals and Entrainment of Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) into Georgiana Slough and the Delta Cross Channel, Northern California

Open-File Report 2018–1028

U.S. Department of the Interior
U.S. Geological Survey

Cover: Image showing junction of the Sacramento River, Delta Cross Channel, and Georgiana Slough in the Sacramento-San Joaquin River Delta, northern California, February 21, 2014. Image source: Google Earth™.

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Effects of the Proposed California WaterFix North Delta Diversion on Flow Reversals and Entrainment of Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) into Georgiana Slough and the Delta Cross Channel, Northern California

By Russell W. Perry, Jason G. Romine, Adam C. Pope, and Scott D. Evans

Prepared in cooperation with National Atmospheric and Oceanic Administration, National Marine Fisheries Service

Open-File Report 2018–1028

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
RYAN K. ZINKE, Secretary

U.S. Geological Survey
William H. Werkheiser, Deputy Director
exercising the authority of the Director

U.S. Geological Survey, Reston, Virginia: 2018

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Contents

Figures

Tables

Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Area	
MAF (million acre-feet)	1,233.482	million cubic meters
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

International System of Units to U.S. customary units

Multiply	By	To obtain
	Area	
kilometer (km)	0.6214	mile (mi)

Abbreviations

DCC	Delta Cross Channel
DSM2	Delta Simulation Model 2
NAA	No Action Alternative
NDD	North Delta Diversion
PA	Proposed Action
R^2	coefficient of determination
WYI	water year index

Effects of the Proposed California WaterFix North Delta Diversion on Flow Reversals and Entrainment of Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) into Georgiana Slough and the Delta Cross Channel, Northern California

By Russell W. Perry, Jason G. Romine, Adam C. Pope, and Scott D. Evans

Abstract

The California Department of Water Resources and Bureau of Reclamation propose new water intake facilities on the Sacramento River in northern California that would convey some of the water for export to areas south of the Sacramento-San Joaquin River Delta (hereinafter referred to as the Delta) through tunnels rather than through the Delta. The collection of water intakes, tunnels, pumping facilities, associated structures, and proposed operations are collectively referred to as California WaterFix. The water intake facilities, hereinafter referred to as the North Delta Diversion (NDD), are proposed to be located on the Sacramento River downstream of the city of Sacramento and upstream of the first major river junction where Sutter Slough branches from the Sacramento River. The NDD can divert a maximum discharge of 9,000 cubic feet per second (ft^3/s) from the Sacramento River, which reduces the amount of Sacramento River inflow into the Delta.

In this report, we conducted three analyses to investigate the effect of the NDD and its proposed operation on entrainment of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) into Georgiana Slough and the Delta Cross Channel (DCC). Fish that enter the interior Delta (the network of channels to the south of the Sacramento River) through Georgiana Slough and the DCC survive at lower rates than fish that use other migration routes (Sacramento River, Sutter Slough, and Steamboat Slough). Therefore, fisheries managers were concerned about the extent to which operation of the NDD would increase the proportion of the population entering the interior Delta, which, all else being equal, would lower overall survival through the Delta by increasing the fraction of the population subject to lower survival rates. Operation of the NDD would reduce flow in the Sacramento River, which has the potential to increase the magnitude and duration of reverse flows of the Sacramento River downstream of Georgiana Slough.

In the first analysis, we evaluate the effect of the NDD bypass rules on flow reversals of the Sacramento River downstream of Georgiana Slough. The NDD bypass rules are a set of operational criteria designed to minimize upstream transport of fish into Georgiana Slough and the DCC, and were developed based on previous studies showing that the magnitude and duration of flow reversals increase the proportion of fish entering Georgiana Slough and the DCC. We estimated the frequency and duration of reverse-flow conditions of the Sacramento River downstream of Georgiana Slough under

each of the prescribed minimum bypass flows described in the NDD bypass rules. To accommodate adaptive levels of protection during different times of year when juvenile salmon are migrating through the Delta, the NDD bypass rules prescribe a series of minimum allowable bypass flows that vary depending on (1) month of the year, and (2) progressively decreasing levels of protection following a pulse flow event.

We determined that the NDD bypass rules increased the frequency and duration of reverse flows of the Sacramento River downstream of Georgiana Slough, with the magnitude of increase varying among scenarios. Constant low-level pumping, the most protective bypass rule that limits diversion to 10 percent of the maximum diversion and is implemented following a pulse-flow event, led to the smallest increase in frequency and duration of flow reversals. In contrast, we found that some scenarios led to sizeable increases in the fraction of the day with reverse flow. The conditions under which the proportion of the day with reverse flow can increase by greater than or equal to 10 percentage points between October and June, when juvenile salmon are present in the Delta, include October–November bypass rules and level-3 post-pulse operations during December–June. These conditions would be expected to increase the proportion of juvenile salmon entering the interior Delta through Georgiana Slough.

In the second analysis, we assessed bias in Delta Simulation Model 2 (DSM2) flow predictions at the junction of the Sacramento River, DCC, and Georgiana Slough. Because DSM2 was being used to simulate California WaterFix operations, understanding the extent of bias relative to USGS streamgages was important since fish routing models were based on flow data at streamgages. We determined that river flow predicted by DSM2 was biased for Georgiana Slough and the Sacramento River. Therefore, for subsequent analysis, we bias-corrected the DSM2 flow predictions using measured stream flows as predictor variables.

In the third analysis, we evaluated the effect of the NDD on the daily probability of fish entering Georgiana Slough and the DCC. We applied an existing model to predict entrainment from 15-minute flow simulations for an 82-year time series of flows simulated by DSM2 under the Proposed Action (PA), where the North Delta Diversion is implemented under California WaterFix, and the No Action Alternative (NAA), where the diversion is not implemented. To estimate the daily fraction of fish entering each river channel, entrainment probabilities were averaged over each day. To evaluate the two scenarios, we then compared mean annual entrainment probabilities by month, water year classification, and three different assumed run timings. Overall, the probability of remaining in the Sacramento River was lower under the PA scenario, but the magnitude of the difference was small (<1 percentage point). When run timing was assumed to occur between December and April, this difference was even less because fish were less exposed to periods when we observed the largest difference in entrainment between scenarios (October and November). The difference in entrainment between scenarios primarily was influenced by the difference in operation of the DCC between PA and NAA. Under the PA scenario, the DCC was open more frequently in October, November, and June, thus exposing more fish to being entrained into the interior Delta by the DCC. It is important to note, however, that we may have observed even less difference in mean annual entrainment probabilities between PA and NAA because we restricted our analysis to flows less than 41,000 ft^3/s. At flows greater than 41,000 ft^3/s, we hypothesize that entrainment into the interior Delta is relatively constant, which would have caused little difference between scenarios at higher flows.

Evaluation of the Effects of the Proposed California WaterFix North Delta Diversion on Flow Reversals and Entrainment of Juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) into Georgiana Slough and the Delta Cross Channel, Northern California

Introduction

This analysis investigates the effects of the North Delta Diversion (NDD) bypass rules (California Department of Water Resources, 2013, table 3.4.1–2) on the frequency and duration of reverse flows of the Sacramento River downstream of Georgiana Slough (fig. 1), in the Sacramento-San Joaquin River Delta (hereinafter referred to as the Delta) of northern California. One goal of the NDD bypass rules is to provide bypass flows that prevent an increase in upstream transport of fish into Georgiana Slough and the Delta Cross Channel (DCC). Bypass flows are defined as flow remaining in the Sacramento River downstream of the North Delta Diversion. These rules were developed based on previous research and understanding of reverse-flow hydrodynamics at this river junction. Research has shown that the entrainment probability of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) into Georgiana Slough and the DCC is highest during reverse-flow flood tides (Perry and others, 2015). Furthermore, the daily proportion of fish entrained into Georgiana Slough increases with the fraction of the day in a reverse flow condition at the Sacramento River downstream of Georgiana Slough (Perry, 2010). Therefore, diverting water from the Sacramento River could increase the frequency and duration of reverse-flow conditions, thereby reducing survival by increasing the proportion of fish entrained into the interior Delta where survival probabilities are lower than in the Sacramento River (Perry and others, 2010, 2013).

The NDD bypass rules also are designed to provide more protection during times of the year when juvenile salmon populations are actively migrating through the Delta (primarily December–June) and during pulse flow events when endangered winter-run Chinook salmon are likely to initiate downstream migration into the Delta (del Rosario and others, 2013). To accommodate adaptive levels of protection, the NDD bypass rules prescribe a series of minimum allowable bypass flows that vary depending on (1) month of the year, and (2) progressively decreasing levels of protection following a pulse flow event. For modeling purposes, pulse events are defined based on discharge of the Sacramento River at Wilkins Slough, and minimum bypass levels are based on varying fractions of discharge of the Sacramento River arriving at the NDD (see California Department of Water Resources, 2013, table 3.4.1–2, for details). For operational purposes, pulse events are based on monitoring for the presence of winter-run-sized fish entering the reach.

Our goal was to estimate the frequency and duration of reverse-flow conditions of the Sacramento River downstream of Georgiana Slough under each of the prescribed minimum bypass flows described in the NDD bypass rules (California Department of Water Resources, 2013, table 3.4.1–2). First, we used historical flow data of the Sacramento River below Georgiana Slough (WGB; U.S. Geological Survey [USGS] streamgage 11447905) to estimate the effect of discharge of the Sacramento River at Freeport (FPT; USGS streamgage 11447650) on (1) the daily probability of a flow reversal, and (2) the daily proportion of each day with reverse flow. We then used these relationships to calculate the change in the probability of a flow reversal and the proportion of the day with reverse flow under each of the prescribed bypass flows described in the NDD bypass rules.

This analysis assumed that (1) the NDD bypass rules are applied based on mean daily discharge at Freeport, and (2) that water is diverted at a constant discharge over an entire day such that the bypass flow is constant over the day. Thus, we assumed that the bypass is operated as strictly defined by the NDD bypass rules. We did not attempt to simulate "real time management" such as varying diversion flow at hourly timescales in response to in situ tidal conditions to prevent reverse flows. Such real-time management criteria have yet to be defined, and we, therefore, expanded on this topic in the discussion.

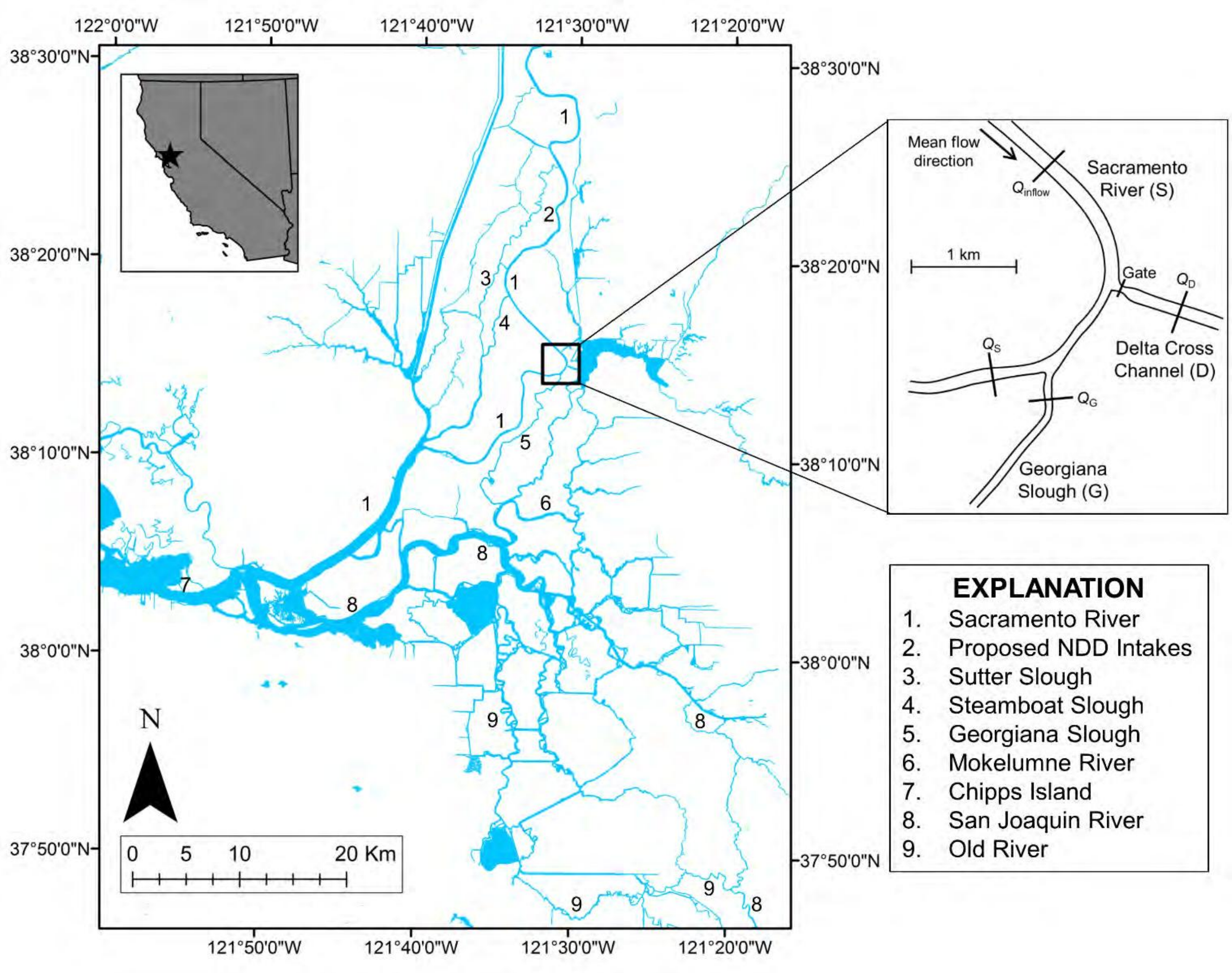

Figure 1. Map showing Sacramento-San Joaquin River Delta with inset of detail of the junction of the Sacramento River with Georgiana Slough and the Delta Cross Channel, northern California. Locations marked in inset map show streamgages. Q_S, discharge of Sacramento River downstream of Georgiana Slough (U.S. Geological Survey streamgage 11447905); Q_D, discharge of the Delta Cross Channel (U.S. Geological Survey streamgage 11336600); Q_G, discharge of Georgiana Slough (U.S. Geological Survey streamgage 11447903); Q_{inflow}, discharge of the Sacramento River upstream of the Delta Cross Channel (U.S. Geological Survey streamgage 11447890); NDD, North Delta Diversion; and km, kilometer.

Methods

We used logistic regression to quantify the relationship between Sacramento River inflows to the Delta and reverse flows of the Sacramento River downstream of Georgiana Slough. Mean daily discharge at Freeport, 15-min discharge data at station WGB, and the daily position of the DCC gate for the period October 2007 to March 2015 were used in the analysis. The 15-min data at WGB was summarized to two daily statistics: (1) A binary indicator value that was set to 1 if reverse flow occurred at any point on a given day and set to 0 if all 15-min flows were positive, and (2) the number of 15-min flow observations for each day that were negative. The position of the DCC gate was coded as a binary indicator variable (1 = open, 0 = closed) for inclusion in the analysis. Dates without a complete record of 15-min flows at WGB or where the DCC gate was not open or closed for the entire day were excluded from the analysis.

To estimate the probability of a flow reversal occurring on a given day, we fit a logistic regression model to the binary indicator variable as a function of daily flow at Freeport:

$$P(\text{reverse}) = \text{logit}^{-1}(\alpha_0 + \alpha_1 Q_{\text{FPT}}) \tag{1}$$

where

logit-1	is the inverse logit function,
QFPT	is mean daily discharge at Freeport,
α0	is the intercept, and
α1	is the slope.

We excluded the DCC gate position from this analysis because we noted that flow reversals always occurred for some part of the day when the DCC was open (that is, P[reverse] = 1 for DCC open). Therefore, the analysis was restricted to days when the DCC was closed.

To estimate the proportion of the day with reverse flow as a function of Freeport flow, we fit a logistic regression model to the number of 15-min reverse flows on each day relative to the total number 15-min flow observations each day:

$$P_{\text{day}}(\text{reverse}) = \text{logit}^{-1}(\beta_0 + \beta_1 Q_{\text{FPT}}) \tag{2}$$

where

β_0	is the intercept, and
β_1	is the slope.

This analysis was conducted separately for periods with the DCC gate open and closed.

We used goodness-of-fit tests to evaluate whether the model adequately fit the data. Because the response variable was binary for the probability of a flow reversal on a given day, we used a Hosmer-Lemeshow goodness-of-fit test (Hosmer and Lemeshow, 2000). For the binomial data used to estimate the proportion of each day with reverse flow, we used chi-square tests to evaluate goodness of fit (Faraway, 2006). In cases where these tests indicated lack of fit, we then used a quasibinomial regression to estimate the variance inflation factor, and then the variances, standard errors, and confidence intervals were inflated by this factor to account for overdispersion.

Given the relationships estimating the effect of Freeport discharge on the frequency (P[reverse]) and duration (P_{day}[reverse]) of flow reversals, we applied the bypass rules over a range of Freeport discharge from 5,000 to 35,000 ft^3/s, which bracketed flows under which we observed a 100-percent probability of a flow reversal to a 0-percent probability of a flow reversal. We compared the probability of flow reversal and the proportion of the day with flow reversals assuming no diversion and diversion under the NDD bypass rules with the DCC closed. We then calculated the difference in these statistics between no diversion and that prescribed under the NDD bypass rules to assess the magnitude of increase in the frequency and duration of reverse flows. Specifically, we did this comparison for the 12 scenarios described under the NDD bypass rules:

1. Constant low-level pumping,
2. October–November bypass rules,
3. Level 1, 2, and 3 post-pulse operations for December–April,
4. Level 1, 2, and 3 post-pulse operations for May,
5. Level 1, 2, and 3 post-pulse operations for June, and
6. July–September bypass rules.

Results

Of the three logistic regressions used, only the analysis for P_{day}(reverse) with the DCC closed had a significant goodness-of-fit test ($\chi^2_{1278} = 2695$, $P < 0.0001$), indicating that the model did not capture all the variation in the observed data. Using quasibinomial regression, we estimated a variance inflation factor of 1.29, which was used to inflate standard errors and confidence intervals.

We determined that the probability of a flow reversal decreased from 1.0 at about 12,500 ft^3/s to 0.0 at about 22,500 ft^3/s (fig. 2). We noted that the proportion of the day with negative flow was about 45 percent at a Freeport discharge of about 6,000 ft^3/s regardless of the DCC gate position (fig. 3). However, DCC gate position had a strong effect on the proportion of the day with reverse flows (table 1). As Freeport discharge increased over 6,000 ft^3/s, the fraction of the day with reverse flows decreased much more sharply with the DCC closed relative to open (fig. 3).

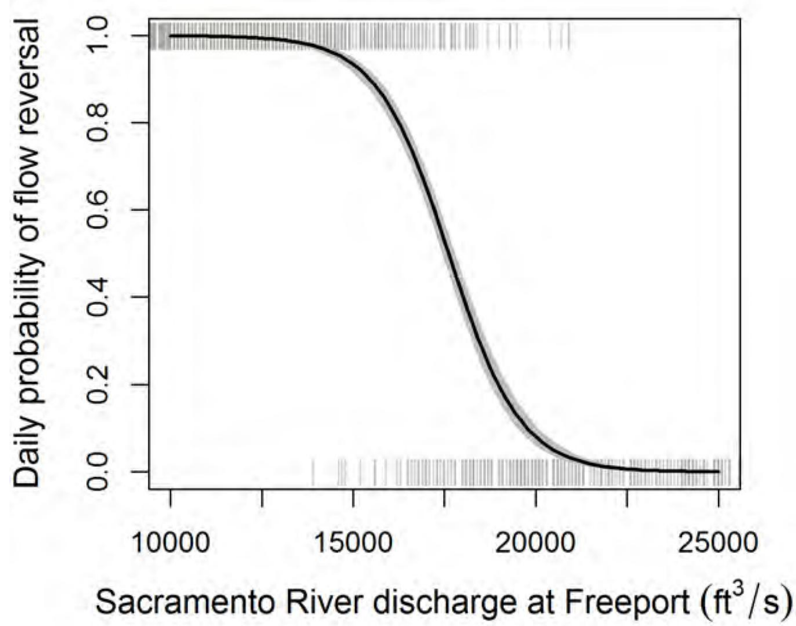

Figure 2. Graph showing effect of mean daily discharge on the probability of a flow reversal occurring on a given day with the Delta Cross Channel gate closed, at Freeport (USGS streamgage 11447650), on the Sacramento River just downstream of Georgiana Slough, northern California. Vertical bars show the days when flow reversals occurred (bars at 1.0) or did not occur (bars at 0.0), the black line shows the fitted logistic regression, and the gray regions on either side of this line show the 95-percent confidence interval about this line.

Table 1. Parameter estimates for the three logistic regression models used to estimate frequency and duration of flow reversals of the Sacramento River downstream of Georgiana Slough as a function of mean daily discharge at Freeport, northern California.

[DCC, Delta Cross Channel; SE, standard error; P, probability]

Response variable	DCC position	Intercept (SE)	Slope (SE)
P(reverse)	Closed	17.92 (1.567)	-1.017×10^{-3} (9.001×10^{-5})
P_{day}(reverse)	Open	0.13 (0.021)	-5.837×10^{-5} (1.600×10^{-6})
	Closed	1.37 (0.035)	-2.409×10^{-4} (3.203×10^{-6})

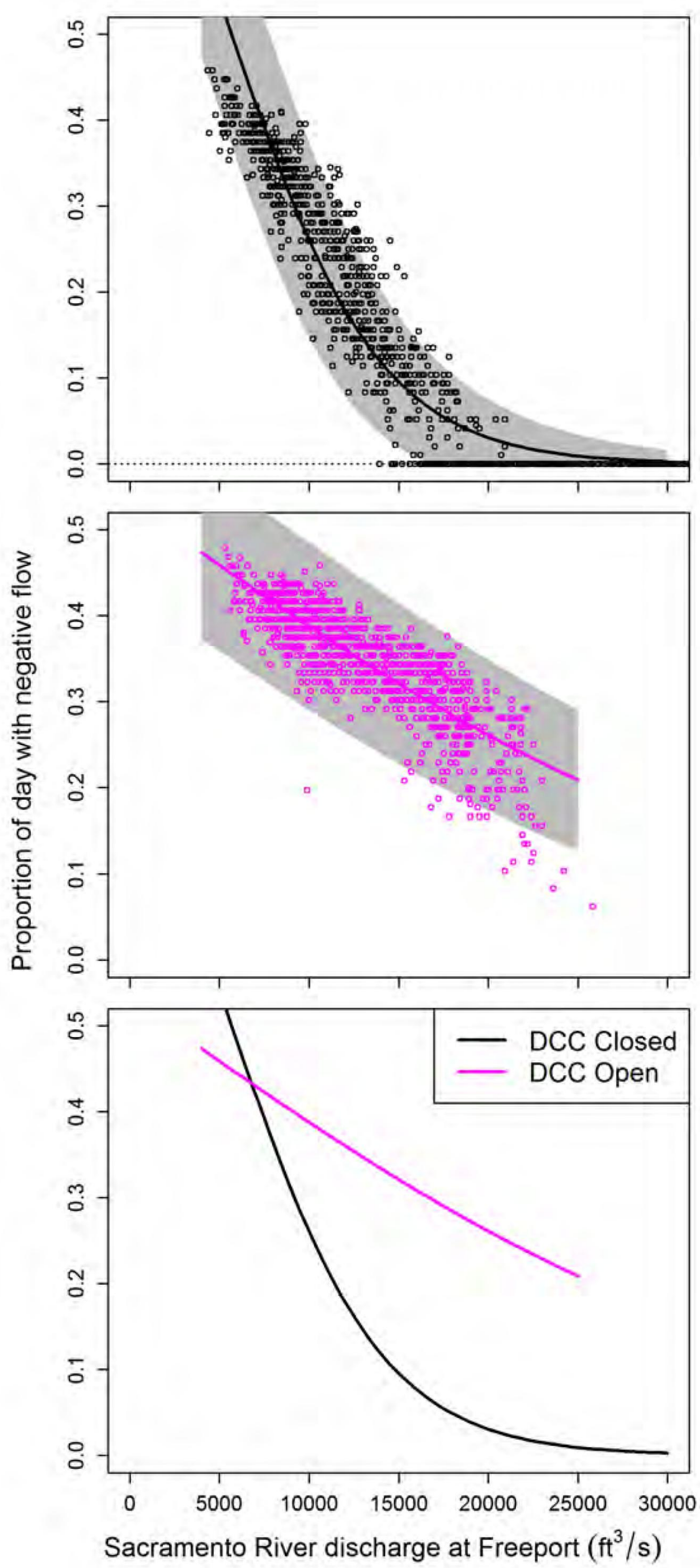

Figure 3. Graphs showing effect of discharge on the duration of flow reversals at Freeport (U.S. Geological Survey streamgage 11447650) on the Sacramento River downstream of Georgiana Slough, northern California. Shaded regions in top two graphs show 95-percent confidence intervals about the expected daily proportion. Bottom graph overlays the two curves to allow comparison. DCC, Delta Cross Channel.

We determined that the NDD bypass rules, as implemented under the assumptions of our simulation, increased the frequency and duration of reverse flows of the Sacramento River downstream of Georgiana Slough, with the magnitude of increase varying among scenarios (figs. 4–15). Constant low-level pumping, the most protective bypass rule, led to the smallest increase in frequency and duration of flow reversals (fig. 4). For example, the probability of a flow reversal increased by a maximum of 22 percentage points at a Freeport discharge of 18,000 ft^3/s, but the maximum increase in the proportion of the day with reverse flow increased by only 2.9 percentage points at a Freeport discharge of 10,000 ft^3/s. In contrast, during December–April, when most populations of juvenile salmon are migrating through the Delta, level 3 post-pulse operations led to sizeable increases in the frequency and duration of flow reversals (fig. 8). Under these conditions, the probability of a flow reversal occurring increased from a 1 percent chance to a 99 percent chance at Freeport flows of 22,000 ft^3/s. More importantly, at this discharge, the proportion of each day with reverse flow increased by about 12 percentage points from 0.019 to 0.146 (fig. 8). These conditions would be expected to increase the proportion of juvenile salmon entering Georgiana Slough.

Juvenile salmon also are present in the Delta, albeit at lower abundances, during other periods with less restrictive bypass rules (for example, May, and October–November). Under October–November bypass rules, the proportion of the day with reverse flow increased by a maximum of 34 percentage points at a Freeport discharge of 16,000 ft^3/s (fig. 5). Under level 3 post-pulse operations in May, the proportion of the day with reverse flow is expected to increase by a maximum of 14.3 percentage points at a Freeport discharge of 21,400 ft^3/s.

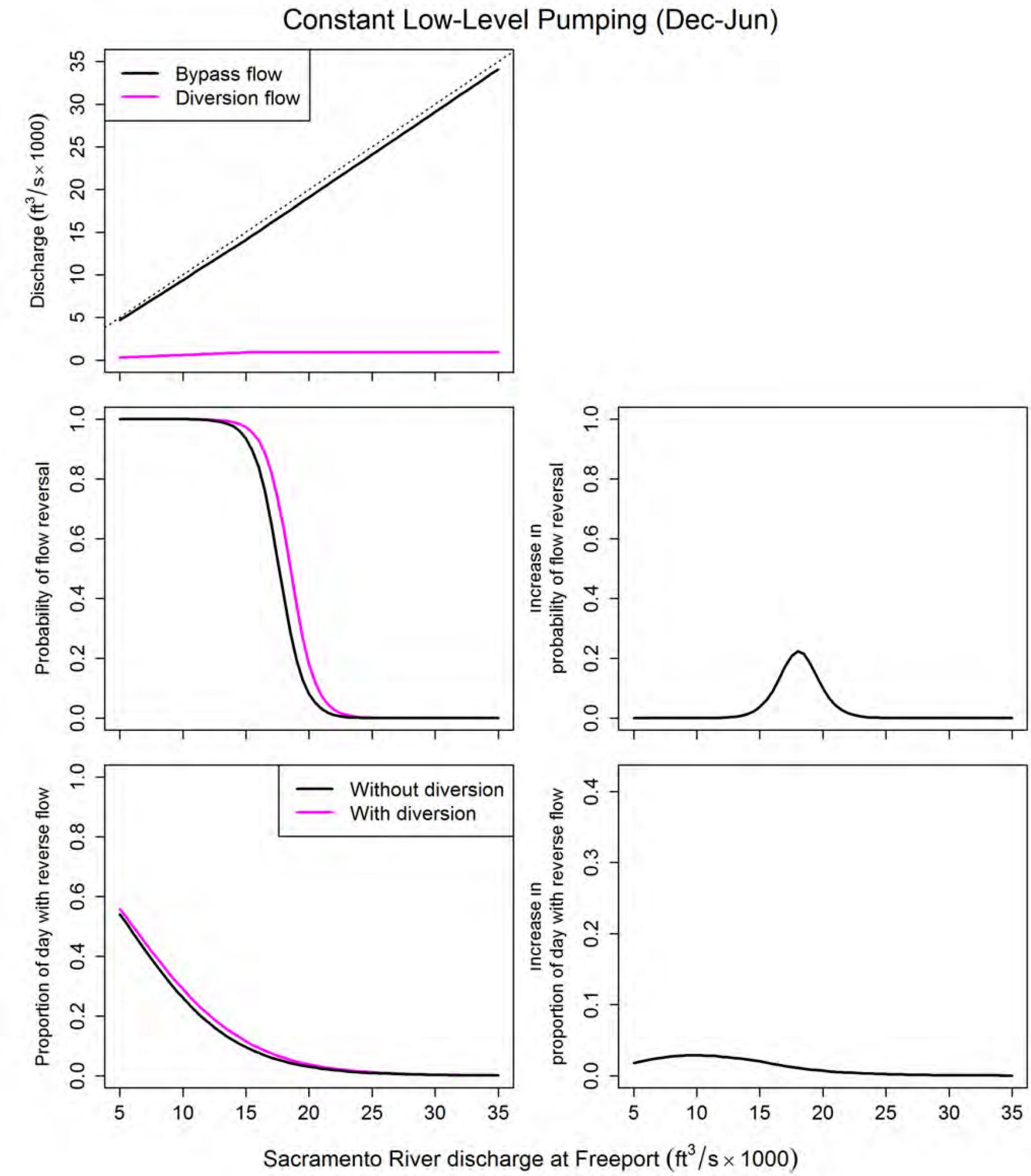

Figure 4. Graphs showing effect of North Delta Diversion (NDD) on bypass discharge (top graph), probability and increase in probability of flow reversal (middle graphs), and proportion of the day and increase in proportion of the day with reverse flow (bottom graphs) for constant low-level pumping as defined in the NDD bypass rules, at Freeport (U.S. Geological Survey streamgage 11447650) on the Sacramento River downstream of Georgiana Slough, northern California. In the top graph, the dotted line shows bypass discharge when diversion discharge is 0.

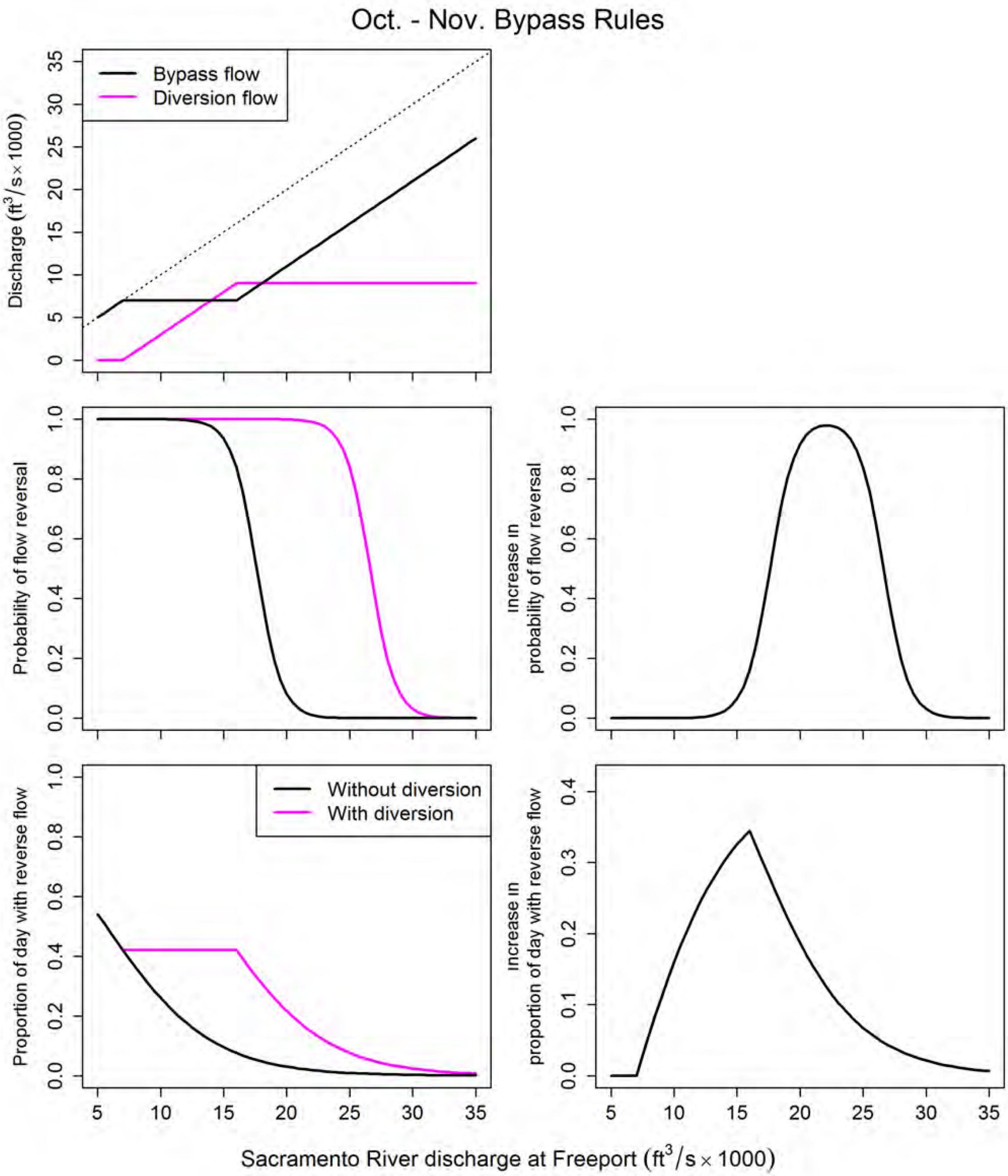

Figure 5. Graphs showing effect of North Delta Diversion (NDD) on bypass discharge (top graph), probability and increase in probability of flow reversal (middle graphs), and proportion of the day and increase in proportion of the day with reverse flow (bottom graphs) for October–November as defined in the NDD bypass rules, at Freeport (U.S. Geological Survey streamgage 11447650) on the Sacramento River downstream of Georgiana Slough, northern California. In the top graph, the dotted line shows bypass discharge when diversion discharge is 0.

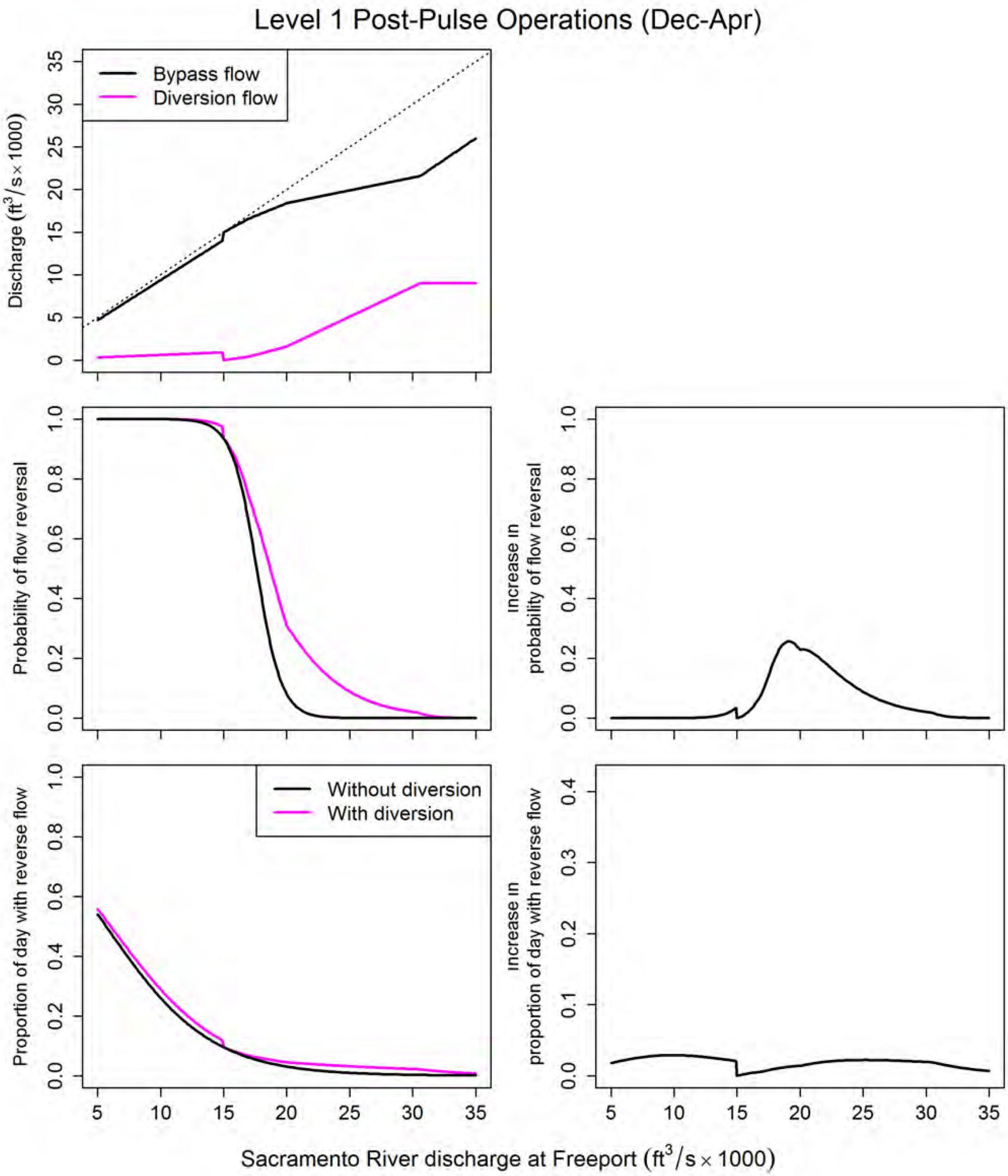

Figure 6. Graphs showing effect of North Delta Diversion (NDD) on bypass discharge (top graph), probability and increase in probability of flow reversal (middle graphs), and proportion of the day and increase in proportion of the day with reverse flow (bottom graphs) for Level 1 post-pulse operations in December–April as defined in the NDD bypass rules, at Freeport (U.S. Geological Survey streamgage 11447650) on the Sacramento River downstream of Georgiana Slough, northern California. In the top graph, the dotted line shows bypass discharge when diversion discharge is 0.

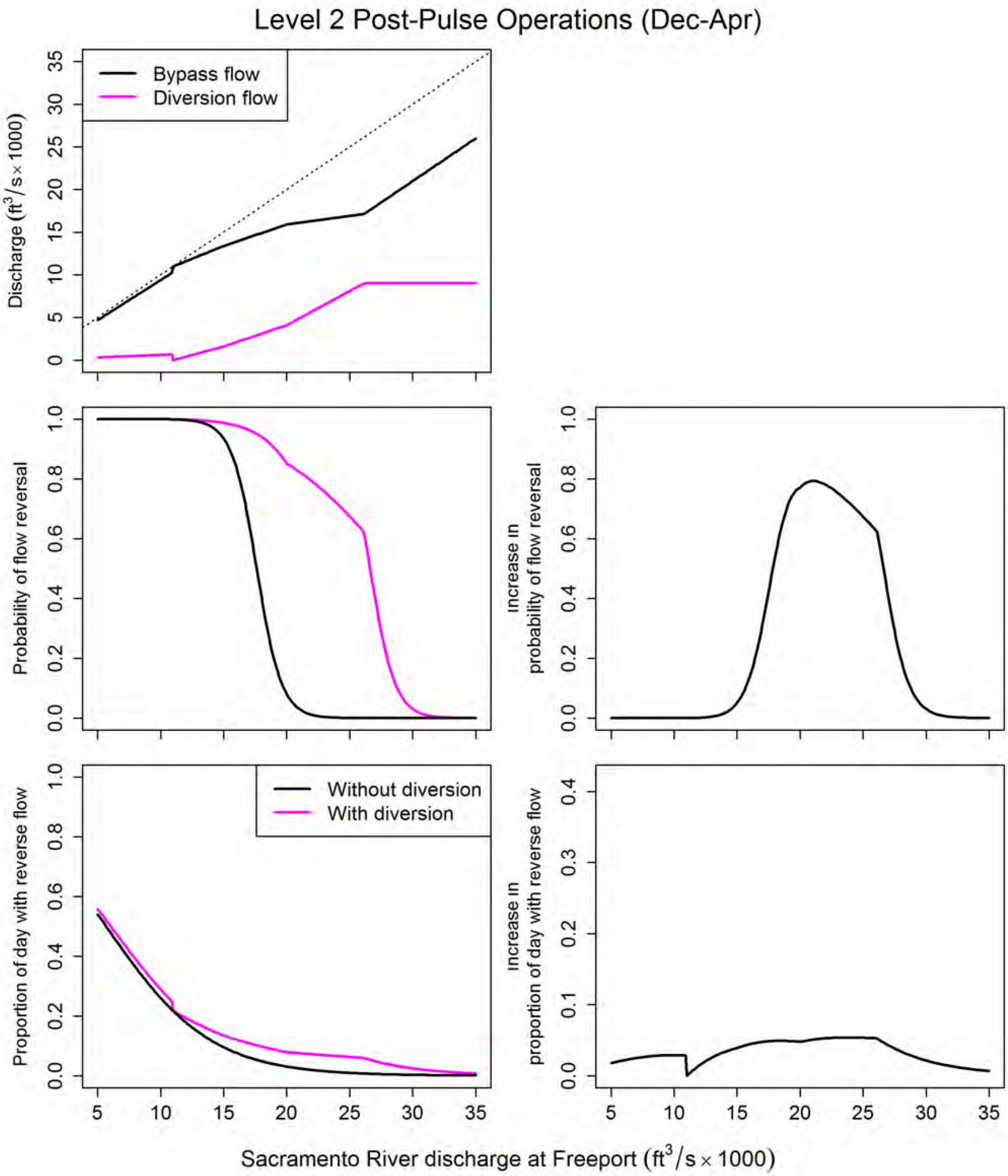

Figure 7. Graphs showing effect of North Delta Diversion (NDD) on bypass discharge (top graph), probability and increase in probability of flow reversal (middle graphs), and proportion of the day and increase in proportion of the day with reverse flow (bottom graphs) for Level 2 post-pulse operations in December–April as defined in the NDD bypass rules, at Freeport (U.S. Geological Survey streamgage 11447650) on the Sacramento River downstream of Georgiana Slough, northern California. In the top graph, the dotted line shows bypass discharge when diversion discharge is 0.

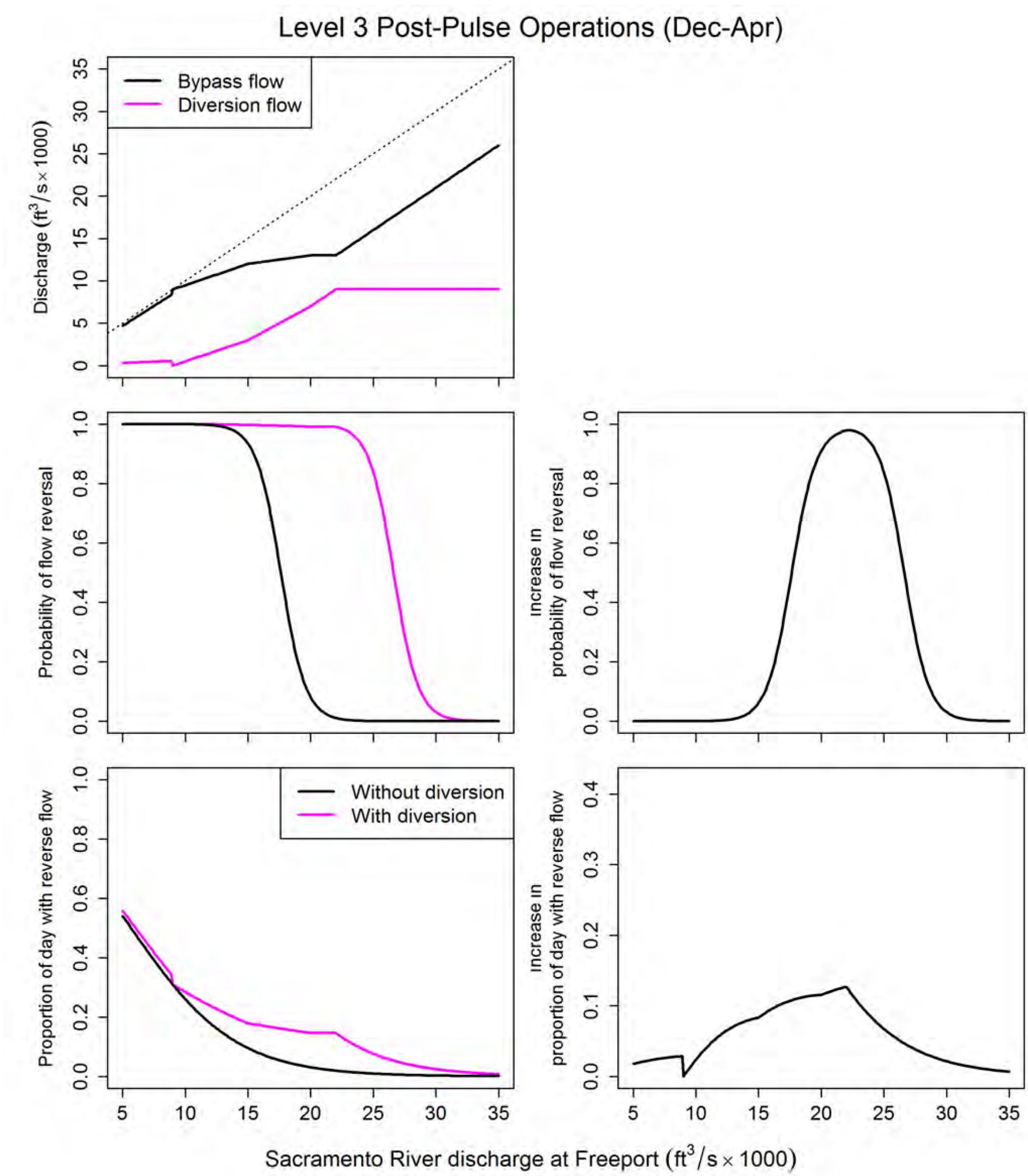

Figure 8. Graphs showing effect of North Delta Diversion (NDD) on bypass discharge (top graph), probability and increase in probability of flow reversal (middle graphs), and proportion of the day and increase in proportion of the day with reverse flow (bottom graphs) for Level 3 post-pulse operations in December–April as defined in the NDD bypass rules, at Freeport (U.S. Geological Survey streamgage 11447650) on the Sacramento River downstream of Georgiana Slough, northern California. In the top graph, the dotted line shows bypass discharge when diversion discharge is 0.

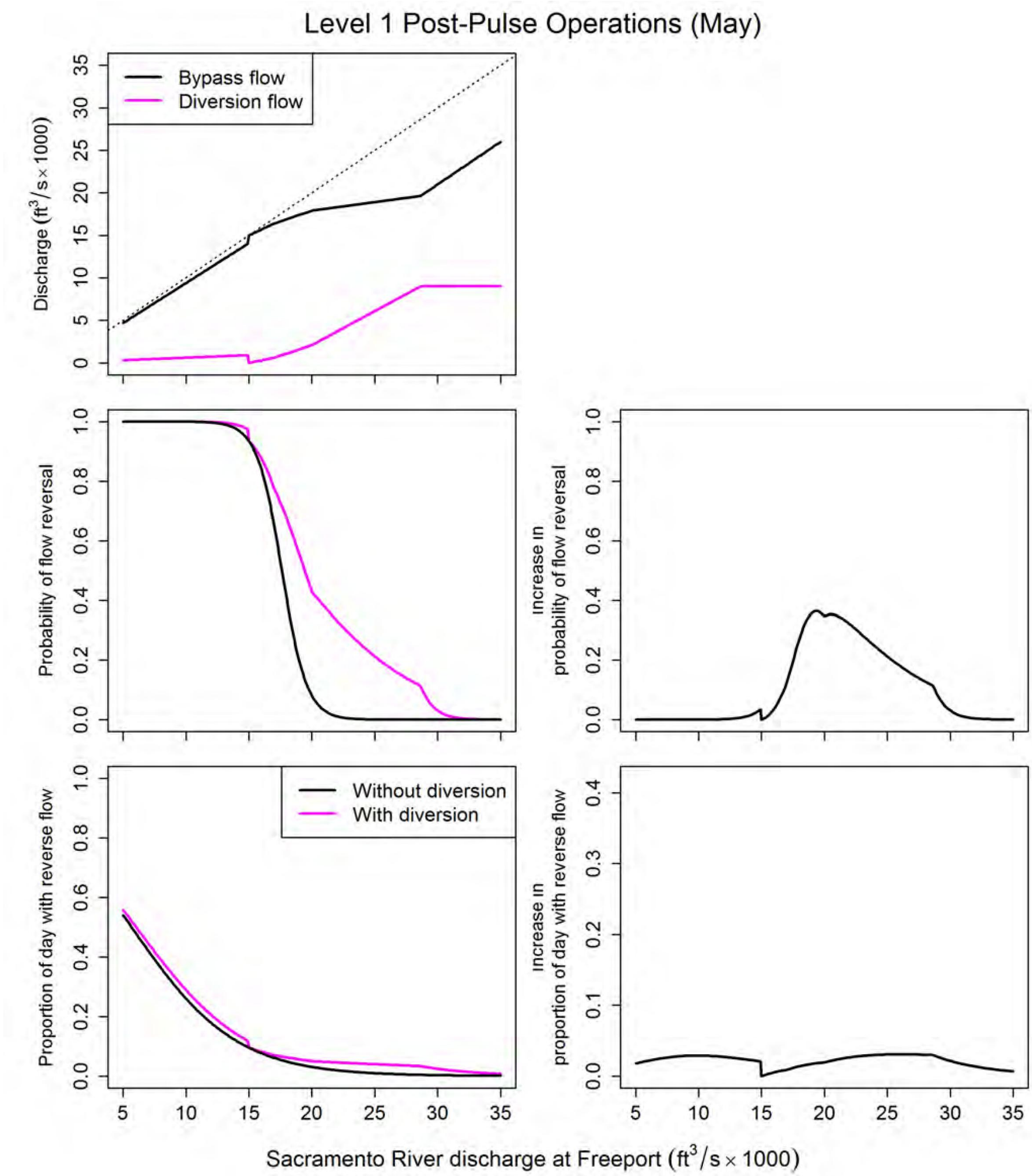

Figure 9. Graphs showing effect of North Delta Diversion (NDD) on bypass discharge (top graph), probability and increase in probability of flow reversal (middle graphs), and proportion of the day and increase in proportion of the day with reverse flow (bottom graphs) for Level 1 post-pulse operations in May as defined in the NDD bypass rules, at Freeport (U.S. Geological Survey streamgage 11447650) on the Sacramento River downstream of Georgiana Slough, northern California. In the top graph, the dotted line shows bypass discharge when diversion discharge is 0.

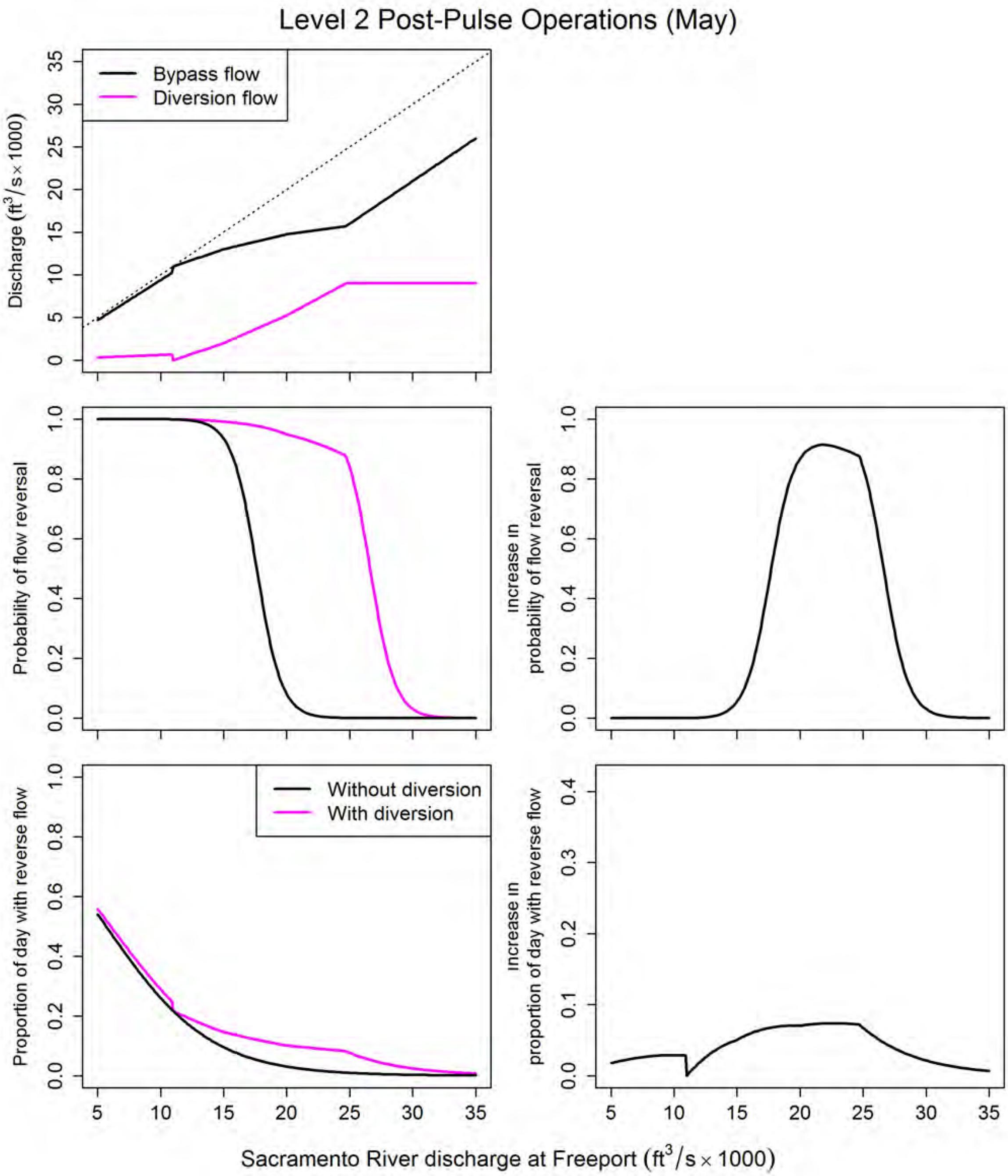

Figure 10. Graphs showing effect of North Delta Diversion (NDD) on bypass discharge (top graph), probability and increase in probability of flow reversal (middle graphs), and proportion of the day and increase in proportion of the day with reverse flow (bottom graphs) for Level 2 post-pulse operations in May as defined in the NDD bypass rules, at Freeport (U.S. Geological Survey streamgage 11447650) on the Sacramento River downstream of Georgiana Slough, northern California. In the top graph, the dotted line shows bypass discharge when diversion discharge is 0.

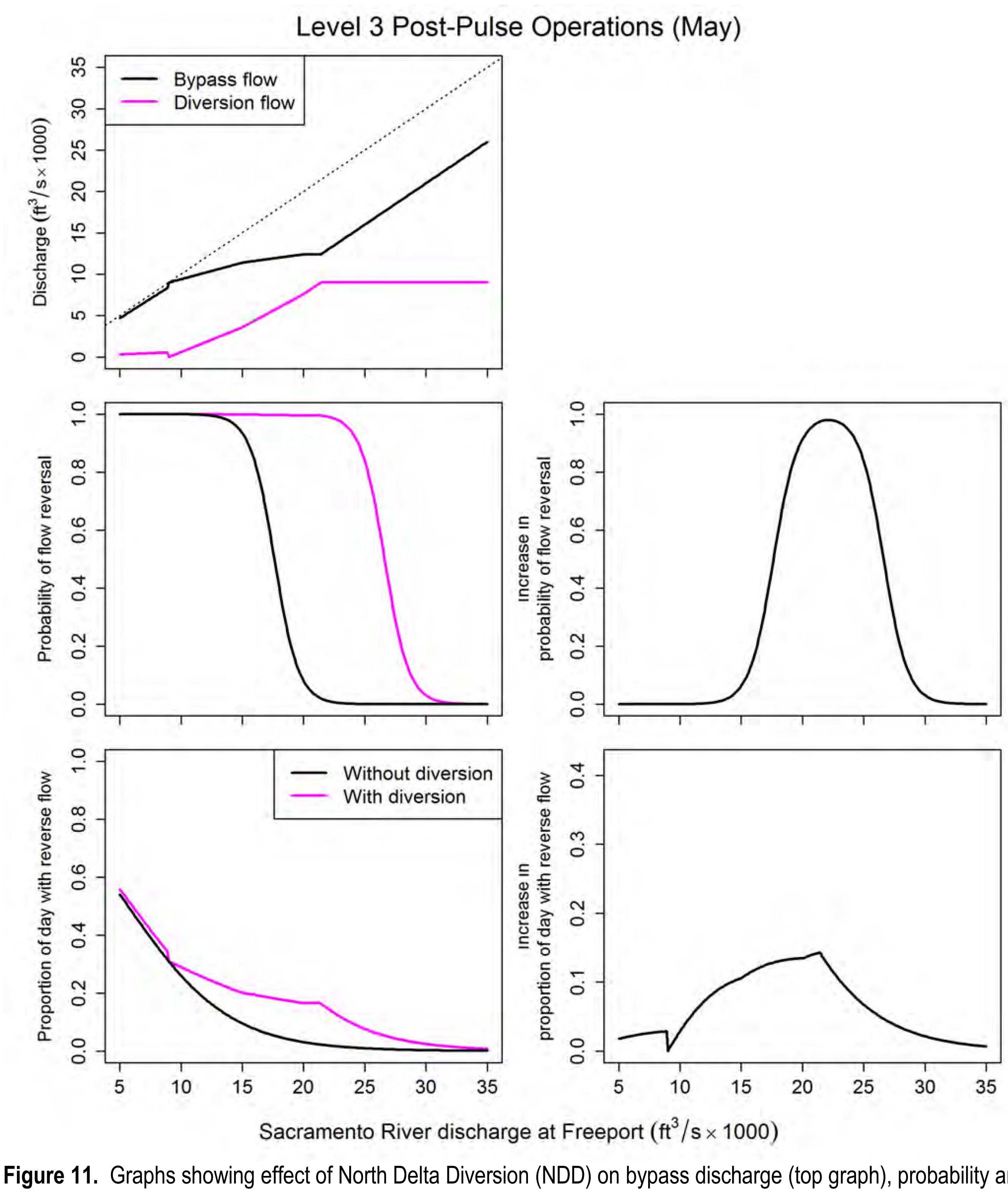

Figure 11. Graphs showing effect of North Delta Diversion (NDD) on bypass discharge (top graph), probability and increase in probability and increase in probability of flow reversal (middle graphs), and proportion of the day and increase in proportion of the day with reverse flow (bottom graphs) for Level 3 post-pulse operations in May as defined in the NDD bypass rules, at Freeport (U.S. Geological Survey streamgage 11447650) on the Sacramento River downstream of Georgiana Slough, northern California. In the top graph, the dotted line shows bypass discharge when diversion discharge is 0.

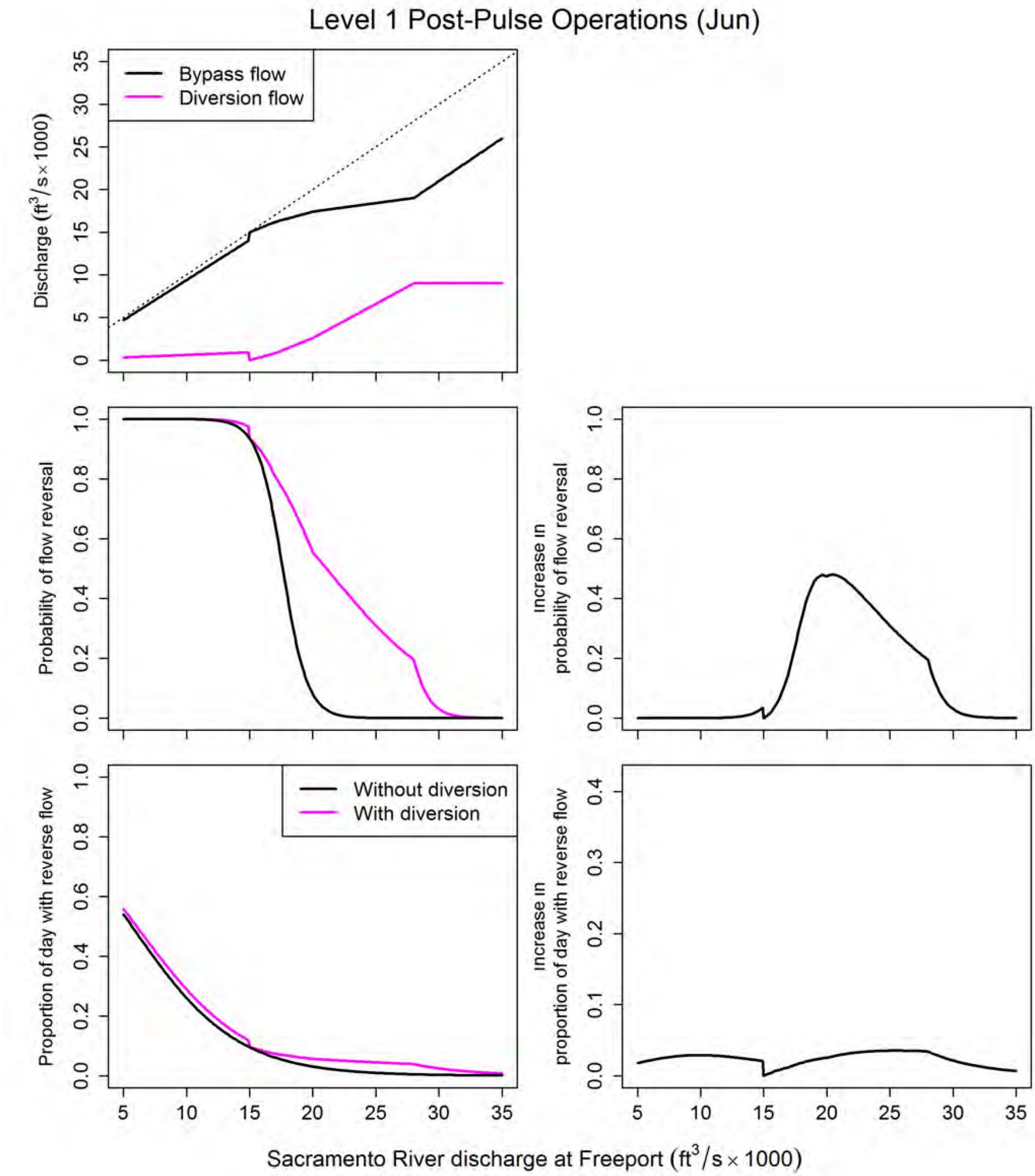

Figure 12. Graphs showing effect of North Delta Diversion (NDD) on bypass discharge (top graph), probability and increase in probability of flow reversal (middle graphs), and proportion of the day and increase in proportion of the day with reverse flow (bottom graphs) for Level 1 post-pulse operations in June as defined in the NDD bypass rules, at Freeport (U.S. Geological Survey streamgage 11447650) on the Sacramento River downstream of Georgiana Slough, northern California. In the top graph, the dotted line shows bypass discharge when diversion discharge is 0.

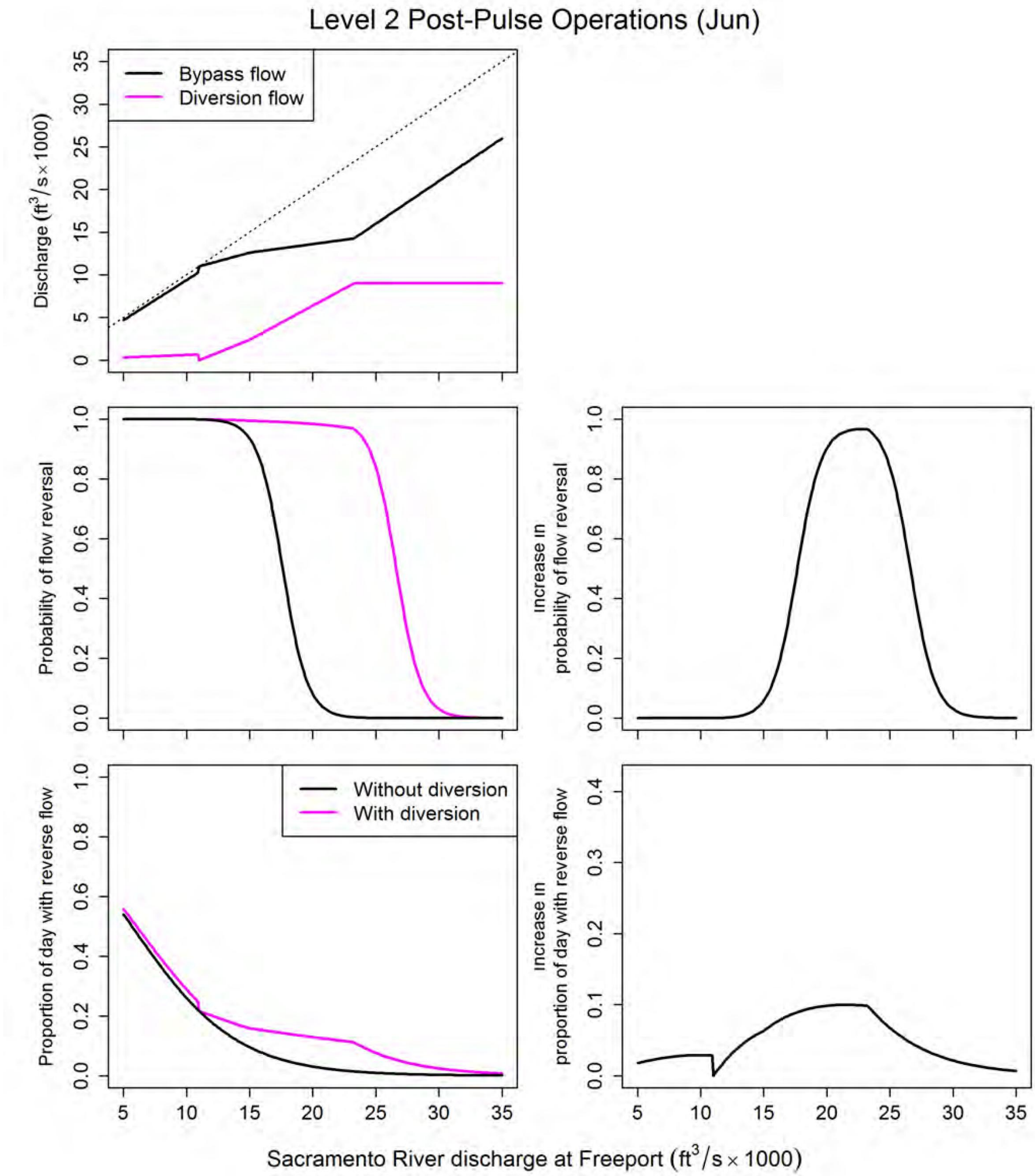

Figure 13. Graphs showing effect of North Delta Diversion (NDD) on bypass discharge (top graph), probability and increase in probability of flow reversal (middle graphs), and proportion of the day and increase in proportion of the day with reverse flow (bottom graphs) for Level 2 post-pulse operations in June as defined in the NDD bypass rules, at Freeport (U.S. Geological Survey streamgage 11447650) on the Sacramento River downstream of Georgiana Slough, northern California. In the top graph, the dotted line shows bypass discharge when diversion discharge is 0.

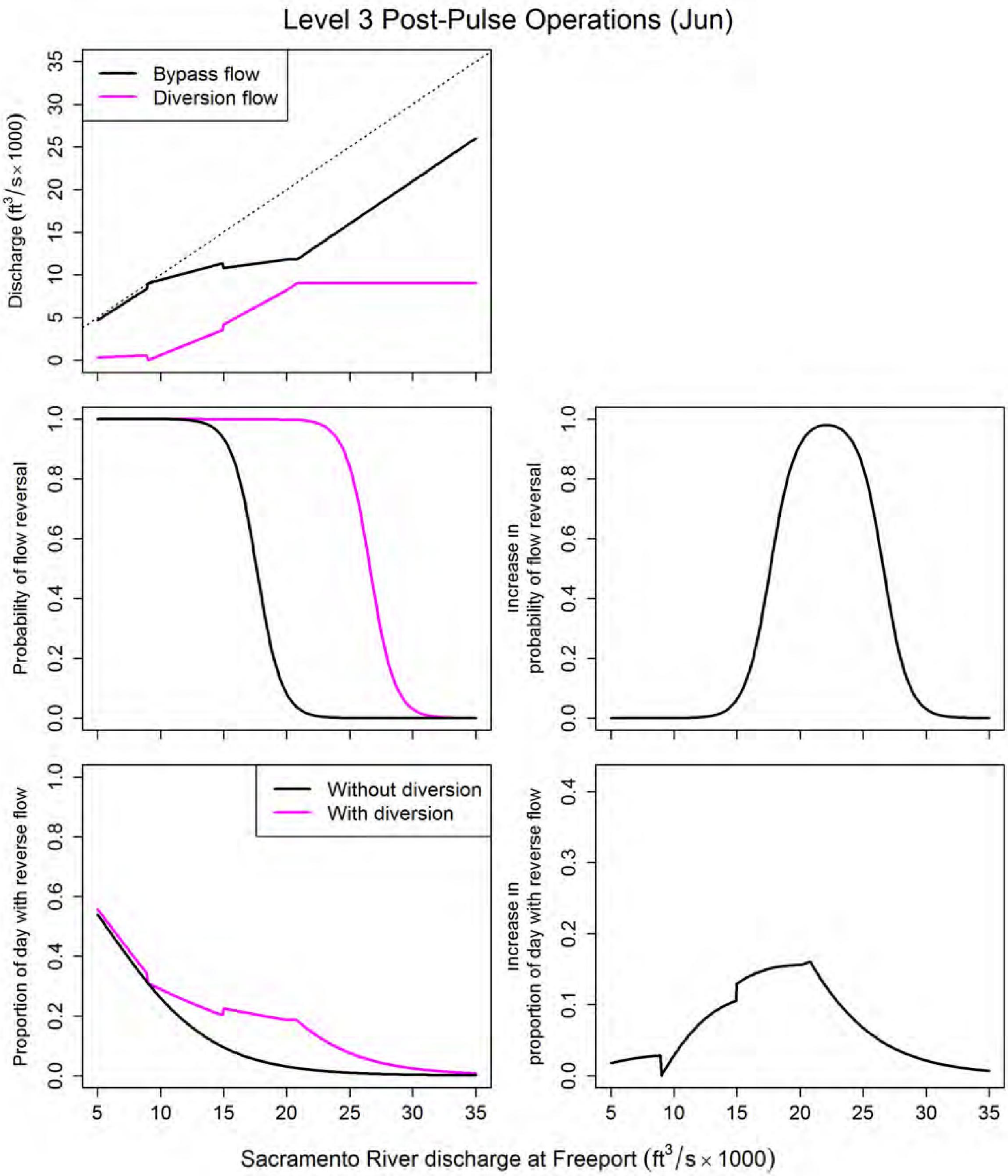

Figure 14. Graphs showing effect of North Delta Diversion (NDD) on bypass discharge (top graph), probability and increase in probability of flow reversal (middle graphs), and proportion of the day and increase in proportion of the day with reverse flow (bottom graphs) for Level 3 post-pulse operations in June as defined in the NDD bypass rules, at Freeport (U.S. Geological Survey streamgage 11447650) on the Sacramento River downstream of Georgiana Slough, northern California. In the top graph, the dotted line shows bypass discharge when diversion discharge is 0.

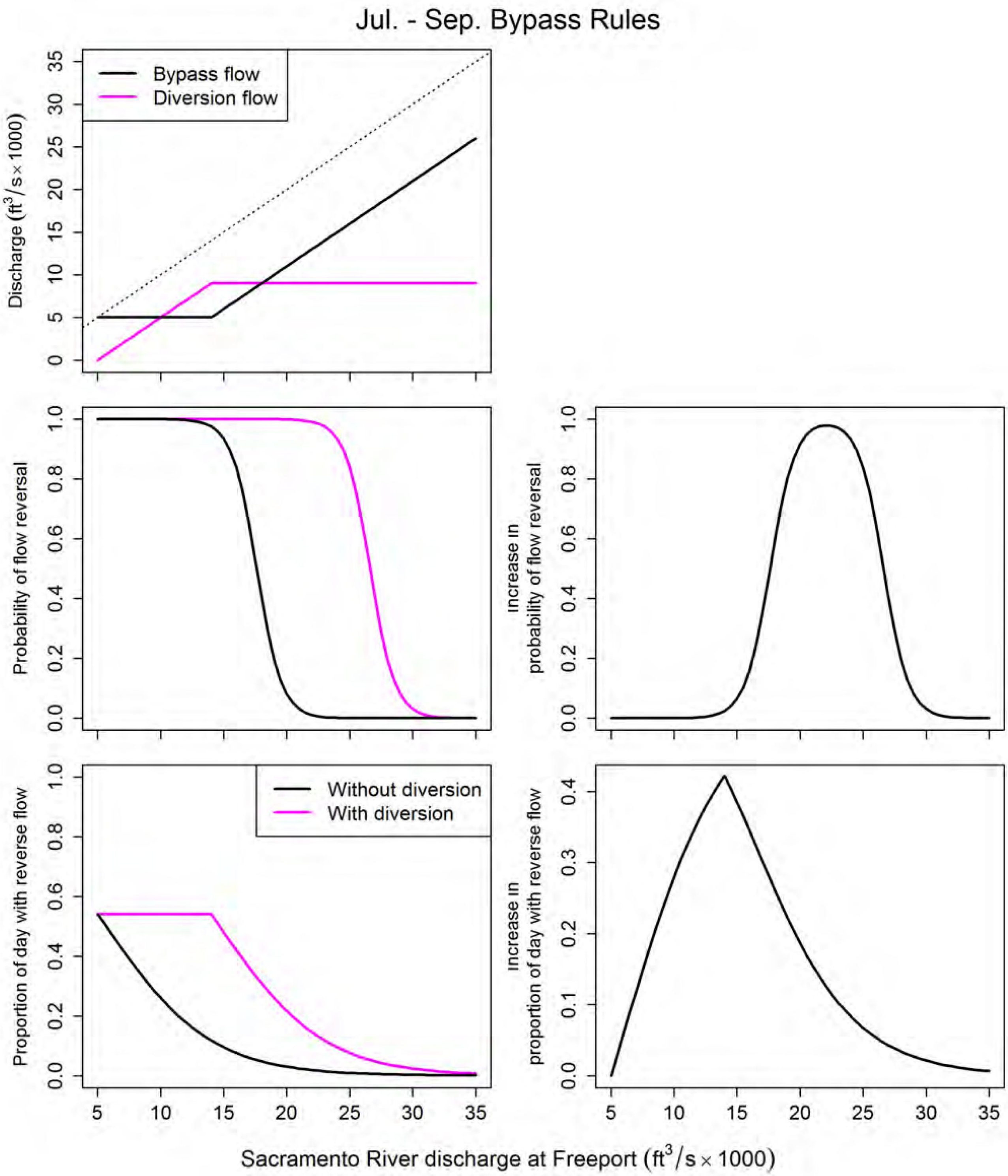

Figure 15. Graphs showing effect of North Delta Diversion (NDD) on bypass discharge (top graph), probability and increase in probability of flow reversal (middle graphs), and proportion of the day and increase in proportion of the day with reverse flow (bottom graphs) for July–September as defined in the NDD bypass rules, at Freeport (U.S. Geological Survey streamgage 11447650) on the Sacramento River downstream of Georgiana Slough, northern California. In the top graph, the dotted line shows bypass discharge when diversion discharge is 0.

Discussion

The NDD bypass rules are designed to allow for diversion of water from the Sacramento River while providing fish protection during peak migration periods into the Delta. Low-level pumping, which is initiated following flow pulses that have been shown to initiate migration of juvenile winter-run Chinook salmon (del Rosario and others, 2013), limits diversion to 10 percent of the maximum diversion capacity (9,000 ft^3/s). Under this criterion, we noted little increase in the proportion of day with reverse flow (fig. 3); therefore, we expect little increase in entrainment of juvenile salmon into Georgiana Slough. In contrast, we noted that the duration of flow reversal could be increased considerably during periods when juvenile salmon are likely to be migrating past Georgiana Slough. The conditions under which the P_{day}(reverse) can increase by greater than or equal to (≥) 10 percent between October and June include October–November bypass rules and level 3 post-pulse operations from December through June (see bottom right graphs in figs. 5, 8, 11, and 14).

We did our analysis under the assumption that the North Delta Diversion was operated at a constant rate for an entire day and followed the NDD bypass rules based on daily mean flows of the Sacramento River at Freeport. It generally is understood that the diversion would be operated “in real time” to prevent reverse flows at Georgiana Slough. However, a clear definition of control rules governing how the diversion would be operated to control flow reversals is required to evaluate the effect of “real time” operations on flow reversal. To our knowledge, such control rules have yet to be developed and evaluated using tools such as Delta Simulation Model 2 (DSM2). Therefore, our analysis evaluates the effect of the NDD bypass rules on flow reversals based on the how the rules were explicitly written according to readily available information on a daily basis (that is, Sacramento River flows at Freeport).

Although it is unclear how real-time operations would be implemented, the diversion could be operated on an hourly basis, in concert with the tides, to increase diversion during ebb tides but to restrict diversion during flood tides. Such operations likely would require detailed real-time predictions of tides and tidally varying river flow in order to account for variation in tidal cycles that affect the frequency, magnitude, and duration of reverse flows at a given Freeport discharge. The relationship between Sacramento River inflows with the probability of flow reversal and proportion of the day with reverse flow is driven by tidal cycles that vary on hourly and biweekly time scales. Spring and neap cycles cause variation in the strength of the tides, which drives variation in the mean river flows at which the Sacramento River reverses downstream of Georgiana Slough. For example, at a Freeport discharge of 7,500 ft^3/s, the proportion of the day with reverse flow ranges from about 0.12 to 0.35. Based on these considerations, if real-time operations are to be used to control flow reversals, we strongly encourage the development of explicit control rules for real-time management and testing of these controls through simulation models such as DSM2.

Corrections of Bias in Delta Simulation Model 2 Discharge Predictions at the Junction of the Sacramento River with the Delta Cross Channel and Georgiana Slough

Introduction

We used the fish entrainment model described in Perry and others (2015) to simulate the probability of fish entering Georgiana Slough and the Delta Cross Channel under the California WaterFix scenarios simulated by Delta Simulation Model 2 (DSM2), a one dimensional hydrodynamic simulation model of the Delta (http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/dsm2.cfm). Because the model of Perry and others (2015) used USGS streamgage flows in the Sacramento River and Georgiana Slough to predict routing of juvenile salmon, we evaluated how well DSM2 predicted USGS streamgage flows. The concern was that bias in DSM2 flow predictions would induce bias in the predicted routing probabilities.

We noted evidence of bias when DSM2 flow predictions at USGS streamgages at Georgiana Slough near Sacramento River (GEO; USGS streamgage 11447903) and Sacramento River below Georgiana Slough (WGB; USGS streamgage 11447905) were compared to the measured flow data. Therefore, we used measured discharge data collected at these sites from November 2006 to December 2011 to correct discharge values predicted by DSM2. Discharge over this time period ranged from -8,440 to 21,000 ft^3/s at WGB and -534 to 8,300 ft^3/s at GEO. This range of flows covers the range of flows included in the Perry and others (2015) routing model that we applied to flows simulated by DSM2. However, the upper end of this range corresponds inflows to the Delta of about 41,000 ft^3/s, as measured in the Sacramento River at Freeport, whereas inflows as simulated under the WaterFix scenarios extend to about 80,000 ft^3/s. Therefore, we apply the routing model to DSM2 simulations where flows were less than 41,000 ft^3/s.

Although DSM2 version 8.1.2 is the current release version, DSM2 simulations for the California WaterFix used DSM2 version 8.0.6 to maintain consistency with the simulations done under the Bay Delta Conservation Plan. Although not presented here, we determined that DSM2 version 8.1.2 showed less bias when used to predict discharge at these streamgages. By using measured flow data to correct DSM2 version 8.0.6 flow predictions, we minimized any potential bias in routing probabilities that would result from using biased flow predictions to predict routing probabilities.

Methods

We developed two multiple linear regression models to predict measured flow at GEO and WGB as a function of DSM2 flows at Sacramento River above Delta Cross Channel (WGA; USGS streamgage 114479890), DCC (Delta Cross Channel), GEO, and WGB. First, we ran DSM2 to simulate the historical conditions during the periods for which we had measured flow data (November 2006–December 2011; input files were obtained from http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2v6/dsm2.cfm). Next, two indicator variables were constructed from the DSM2 simulations—(1) an indicator variable (I_{WGB}) was used to provide the direction of flow at WGB (upstream flow=1, downstream flow=0) and (2), DCC_{gate} was used to indicate the status of the DCC gates (open=1, closed=0). Interactions between covariates also were included within the model. The model that resulted in the highest coefficient of determination (R^2) and that met all assumptions of linear regression (that is, homogeneity of residuals, low skew and kurtosis, etc.) was selected as the best-fit model. Lagged DSM2 flows were used to improve tidal phase shift. Alternative models were assessed to evaluate whether lagged flow variables improved model fit. Variables were lagged by 15-min time steps from 15 to 150 min.

Results

The best-fit model for the GEO streamgage included flow at all four streamgages (WGA, WGB, GEO, and DCC), lagged by two time steps or 30 min (table 2). The indicator variable I_{WGB} and DCC gate position parameter (DCCgate) were included in the final model as main effects. The final model also included two- and three-way interactions. Two-way interactions included the interactions between lagged flow at each streamgage and DCC gate operation (DCCgate) and the interactions between lagged flow at each streamgage and the flow indicator parameter I_{WGB}. The interaction between the indicator variable I_{WGB} and DCC gate position also was retained in the final model. Three-way interactions consisted of the interactions between lagged flow at each streamgage, DCC gate position, and the flow indicator variable I_{WGB}. The model fit the measured data reasonably well (fig. 16). Residuals between predicted and measured discharge at GEO were normally distributed and centered near 0. R^2 was 0.949.

The model for the WGB streamgage was similar to the model used to correct flows at GEO; however, flows were lagged by three time steps or 0.75 hour (that is, $Q_{GEO,3}$; table 3). Discharge from all streamgages, the flow indicator parameter, and the DCC_{gate} indicator were included as main effects in the model (table 3). Two- and three-way interactions also were included in the final model. Two-way interactions retained in the final model consisted of the interactions between flow at each streamgage and DCC gate position. The interaction between flow at WGA, WGB, and GEO, and the flow indicator variable I_{WGB} also was retained. The flow indicator variable that interacted with gate operations also was retained in the final model. Three-way interactions consisted of flow at WGA, WGB, and GEO that interacted with the DCC gate operations and the flow indicator parameter. The model provided a good fit to the data (R^2=0.962), and residuals between corrected flow and observed flow were normally distributed and had a mean of about 0 for all model fits (fig. 17).

Table 2. Parameter estimates for correction of flow at Georgiana Slough near Sacramento River (GEO; U.S. Geological Survey streamgage 11447903), northern California.

[Parameters were lagged by two time steps or 30 minutes. Second subscript in each parameter indicates the number of lag steps. Q, discharge; GEO, Georgiana Slough; WGB, Sacramento River below Georgiana Slough; WGA, Sacramento River above Walnut Grove; DCCgate, indicator variable for position of the Delta Cross Channel gate position (1 = open, 0 = closed); I, indicator variable for flow direction at WGB (1 = upstream, 0 = downstream)]

	Parameter	Estimate	Standard error
Main effects	(Intercept)	-81.800	4.616
	$Q_{GEO,2}$	0.568	0.009
	$Q_{WGB,2}$	-0.099	0.007
	$Q_{WGA,2}$	0.238	0.007
	$Q_{DCC,2}$	-0.152	0.010
	I_{WGB}	894.100	21.910
	DCCgate	219.600	8.072
Two-way interactions	$Q_{GEO,2} \times$ DCCgate	-0.731	0.016
	$Q_{WGB,2} \times$ DCCgate	-0.296	0.011
	$Q_{WGA,2} \times$ DCCgate	0.330	0.012
	$Q_{DCC,2} \times$ DCCgate	-0.195	0.014
	$I_{WGB} \times$ DCCgate	-483.200	24.150
	$Q_{GEO,2} \times I_{WGB}$	-0.148	0.026
	$Q_{WGB,2} \times I_{WGB}$	-0.050	0.020
	$Q_{WGA,2} \times I_{WGB}$	-0.015	0.022
	$Q_{DCC,2} \times I_{WGB}$	-0.111	0.024
Three-way interactions	$Q_{GEO,2} \times I_{WGB}$ * DCCgate	0.220	0.032
	$Q_{WGB,2} \times I_{WGB}$ * DCCgate	0.203	0.023
	$Q_{WGA,2} \times I_{WGB}$ * DCCgate	-0.209	0.025
	$Q_{DCC,2} \times I_{WGB}$ * DCCgate	0.333	0.027

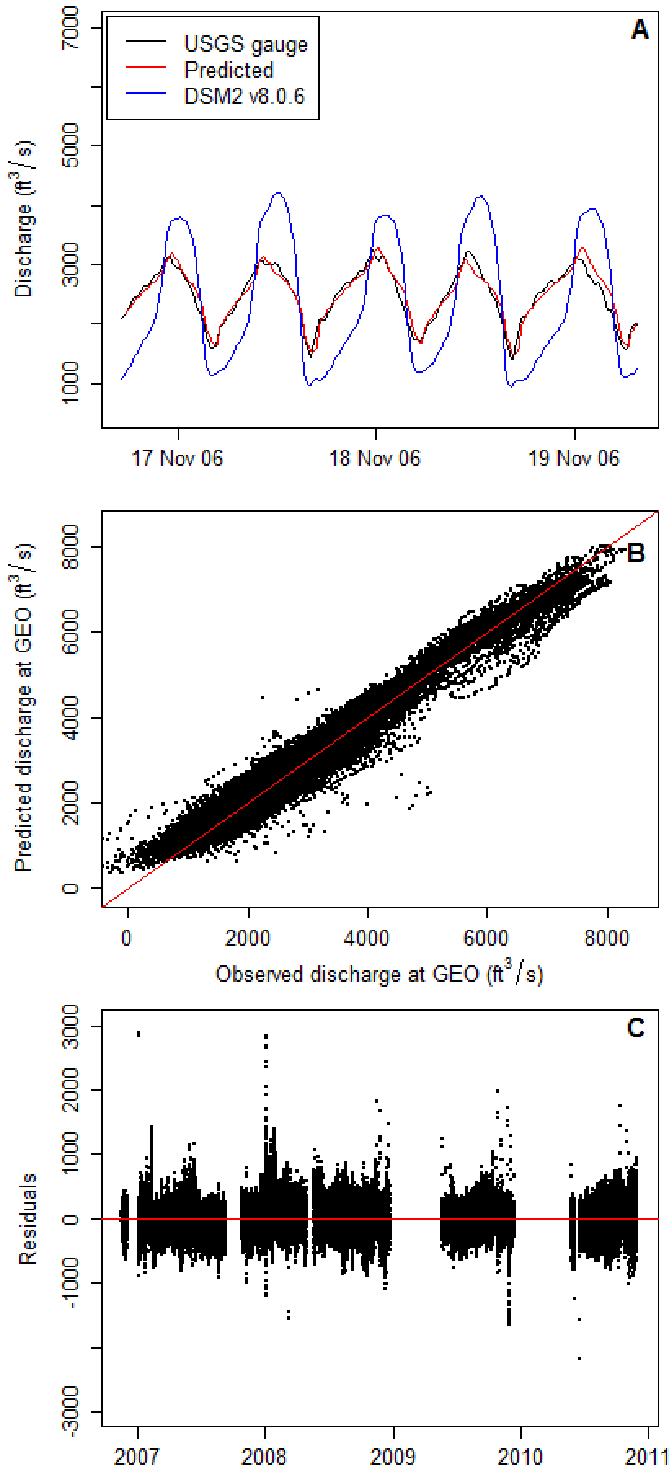

Figure 16. Graphs showing (A) comparison of observed (i.e., measured) (Delta Simulation Model 2, version 8.0.6 [DSM2 v8.0.6]) and regression-corrected (predicted) discharge, during November 17–19, 2006; (B) comparison of observed and predicted discharge; and (C) residuals of predicted and observed discharge during 2007–11, at the Georgiana Slough near Sacramento River (GEO; U.S. Geological Survey [USGS] streamgage 11447903), northern California. Diagonal red line in graph (B) shows where observed discharge equals predicted discharge. The horizontal red line in graph (C) shows where residuals are zero. ft³/s, cubic foot per second.

Table 3. Parameter estimates for correcting Delta Simulation Model 2, version 8.0.6, predicted flow at Sacramento River below Georgiana Slough (WGB; U.S. Geological Survey streamgage 11447905), northern California.

[Parameters were lagged by three time steps or 0.75 hour. Second subscript in each parameter indicates the number of lag steps. Q, discharge; GEO, Georgiana Slough; WGB, Sacramento River below Walnut Grove; WGA, Sacramento River above Walnut Grove; DCCgate, indicator variable for position of the Delta Cross Channel gate position (1 = open, 0 = closed); I, indicator variable for flow direction at WGB (1 = upstream, 0 = downstream)]

	Parameter	Estimate	Standard error
Main effects	(Intercept)	-2317	22
	$Q_{GEO,3}$	2.326	0.039
	$Q_{WGB,3}$	2.173	0.030
	$Q_{WGA,3}$	-1.283	0.033
	$I_{WGB,3}$	1392	87
	DCCgate,3	722	38
	$Q_{DCC,3}$	1.447	0.042
Two-way interactions	$Q_{GEO,3}$ × DCCgate,3	0.678	0.065
	$Q_{WGB,3}$ × DCCgate,3	1.002	0.042
	$Q_{WGA,3}$ × DCCgate,3	-1.055	0.045
	I_{WGB} × DCCgate,3	-394	99
	$Q_{GEO,3}$ × $I_{WGB,3}$	-0.314	0.052
	$Q_{WGB,3}$ × $I_{WGB,3}$	0.017	0.038
	$Q_{WGA,3}$ × $I_{WGB,3}$	-0.349	0.041
	$Q_{DCC,3}$ × DCCgate,3	1.219	0.051
Three-way interactions	$Q_{GEO,3}$ × I_{WGB}*DCCgate,3	-0.491	0.082
	$Q_{WGB,3}$ × I_{WGB}*DCCgate,3	-0.263	0.042
	$Q_{WGA,3}$ × I_{WGB}*DCCgate,3	0.256	0.045

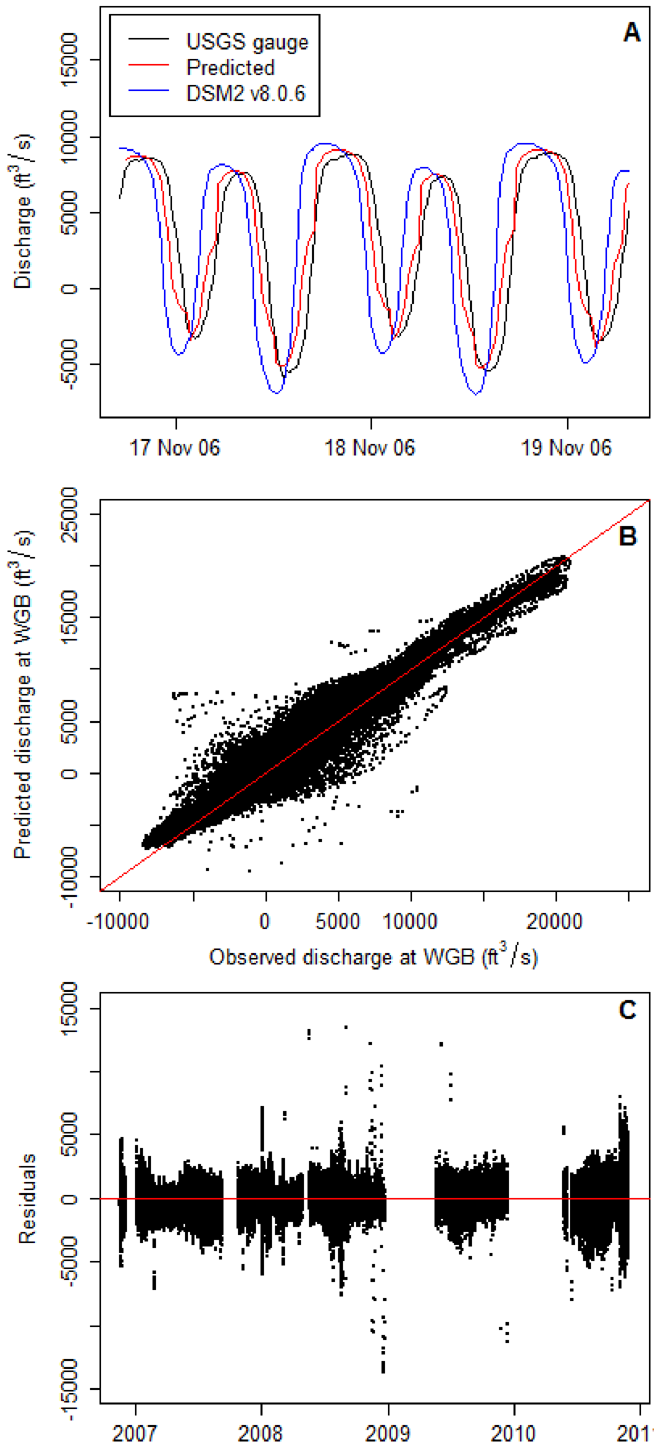

Figure 17. Graphs showing (A) comparison of observed (Delta Simulation Model 2, version 8.0.6 [DSM2 v8.0.6], and regression-corrected (predicted) discharge, during November 17–19, 2006; (B) comparison of observed and predicted discharge; and (C) residuals of the predicted and measured discharge during 2007–11, at the Sacramento River below Georgiana Slough (WGB; U.S. Geological Survey streamgage 11447905), northern California. Diagonal line in graph (B) has slope of 1 and an intercept of 0. Diagonal red line in graph (B) shows where observed discharge equals predicted discharge. The horizontal red line in graph (C) shows where residuals are zero. ft³/s, cubic foot per second ft³/s, cubic foot per second.

Discussion

We used lagged flow variables in conjunction with indicator variables to create models to adjust DSM2 predicted flows at both GEO and WGB. Our models provide a good adjustment for correcting the DSM2 output; however, the predictive power of our model is limited to the range of flows used for the correction. Empirical data were only available for 2006–11. Therefore, one should use caution in applying the model to predict flows outside of range of flows used in the model development.

Lags in the model covariates improved model fits, suggesting that DSM2 version 8.0.6 does not adequately predict tidal phasing at this location. Given the time lags, it seems that DSM2 is predicting water pulses to arrive later than measured at WGB and earlier than measured at GEO. Additionally, DSM2 routinely overestimated the magnitude of flow at WGB. In contrast, DSM2 accurately estimated the magnitude of flow at GEO. This suggests that the complex hydrodynamics at this junction are not fully captured by DSM2.

Simulation of Effects of the North Delta Diversion on Daily Entrainment Probability of Juvenile Chinook Salmon into Georgiana Slough and the Delta Cross Channel

Introduction

This analysis investigates the effect of the proposed North Delta Diversion (NDD) on entrainment of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) into Georgiana Slough and the Delta Cross Channel (DCC). Specifically, we used the entrainment probability model of Perry and others (2015) to predict entrainment probabilities from flows simulated by Delta Simulation Model 2 (DSM2) under the California WaterFix No Action Alternative (NAA, no diversion implemented) and Proposed Action (PA, diversion implemented) from October to June for each water year[1]in the 82-year simulation period (ICF International, 2016). The entrainment model is based on a multinomial regression analysis that estimated the probability (π) of individual fish entering the DCC (π_{DCC}), Georgiana Slough (π_{GEO}), and the Sacramento River (π_{SAC}) from three variables: (1) Instantaneous river discharge (that is, measured every 15 min) entering Georgiana Slough (GEO), (2) instantaneous discharge of the Sacramento River below Georgiana Slough (WGB), and (3) DCC gate position (1 = open, 0 = closed). The entrainment model was based on acoustic telemetry data collected between 2006 and 2009 from 919 juvenile late-fall Chinook salmon that passed the river junction over river flows of the Sacramento River at Freeport ranging from 6,802 ft^3/s to 40,700 ft^3/s. A complete description of the model, including model equations, estimated parameters, and goodness-of-fit, is available in Perry and others (2015) and Perry (2010).

Methods

To apply the entrainment model of Perry and others (2015) to DSM2 output, we (1) corrected DSM2 discharge simulations at WGB and GEO using the regression correction described in the previous section, (2) formed covariates required for the entrainment model from the corrected DSM2 discharge simulations, and (3) simulated route entrainment probabilities for the entire 82-year time series of 15-min flows simulated under the NAA and PA scenarios. We then tabulated daily entrainment probabilities as the mean of 15-min entrainment probabilities for each day. Daily entrainment probabilities represent the expected fraction of fish entering each channel on a particular date under the assumption that fish migrate past this river junction uniformly over the diel period. Although nocturnal migration has been documented for late-fall run Chinook salmon (Chapman and other, 2013), we used a uniform distribution because diel activity patterns can vary considerably with environmental variables and species (Bradford and others, 2001). As a sensitivity analysis, we compared differences between scenarios for day and night entrainment (appendix 1, figs. 1.1 and 1.2).

[1]The 12-month period from October 1, for any given year, through September 30, of the following year. The water year is designated by the calendar year in which it ends.

The entrainment model was based on data collected at a maximum Freeport discharge of 40,700 ft^3/s, whereas the DSM2 simulations include Freeport flows of as much as about 80,000 ft^3/s. Therefore, we evaluated the behavior of the model at flows greater than 40,000 ft^3/s because we were concerned about using the entrainment model outside the range of data used to inform the model. Simulated daily entrainment probabilities based on DSM2 output increased from about 0.35 to 0.50 as Freeport discharge increased from about 40,000 ft^3/s to 80,000 ft^3/s (fig. 18). We compared these predictions to estimates from Perry and others (2014), who quantified the effect of a non-physical barrier on entrainment into Georgiana Slough when Freeport flows were about 80,000 ft^3/s. At this flow level, Perry and others (2014) estimated a mean entrainment probability into Georgiana Slough of about 0.30 with the non-physical barrier off, compared to 0.50 simulated using the Perry and others (2015) model. This finding suggests that entrainment probabilities remain relatively constant at flows between 40,000 ft^3/s and 80,000 ft^3/s rather than increasing as the model of Perry and others (2015) would predict. Because the Perry and others (2015) model seems to overestimate entrainment at high flows, we restricted our analysis of simulated daily entrainment probabilities to flows at Freeport of 41,000 ft^3/s or greater.

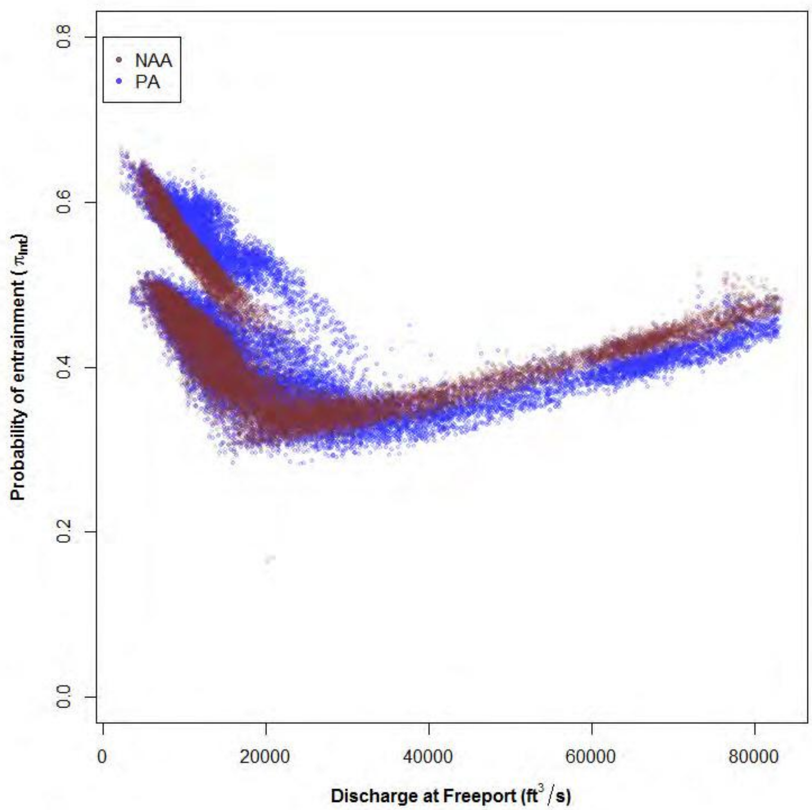

Figure 18. Graph showing daily probability of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) entering the interior Sacramento-San Joaquin River Delta ($\pi_{Int} = \pi_{GEO} + \pi_{DCC}$) as a function of Sacramento River discharge at Freeport (FPT; USGS streamgage 11447650) for the No Action Alternative (NAA) and Proposed Action (PA) simulations done using Delta Simulation Model 2, northern California. π_{Int}, probability of juvenile Chinook salmon entering the interior Delta; π_{GEO}, probability of juvenile Chinook salmon entering Georgiana Slough]; π_{DCC}, probability of juvenile Chinook salmon entering Sacramento River.

Ideally, if daily inflows to the Delta were the same between NAA and PA scenarios, then daily entrainment probabilities could be compared directly among common dates using different management alternatives between scenarios. However, daily inflows to the Delta vary between scenarios owing to upstream flow management that differs between scenarios, making direct comparison of daily entrainment probabilities problematic. Therefore, we compared scenarios by summarizing daily entrainment probabilities within each year by averaging daily entrainment probabilities over (1) each year, (2) each month within years, and (3) over three alternative run-timing distributions. Summary statistics included days when Freeport flows were less than or equal to 41,000 ft^3/s and excluded days when flows were >41,000 ft^3/s. The three run-timing scenarios were (1) a uniform distribution, where an equal proportion of fish out-migrated on each day of each month; (2) an early-run timing representing winter-run Chinook in years when flow conditions trigger an early migration into the Delta, and (3) a late-run timing representing winter-run Chinook in years when the migration begins in December (fig. 19). Estimates of annual entrainment probability for the different run timings were calculated as a weighted average of the daily entrainment probability weighted by the proportion of the run migrating on a given day (assuming an equal migration on each day of a given month). Run-timing distributions were based on winter-run-sized juvenile Chinook rotary screw trapping data from Knights Landing (Yvette Redler, National Marine Fisheries Service, written commun., January 7, 2016). We then categorized these annual statistics according to California Department of Water Resources water-year classification and compared box plots of annual entrainment probabilities for different water year types. California Department of Water Resources uses five classifications for water year type in the Sacramento Valley that are based on water year index value (WYI) in millions of acre-feet (MAF):

1. W=Wet, WYI ≥ 9.2;
2. AN=Above Normal, 7.8 ≤ WYI ≤ 9.2;
3. BN=Below Normal, 6.5≤ WYI ≤7.8;
4. D=Dry, 5.4≤ WYI ≤6.5; and
5. C=Critical, WYI ≤ 5.4 (Kapahi and others, 2006).

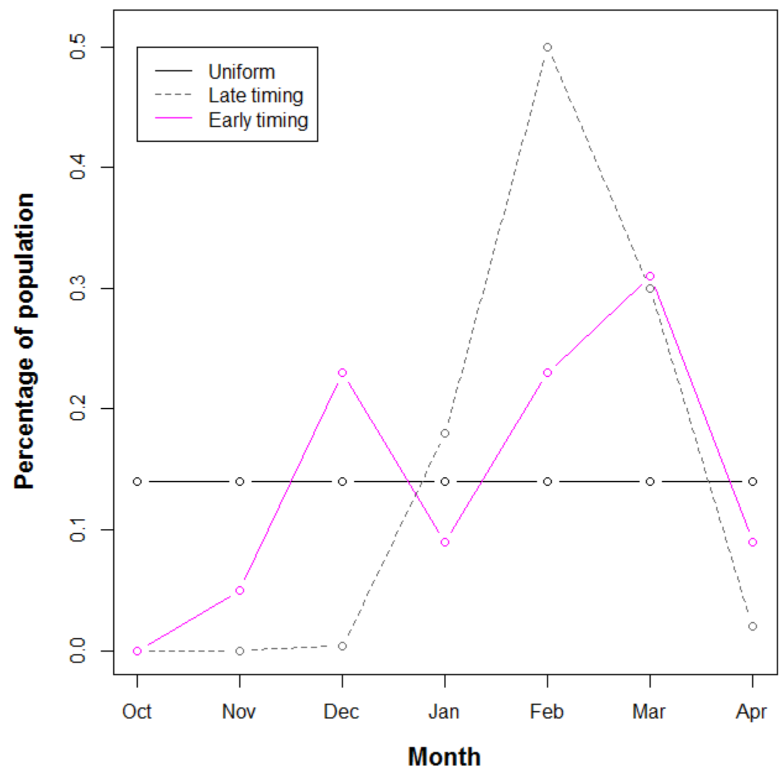

Figure 19. Graph showing run-timing scenarios used to estimate mean annual entrainment probabilities, with the early and late timings representing two scenarios for winter-run Chinook salmon in the Sacramento River, northern California, October–April.

Results

We estimated entrainment probabilities for NAA and PA under three run-timing distributions over an 82-year period. The mean annual entrainment probabilities generally differed little between NAA and PA (table 4); however, we noted small but consistent differences in entrainment between scenarios that varied across years (figs. 20–23). For example, under uniform run timing, the annual probability of fish remaining in the Sacramento River for the PA scenario was 0–4 percent lower than under the NAA scenario, indicating higher entrainment into the interior Delta (fig. 20). Mean annual entrainment into the DCC was consistently higher under the PA scenario, but differences in mean annual entrainment into Georgiana Slough indicated both positive and negative deviations (fig. 20). These findings indicate that the increased entrainment into the DCC was largely responsible for the lower probability of fish remaining in the Sacramento River.

Table 4. Mean predicted annual entrainment probabilities (with standard deviations in parentheses) under different run-timing scenarios for No Action Alternative (NAA) and Proposed Action (PA) simulations done using Delta Simulation Model 2, Sacramento-San Joaquin River Delta, northern California.

Run-timing scenarios	Sacramento River		Georgiana Slough		Delta Cross Channel	
	NAA	PA	NAA	PA	NAA	PA
Uniform	0.571 (0.031)	0.556 (0.028)	0.349 (0.017)	0.346 (0.017)	0.072 (0.03)	0.089 (0.024)
Late	0.555 (0.132)	0.547 (0.129)	0.344 (0.09)	0.352 (0.094)	0 (0)	0 (0)
Early	0.558 (0.085)	0.549 (0.082)	0.346 (0.061)	0.352 (0.063)	0.018 (0.018)	0.021 (0.018)

The differences in entrainment between PA and NAA under the early run timing indicated a slightly higher (by about 1 percentage point) mean annual probability of entering the DCC (fig. 21). However, for the late run timing, we noted little difference in entrainment between the NAA and PA scenarios, and the proportion entrained into the DCC was very low because of little overlap between the late run timing and DCC operation (fig. 21). The differences in annual entrainment among the run timing scenarios suggested that daily entrainment probabilities varied seasonally, thereby affecting annual entrainment differentially for the alternative run timings.

Examination of the distribution of mean monthly entrainment probabilities indicated seasonal patterns that varied among water year types (fig. 22). In all but critically dry years, median π_{SAC} (the probability of fish remaining in the Sacramento River) under the PA scenario was as much as 5 percentage points lower than under the NAA scenario for October and November (fig. 22). This difference also was apparent for June in wet years. Because the early and late run timings had 0 probability of migrating in October and low (early) or 0 (late) probability of migrating in November, these run-timing distributions had little exposure to the differences in operation between PA and NAA during these months, leading to little difference in mean annual entrainment probabilities (figs. 20 and 21).

For the months of October, November, and June, fish had a lower probability of remaining in the Sacramento River owing primarily to a higher probability of entering the DCC. This occurred because the DCC gates were open more frequently in October and November (fig. 23), which contributed to the higher mean monthly probability of entering the DCC. For example, we identified days when the DCC was open under PA but closed under NAA (fig. 24). Under NAA, the DCC remained closed owing to NDD Bypass flows >25,000 ft^3/s, a trigger that causes closure of the DCC in order to limit the potential for flooding and scour at the facility (fig. 24G). However, under PA, water diversion reduced bypass flows to less than 25,000 ft^3/s, which allowed the DCC gates to remain open (fig. 24). In turn, opening the DCC gates substantially reduced the instantaneous probability of fish remaining in the Sacramento River by increasing the probability of fish entering the DCC (fig. 24).

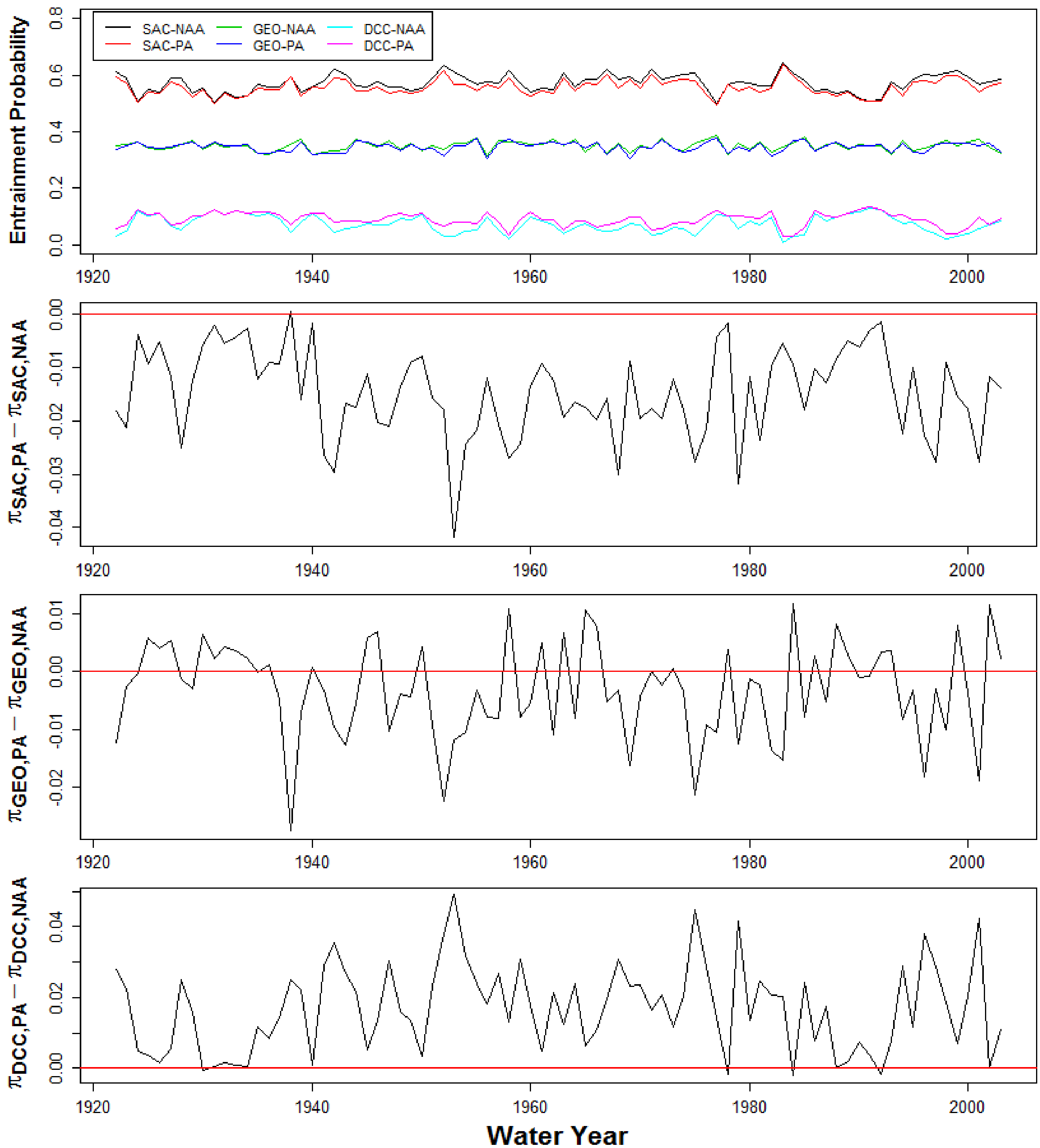

Figure 20. Graphs showing comparison of predicted mean annual juvenile Chinook salmon entrainment probability (π) assuming uniform run timing for the Sacramento River (SAC), Georgiana Slough (GEO), and Delta Cross Channel (DCC) between the Proposed Action (PA) and No Action Alternative (NAA), Sacramento-San Joaquin River Delta, northern California, water years 1922–2003. Mean annual entrainment probabilities (top graph) and the difference in entrainment between scenarios for SAC, GEO, and DCC (bottom three graphs, respectively) are shown. Values above horizontal red line indicate greater entrainment under the PA scenario.

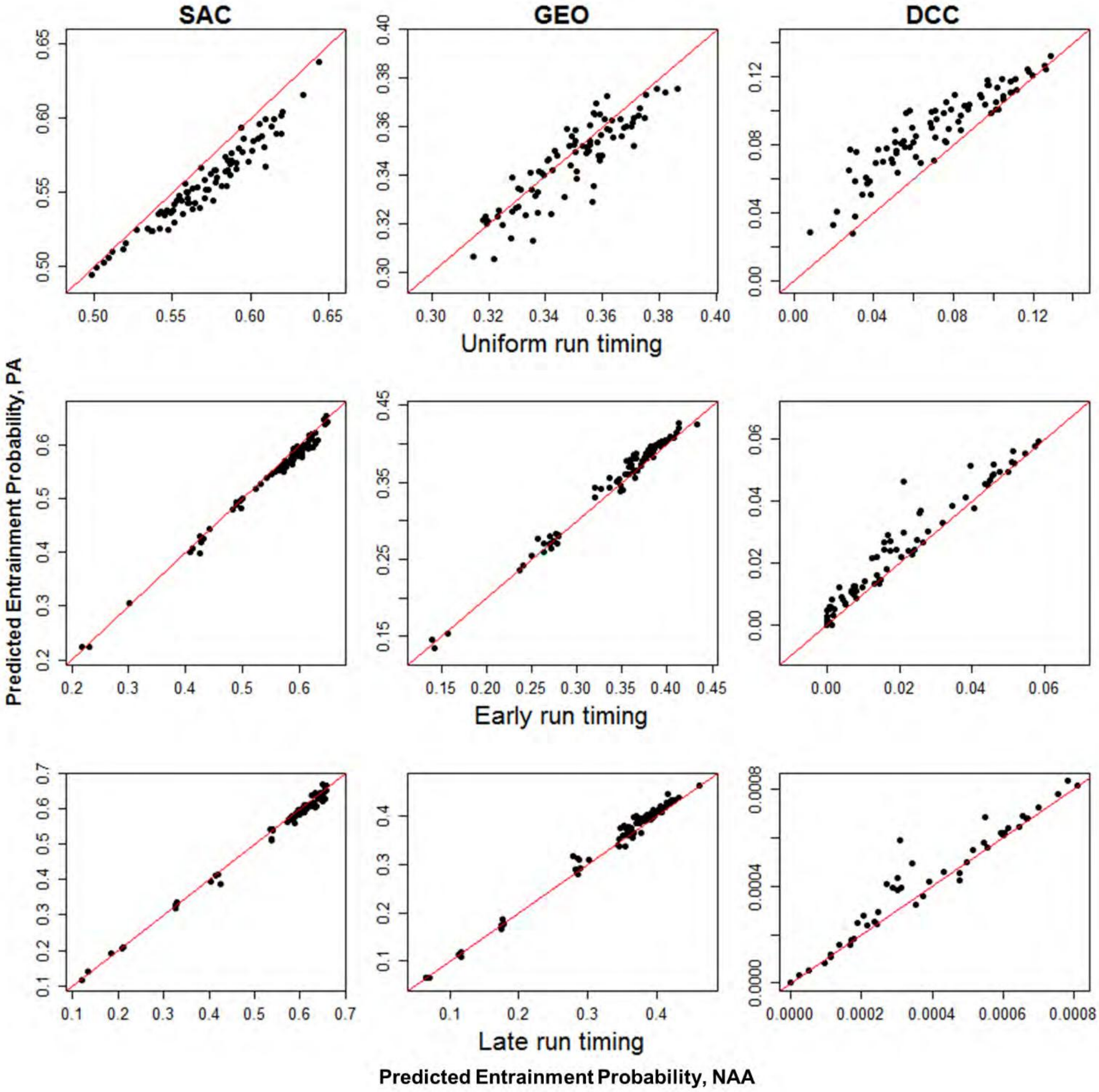

Figure 21. Graphs showing comparison of predicted mean entrainment probability for the Sacramento River (SAC), Georgiana Slough (GEO), and Delta Cross Channel (DCC) between the Proposed Action (PA) and No Action Alternative (NAA) for uniform arrival and two different run timings for winter-run Chinook salmon, Sacramento-San Joaquin River Delta, northern California. Data points (black dots) are paired by year, and diagonal line has slope of 1 and an intercept of 0.

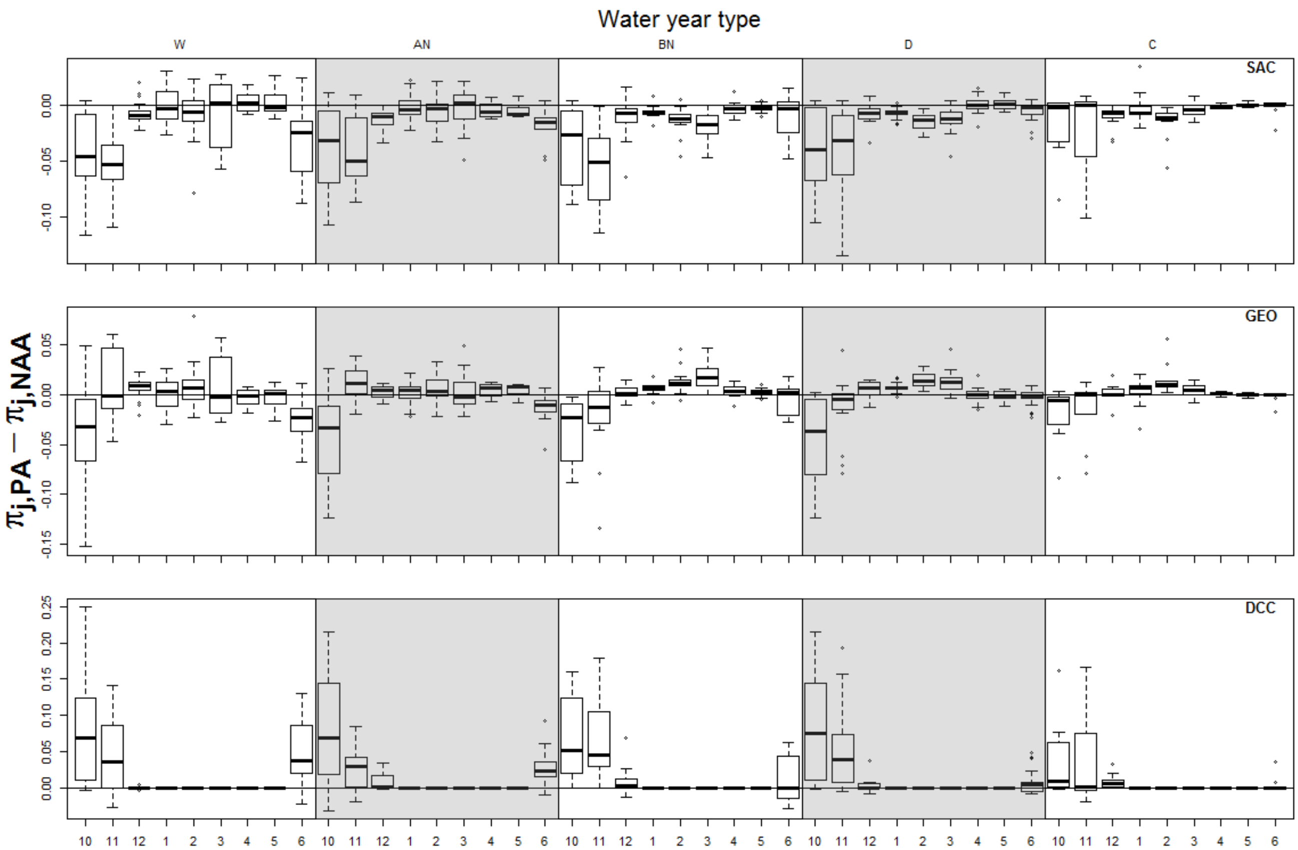

Figure 22. Boxplots showing differences in predicted juvenile Chinook salmon entrainment probability between the Proposed Action (PA) and No Action Alternative (NAA) (π_j, PA-π_j, NAA) by water year type and month assuming a uniform run timing (W=Wet, AN=Above Normal, BN=Below Normal, D=Dry, C=Critical), Sacramento-San Joaquin River Delta, northern California, October–June (x-axis labels showing month of year). Boxes range from the 25th to the 75th percentiles with a line indicating the median, whiskers extend 1.5 times past the length of the box, and dots represent data points beyond the whiskers.

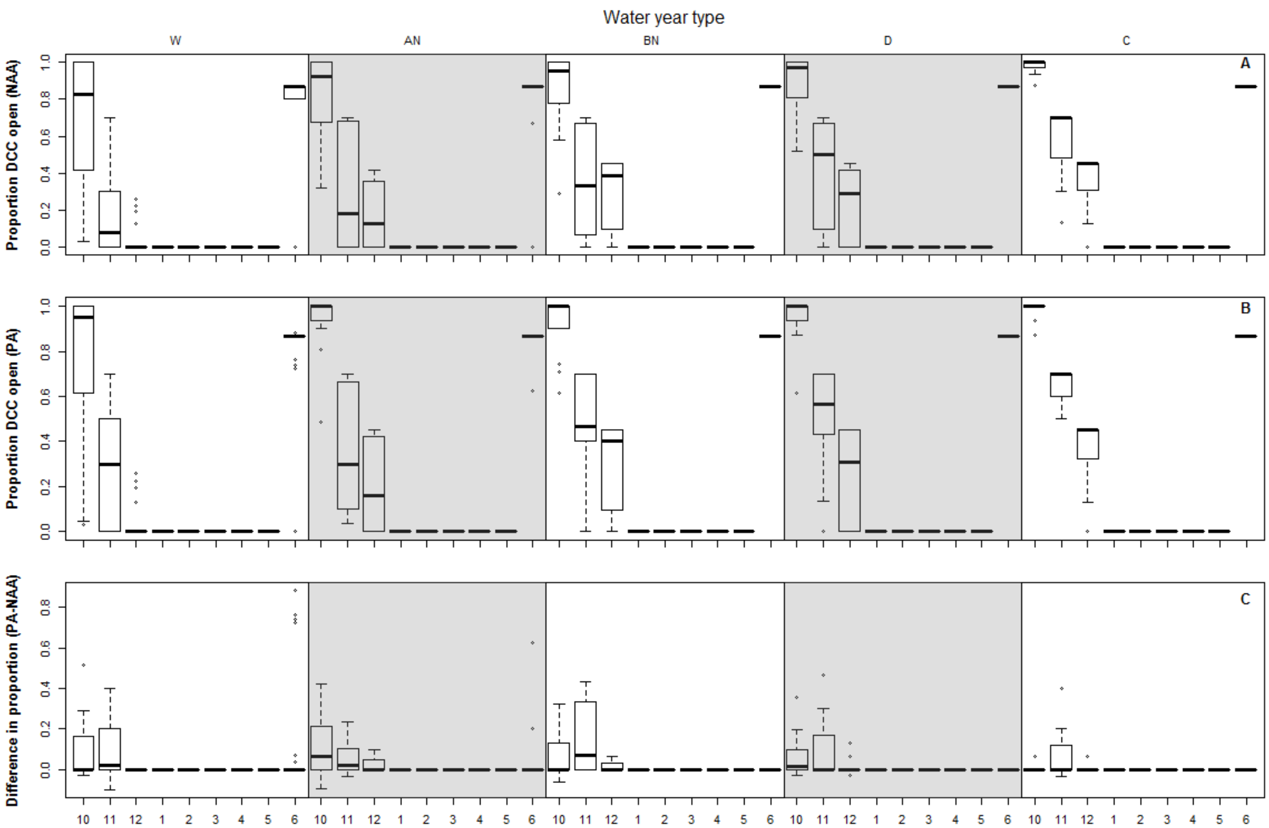

Figure 23. Boxplots showing proportion of each month that the Delta Cross Channel (DCC) was open for the No Action Alternative (NAA, boxplots in panel A), Proposed Action (PA, boxplots in panel B), and the difference between PA and NAA (boxplots in panel C) by water year type (W=Wet, AN=Above Normal, BN=Below Normal, D=Dry, C=Critical), Sacramento-San Joaquin River Delta, northern California. Boxes range from the 25th to the 75th percentiles with a line indicating the median, whiskers extend 1.5 times past the length of the box, and dots represent data points beyond the whiskers.

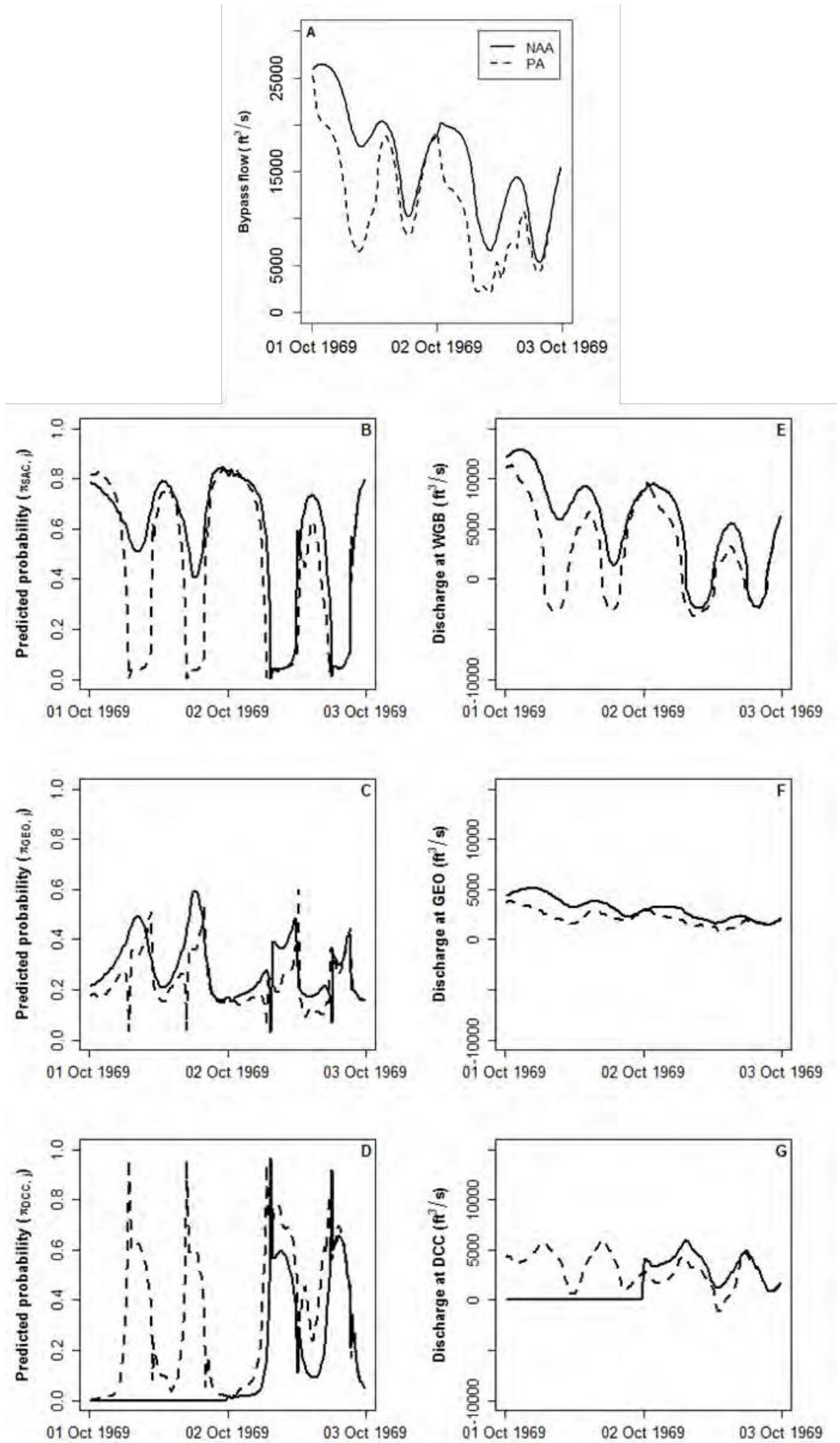

Figure 24. Graphs showing comparison of bypass flows (A) and predicted probability of juvenile Chinook salmon entrainment (π) into Sacramento River (WGB) (B), Georgiana Slough (GEO) (C), and the Delta Cross Channel (DCC) (D) for the Proposed Action (PA) and No Action Alternative (NAA) when the DCC was open under PA but closed under NAA, Sacramento-San Joaquin River Delta, northern California, October 1–3, 1969. Discharges (in cubic feet per second [f^3/s]) entering each route for NAA and PA also are shown graphs E, F, and G.

We determined that much of the interannual variation in mean annual entrainment probabilities could be attributed to water year classification. For example, mean annual π_{SAC} for the uniform run timing decreased from a median of about 0.60 to 0.52 as water year type transitioned from wet to critically dry years (fig. 25). In contrast, mean annual π_{GEO} and π_{DCC} increased as water years transitioned from wet to critically dry (fig. 25). Between scenarios, π_{SAC} under PA was less than under the NAA scenario for all water year types for a uniform run timing (fig. 26). For the early and late run timings, we observed little difference between PA and NAA for π_{SAC} for wet and above normal water years, but π_{SAC} was consistently lower than the other locations for PA relative to NAA (fig. 26). Although we noted some consistent differences between PA and NAA among water year types, the median difference between scenarios was <2 percentage points for all mean annual entrainment probabilities.

Discussion

We used previously developed entrainment models to predict the probability of fish entrainment into the interior Delta through Georgiana Slough and the DCC under the PA and NAA scenarios for different run timings and water year types. Overall, the probability of remaining in the Sacramento River was lower under the PA scenario, but the magnitude of the difference was small. However, when run timing was assumed to occur between December and April, this difference was even less because fish were less exposed to periods when we observed the largest difference in entrainment between scenarios (October and November).

Although we observed relatively small differences in entrainment, we restricted our analysis to flows <41,000 ft^3/s to avoid potential bias in predicted entrainment probabilities at higher flows. When the entrainment model of Perry and others (2015) was used to predict entrainment at higher flows, the model predicted that entrainment increased with increasing river flow to as much as about 50-percent entrainment at flows of 80,000 ft^3/s at Freeport (fig. 18). However, comparison to estimates of entrainment from Perry and others (2014) at similar flows indicated entrainment into Georgiana Slough of only about 30 percent. The entrainment model was fit to data that encompassed the range of flows where the Sacramento River transitions from strongly reversing to non-reversing flows. Thus, the parameterization of the model captured changes in entrainment owing to the strength of reversing flows, and indicated that highest entrainment occurred at the lowest flows where tidal forcing increased the magnitude and duration of reverse flows. The available empirical evidence suggests that entrainment stabilizes as inflows increase above the level at which reverse flows cease, but more data is needed to substantiate this observation. Assuming that this pattern holds true, excluding the high-flow observations from our analysis would tend to weight the mean annual entrainment probabilities more towards the higher daily entrainment probabilities that occur at lower discharges. Therefore, we may have observed even less difference in mean annual entrainment probabilities between PA and NAA had we used a model that predicted that daily entrainment probabilities are relatively constant at flows >41,000 ft^3/s.

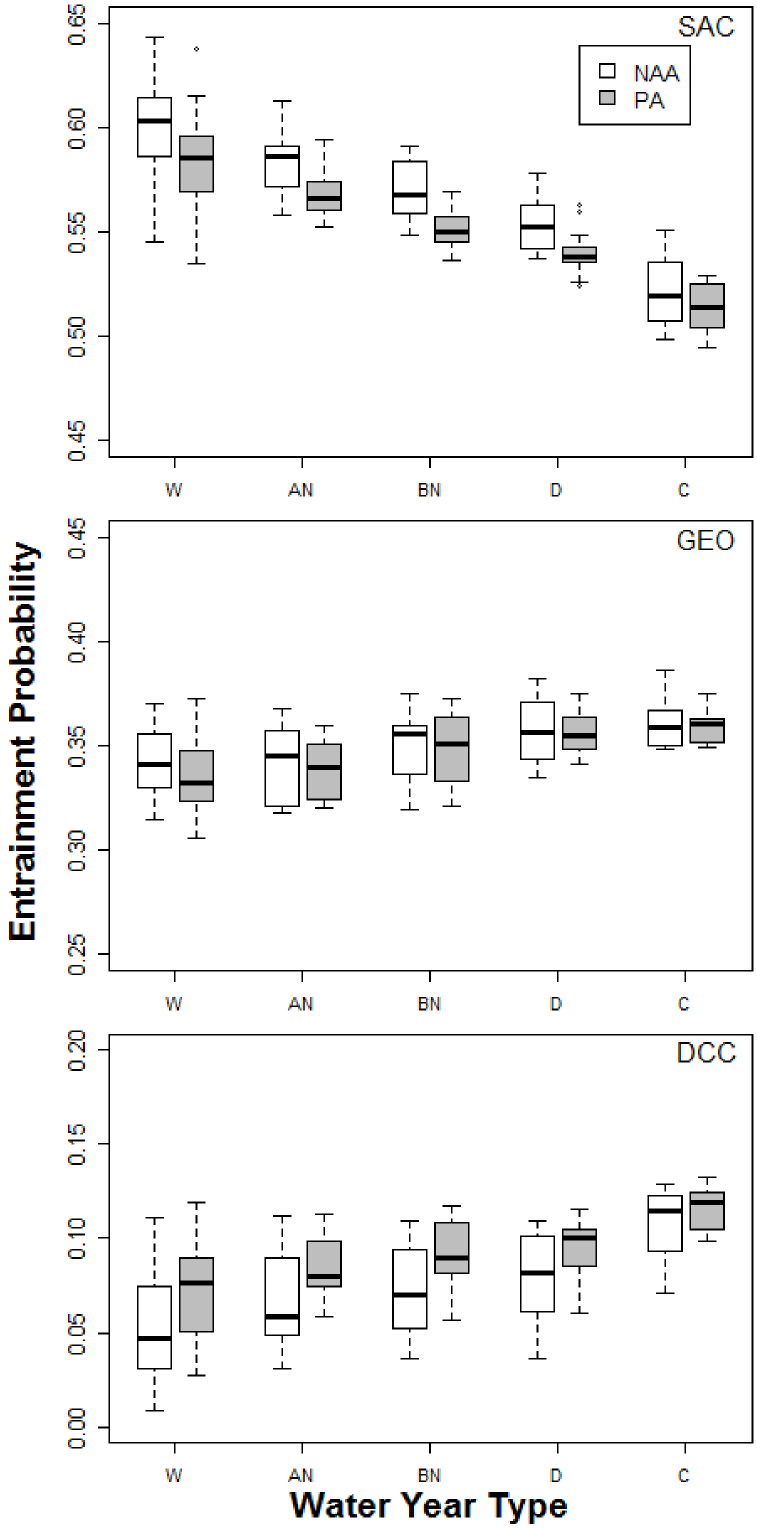

Figure 25. Boxplots showing predicted mean annual probability of juvenile Chinook salmon entrainment for the Sacramento River (SAC), Georgiana Slough (GEO), and Delta Cross Channel (DCC) between the No Action Alternative (NAA) and Proposed Action (PA) by water year type based on a uniform run-timing distribution (W=Wet, AN=Above Normal, BN=Below Normal, D=Dry, C=Critical), Sacramento-San Joaquin River Delta, northern California. Boxes range from the 25th to the 75th percentiles with a line indicating the median, whiskers extend 1.5 times past the length of the box, and dots represent data points beyond the whiskers.

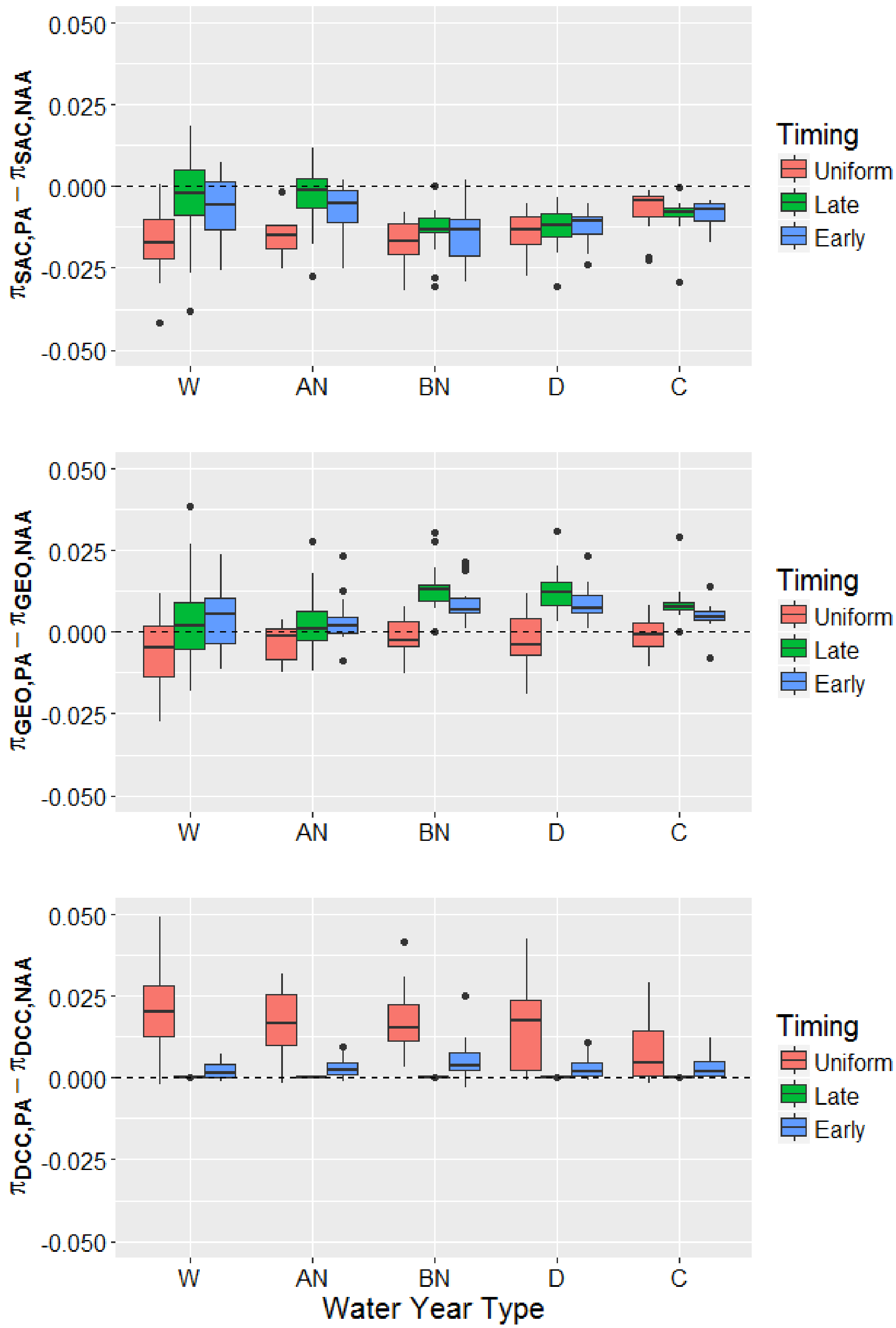

Figure 26. Boxplots showing difference in predicted mean annual probability (π) of juvenile Chinook salmon entrainment between No Action Alternative (NAA) and Proposed Action (PA) for each route (SAC = Sacramento River, GEO = Georgiana Slough, DCC = Delta Cross Channel) by water year type (W=Wet, AN=Above Normal, BN=Below Normal, D=Dry, C=Critical) and run-timing scenario, Sacramento-San Joaquin River Delta, northern California. Boxes range from the 25th to the 75th percentiles with a line indicating the median, whiskers extend 1.5 times past the length of the box, and dots represent data points beyond the whiskers.

The difference in entrainment between scenarios primarily was controlled by the difference in operation of the DCC between PA and NAA. Under the PA scenario, the DCC was open more frequently, thus exposing more fish to being entrained into the interior Delta through the DCC. Two triggers were assumed in the modeling to require the DCC to close: (1) Flow below the NDD exceeding 25,000 ft^3/s (because of flood/scour concerns at the DCC), and (2) flow at Wilkins Slough on the Sacramento River exceeding 7,500 ft^3/s (based on a hydrological criterion included in actual DCC gate operation management to warn of salmon presence in the system). Water diversions have no effect on flow at Wilkins Slough, which leaves the flow downstream of the diversion as the primary driver of the differences between entrainment under the PA and NAA scenarios. Diversions under the PA reduced the flow to less than 25,000 ft^3/s, thus increasing the number of days the DCC could remain open. This was particularly evident in October and November during wet and above normal water year types when discharge upstream of the diversion was >25,000 ft^3/s. For example, under PA in October during wet years, the DCC was open for about 3 more days than under the NAA scenario. During drier water year types, the DCC was operated similarly for PA and NAA because flows in those years rarely exceeded 25,000 ft^3/s. When the DCC was operated in a similar manner between scenarios (drier years), entrainment to the interior was higher under both scenarios owing to the general relationship between flow and entrainment to the interior Delta. Under lower flows, entrainment to the interior Delta is higher because of tidal forcing at the Georgiana Slough divergence (Perry, 2010; Perry and others, 2015).

Perry and others (2013) examined the sensitivity of overall survival of emigrating juvenile Chinook salmon to changes in entrainment into the interior Delta. In this analysis, they determined that completely eliminating entrainment to the interior Delta resulted in a 2–7 percentage point increase in overall survival through Delta, under the assumption of no change in route-specific survival. Thus, we expect that a 3–5 percentage point difference in the probability of being entrained to the interior Delta between PA and NAA would contribute relatively little to the change in overall survival. However, reduced inflows to the Delta owing to the NDD may simultaneously influence both route-specific survival and migration routing. Such simultaneous changes may result in larger expected changes in survival than the effect of routing alone on overall survival.

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Appendix 1. Sensitivity Analysis—Differences between Scenarios for Day and Night Entrainment

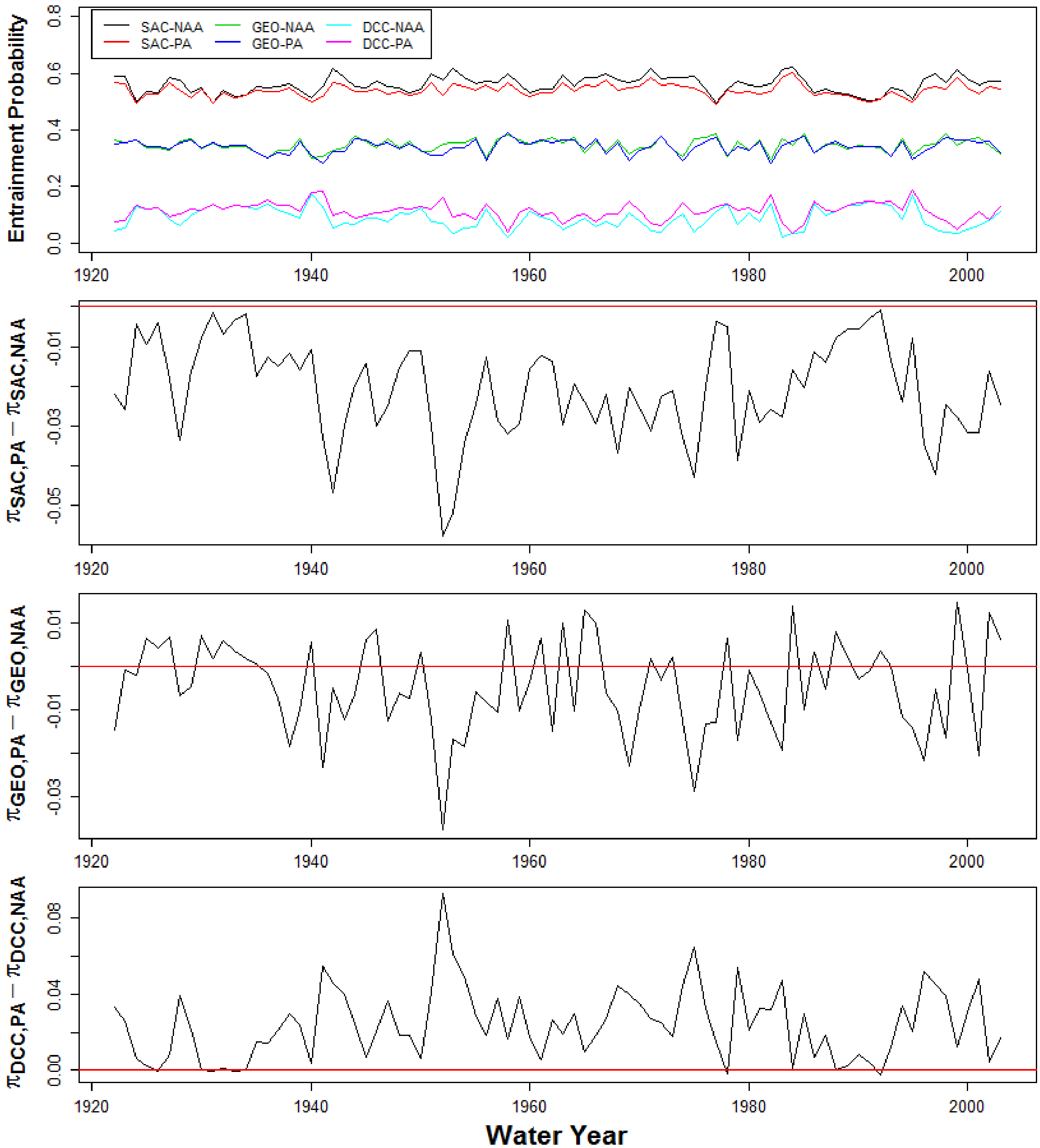

Figure 1.1. Graphs showing comparison of predicted mean annual probability(π) of juvenile Chinook salmon entrainment during daytime hours assuming uniform run timing for the Sacramento River (SAC), Georgiana Slough (GEO), and Delta Cross Channel (DCC) between the Proposed Action (PA) and No Action Alternative (NAA), Sacramento-San Joaquin River Delta, northern California, water years 1922–2003. Mean annual entrainment probabilities (top graph) and the difference in entrainment between scenarios for SAC, GEO, and DCC (bottom three graphs, respectively) are shown. Values above horizontal red line indicate greater entrainment under the PA scenario.

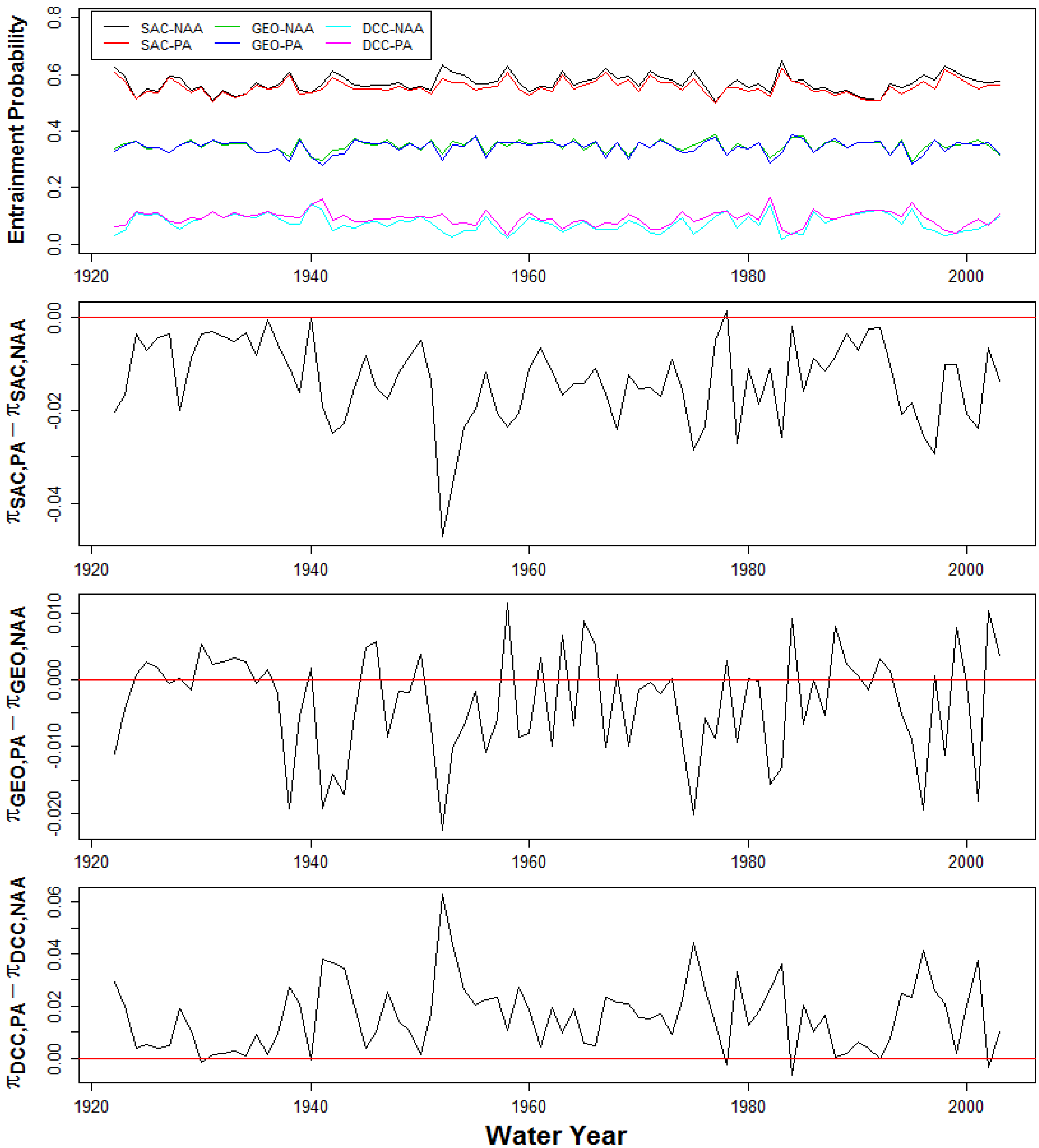

Figure 1.2. Graphs showing comparison of predicted mean annual probability (π) of juvenile Chinook salmon entrainment during nighttime hours assuming uniform run timing for the Sacramento River (SAC), Georgiana Slough (GEO), and Delta Cross Channel (DCC) between the Proposed Action (PA) and No Action Alternative (NAA), Sacramento-San Joaquin River Delta, northern California, water years 1922–2003 Mean annual entrainment probabilities (top graph) and the difference in entrainment between scenarios for SAC, GEO, and DCC (lower panels). Values above the horizontal red line indicate greater entrainment under the PA scenario.

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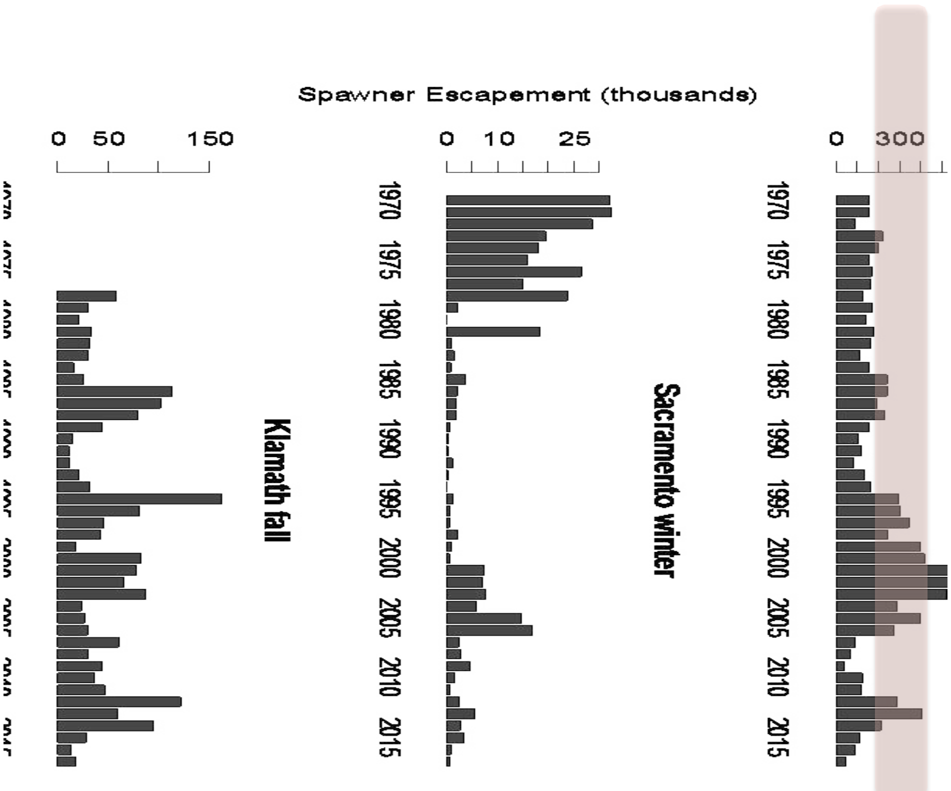
Seattle, Washington 98115
https://wfrc.usgs.gov/

Perry and others—Effects of Proposed California Delta Diversion on Flow Reversals and Entrainment of Salmon into Georgiana Slough and Delta Cross Channel, California—Open-File Report 2018-1028

ISSN 2331-1258 (online)
https://doi.org/10.3133/ofr20181028



California Chinook salmon escapements very poor in 2015, 2016, and 2017

Climate-driven declines in stream and ocean productivity have likely been major contributors

Climate and California salmon 2014-present

Freshwater: California's hot drought from 2012-2016 had extensive negative impacts on salmon

- record-low winter-run egg-to-fry survival rates in 2014-15
- high water temperature and exceptionally high disease and infection rates in Klamath salmon in 2014-15
- JSATS data showed very low outmigration survivals in 2013-14-15-16; much higher outmigration survivals in 2017

Ocean: record-warm ocean temperatures/subtropical conditions in 2014-2015 had extensive negative impacts

- Ocean indicators point to strong sub-tropical influences on West Coast marine life in 2014-15 coast-wide; recovery to more productive conditions south of Mendocino in 2016-17

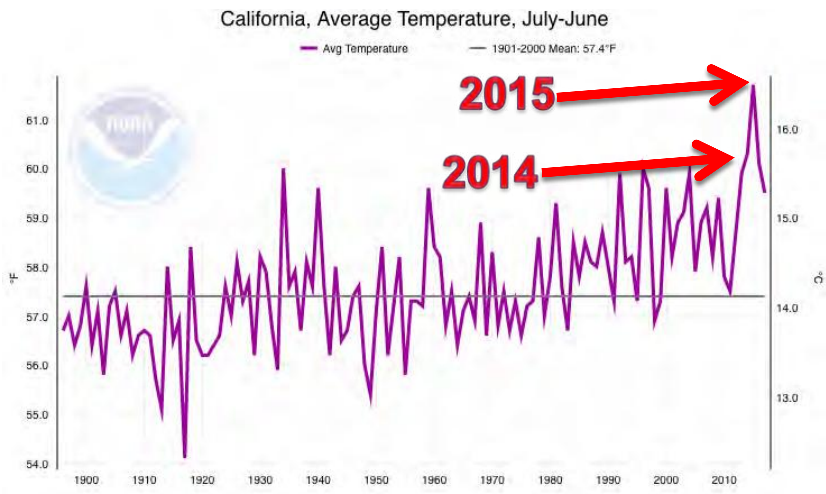
2014-17: exceptionally warm years for California

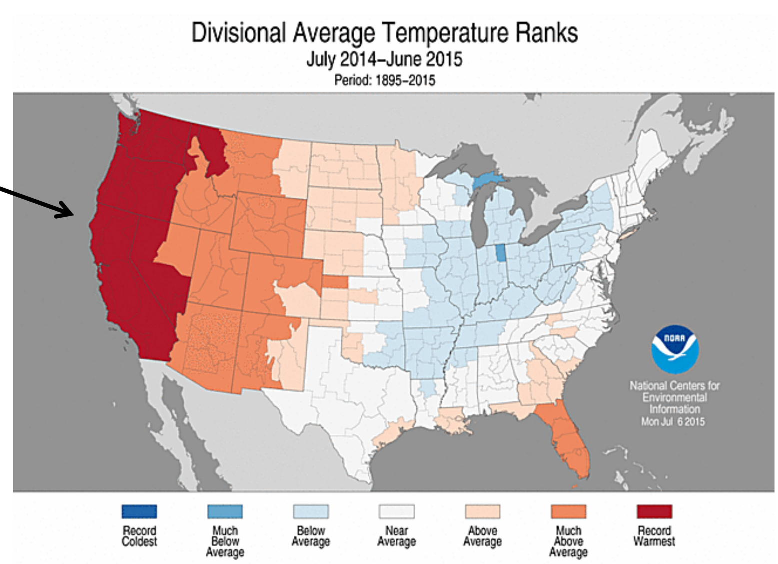
- Surface air temperature record for July 2014-June 2015 was almost off the charts, ~ 1 °C warmer than the previous record

- 2015 Western Snow Drought came with record high temperatures for the entire west coast

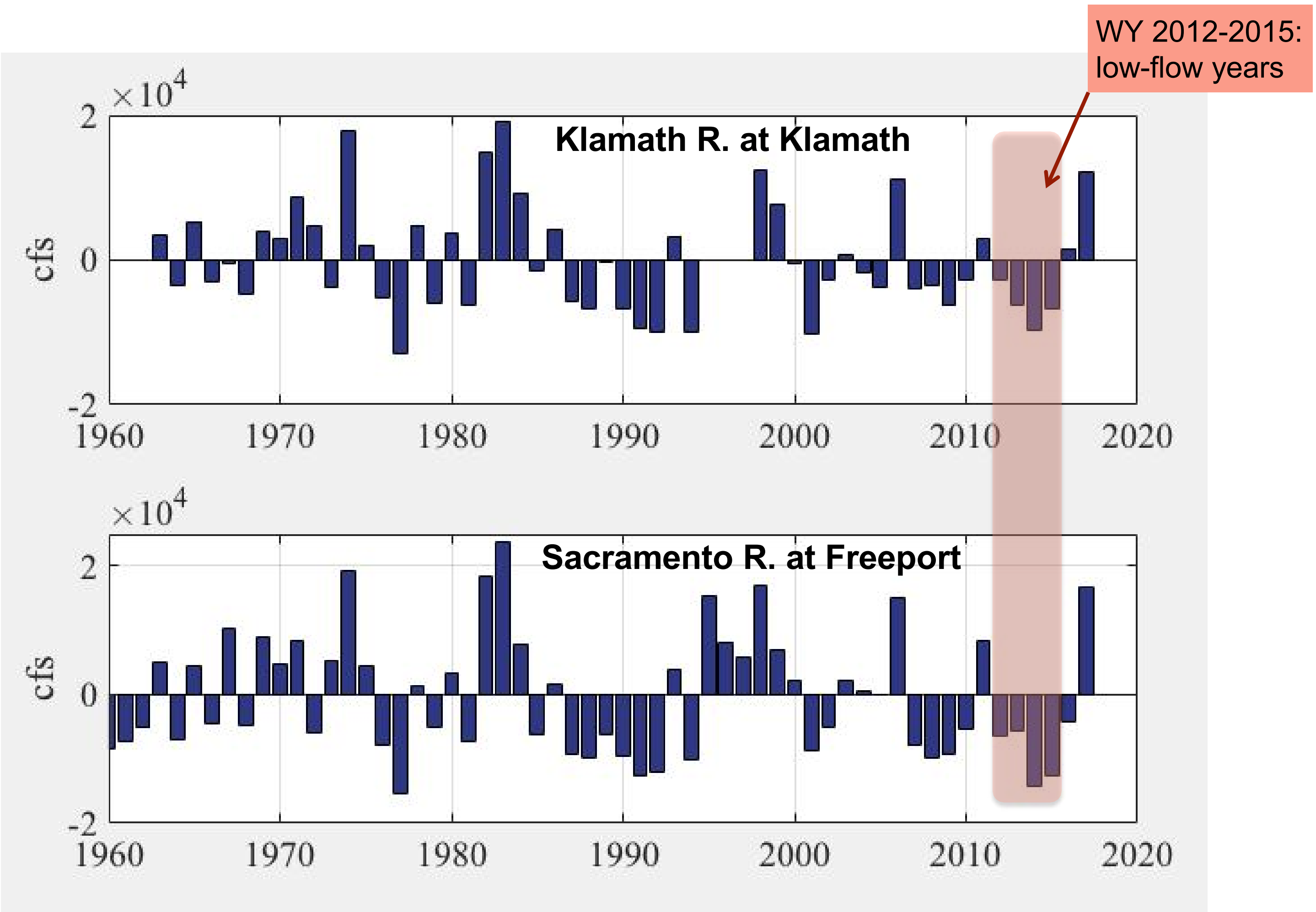
- The "hot drought" was amplified ~30% by high temperatures

- 2016 and 2017 a bit cooler than 2014



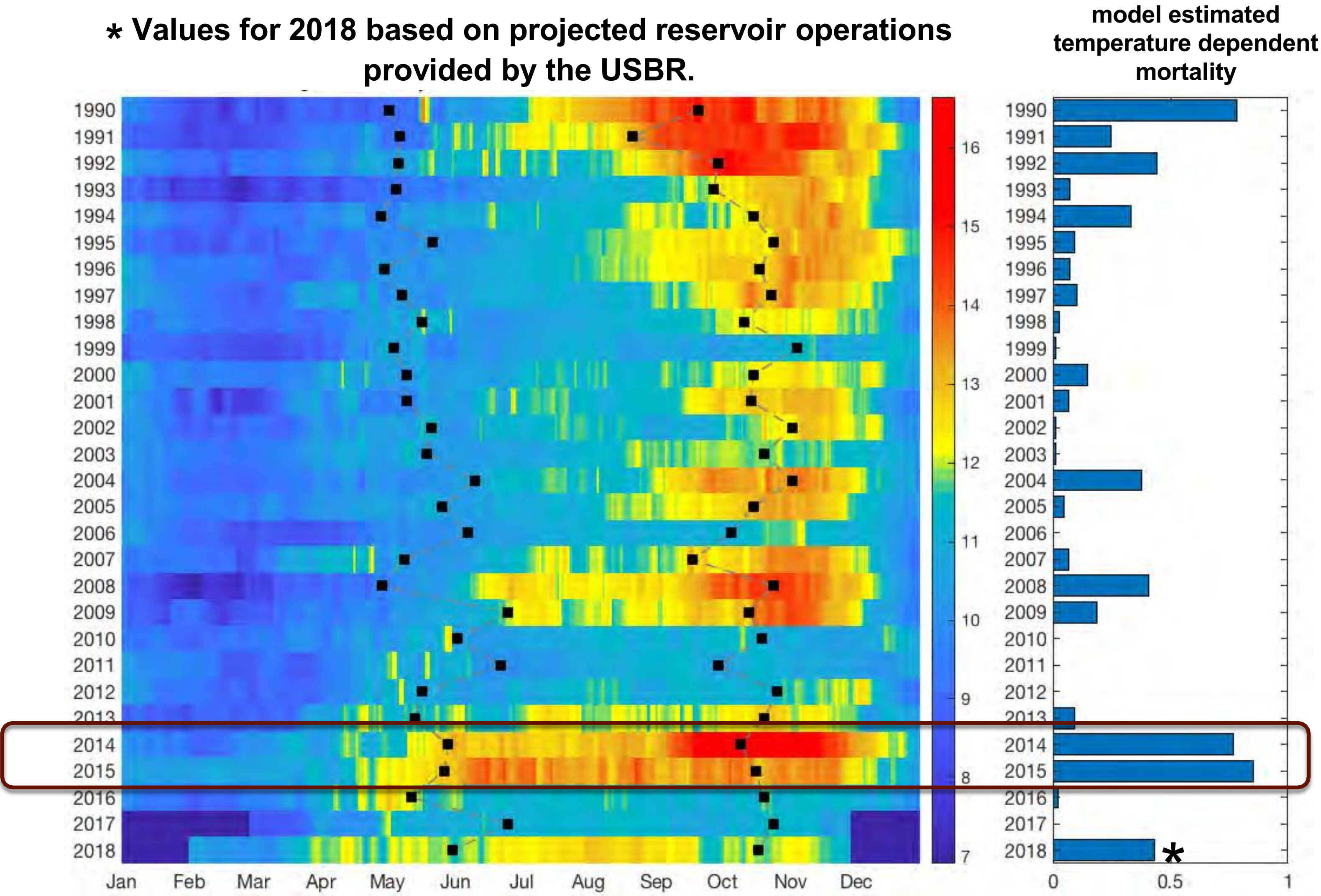


Water year streamflow anomalies in the
Klamath and Sacramento Rivers



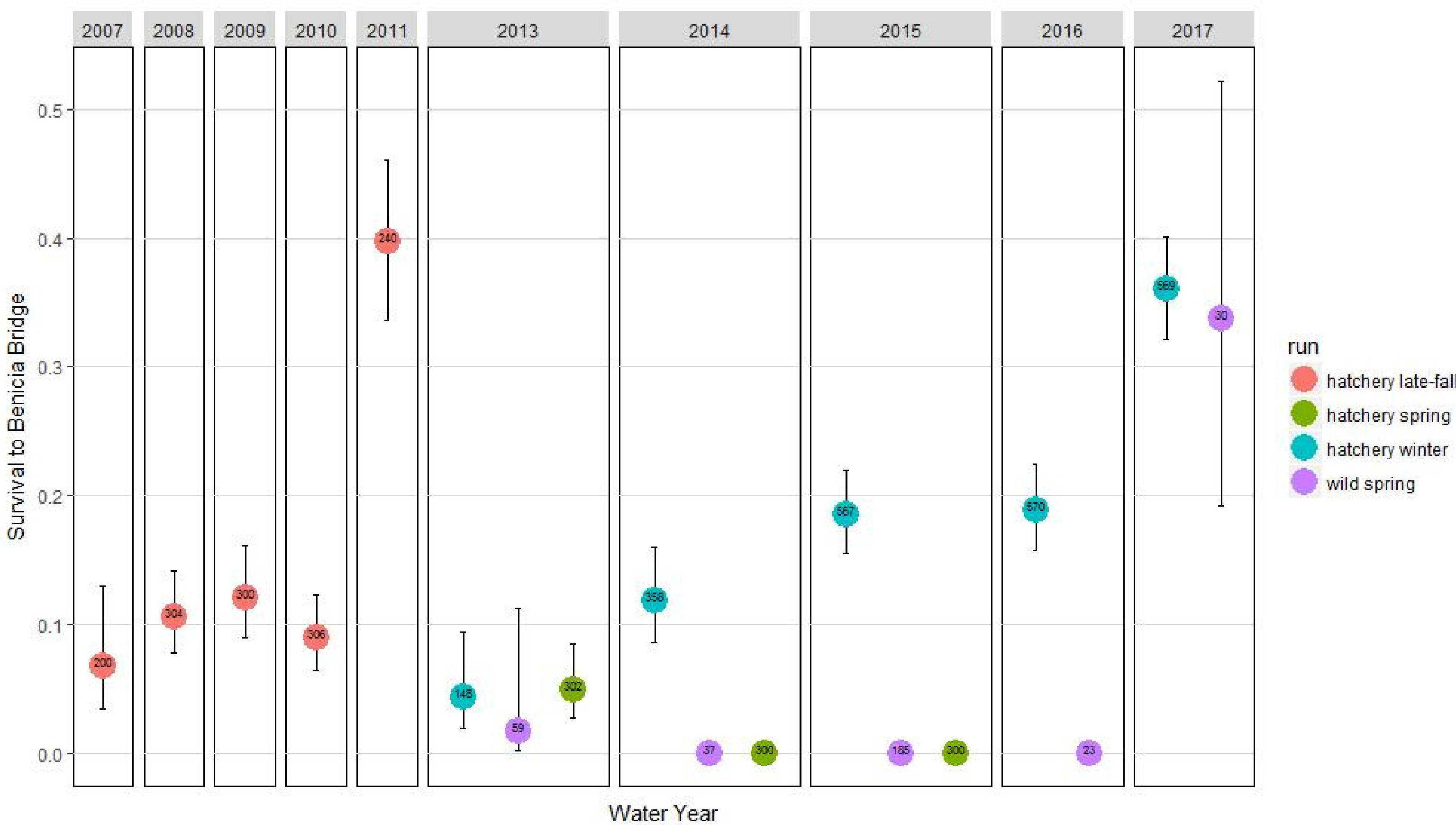
Daily mean water temperatures in winter-run Chinook salmon spawning habitat between Keswick Dam and Clear Creek

*** Values for 2018 based on projected reservoir operations provided by the USBR.**



Slide provided by Eric Danner, SWFSC/NMFS

Smolt Outmigration Survival Rates to Benicia from JSATs

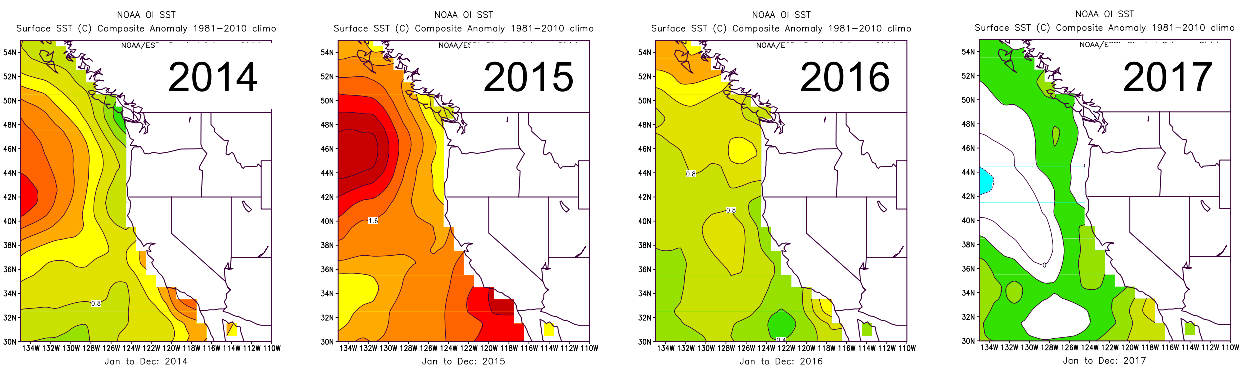


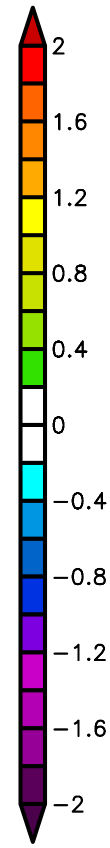
Slide provided by Cyril Michel/UCSC/NMFS

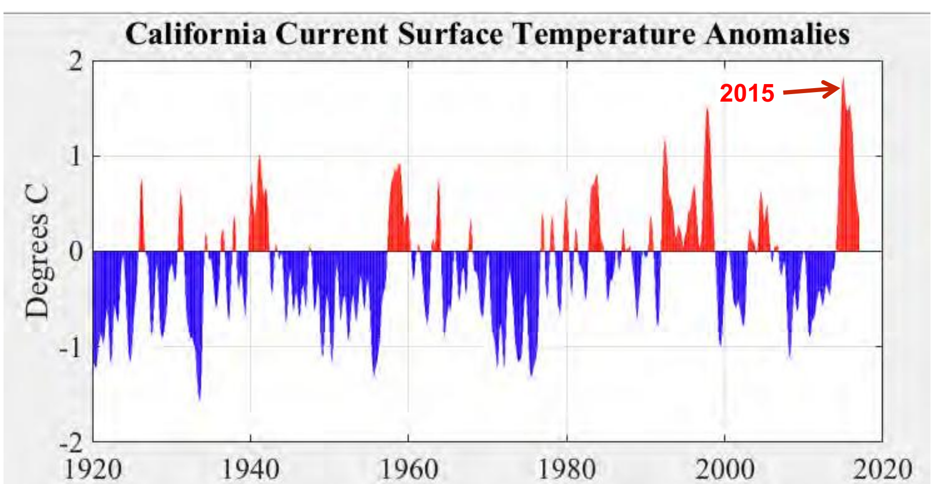
How bad were ocean conditions for CA salmon from 2014-2017?

- Mostly really bad!
- Record high CCS temperatures: 2015 was the warmest year on record, 2014-2016 the warmest 3 year average
- Poor growth/survival conditions for CA salmon and many other top predators (sea lions, sea birds)
- Affected salmon abundance and fisheries 2016-2017, and will likely affect abundance through at least 2018
- High temperatures were caused by “the blob”, weak winds, and the extreme tropical El Niño in 2015-16

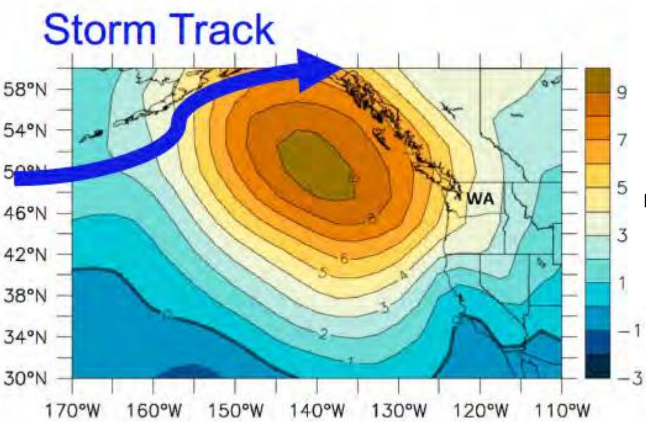
Ocean temperatures from 2014-2017

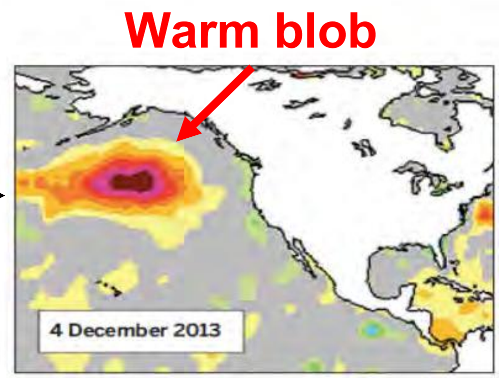




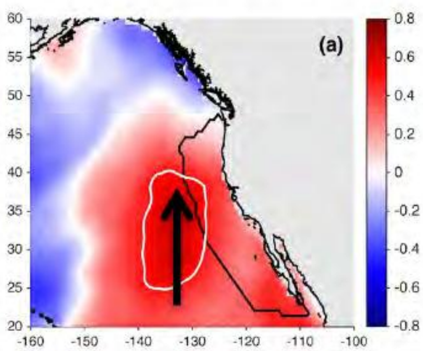


What caused the recent extreme ocean temperatures?

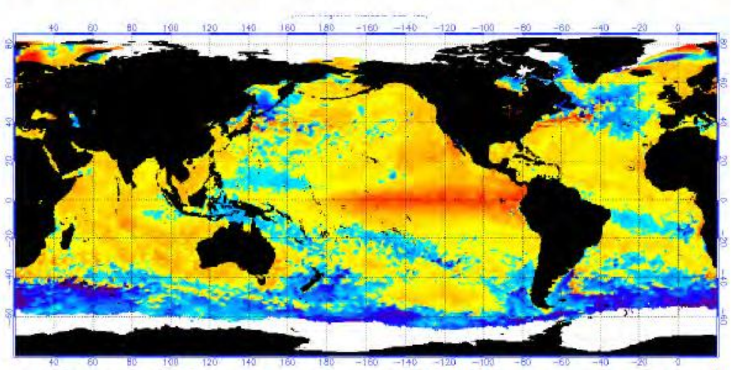




High pressure ridge → Reduced storm-driven mixing → Warm Gulf of Alaska



+ Anomalous winds off US west coast



+ One of the strongest El Niños on record

Jacox et al. 2017, BAMS

Biological Impacts

Pacific Ocean 'blob' draws scrutiny of researchers

A huge swath of unusually warm water that has
s to the normally cool
has grown to the
ean temperature
anomaly on record, researchers now say, profoundly affecting climate and marine life from Baja California to Alaska.

Warming Pacific Makes for Increasingly Weird Ocean Life

A "blob" of warm water that's partly to blame for dead birds and stranded sea lions in the Pacific may share a cause with Boston's snows and California's drought.

Huge Toxic Algal Bloom Shuts Down West Coast Fisheries

Mysterious Sea Lion Die-Off Strikes Again on California Coast

Tiny sea lion pups are washing up on beaches in unusually high numbers—for the third winter in a row.

Experts puzzled as 30 whales stranded in 'unusual mortality event' in Alaska

Scientists 'very concerned' and suspect toxic algae, though Noaa concedes 'bottom line is we don't know what's causing deaths'

Record Algae Bloom Laced With Toxins is Flourishing in "The Blob" — and Spreading in the North Pacific

Unusual warm ocean conditions off California, West Coast bringing odd species

Unusual species in Alaska waters indicate parts of Pacific warming dramatically

Why are so many whales dying on California's shores?

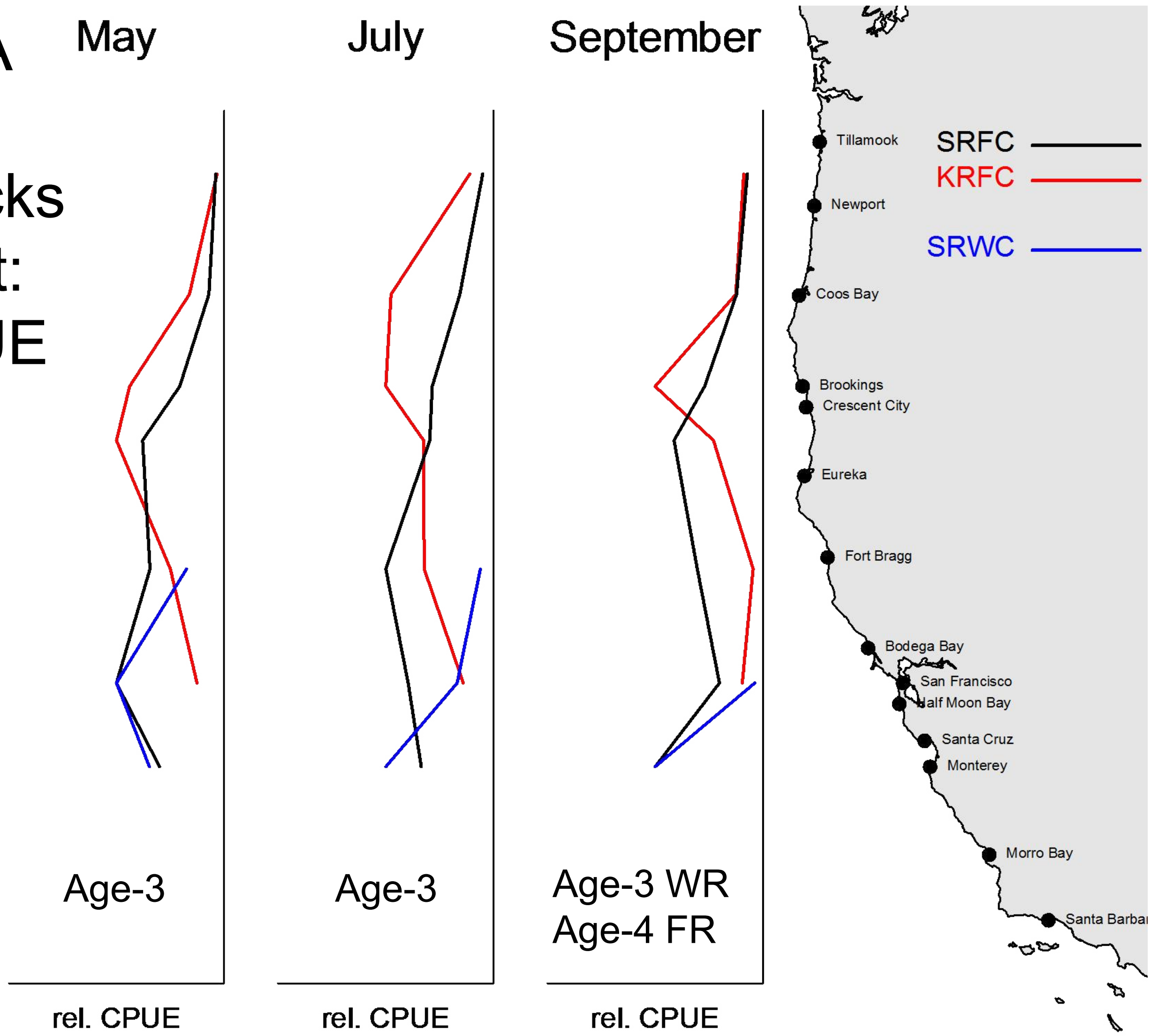
The Gulf of Alaska is unusually warm, and weird fish are showing up

In this Aug. 29 photo, a 7-foot ocean sunfish rarely seen in Washington waters washed ashore on a beach near Ilwaco, Wash., with Julie Mohler, a biological technician working as an interpretative assistant. (AP Photo/Cape Disappointment State Park, Eric Wall)

Where CA Chinook salmon stocks are caught: ocean CPUE

Sacramento R. stocks based on sport fishery recoveries

Klamath stocks based on commercial fisheries

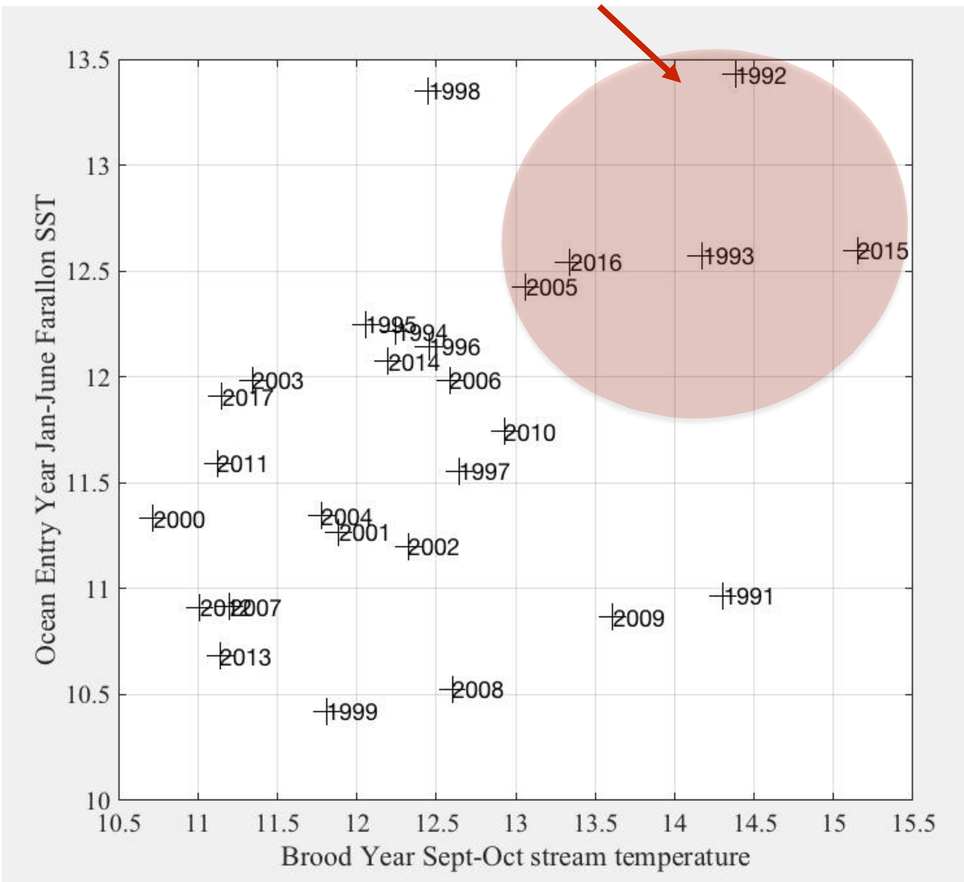


From Will Satterthwaite, SWFSC

Spring 2017 ocean conditions from the State of the CCS report: Northern CCS still unproductive, while Central/Southern CCS were near normal

Indicator	Basin	Northern CCS	Central CCS	Southern CCS
ONI	Average			
PDO	Above average			
NPGO	Near average			
NPH	Below average			
Upwelling		Below average	Average	Above average
Cumulative upwelling		Average	Below average	Average
SST		Above average	Average	Average
Chlorophyll		Below average	Average	Average
Harmful algal blooms		No	No	Yes
Copepods		Southern derived and rich	-	-
Forage		Off-shore and southern derived assemblage	Typical assemblage	Typical assemblage along with increased anchovy abundances.
Salmon survival		Below average juvenile abundance at sea	*Ecosystem indicators related to salmon suggest average*	-
Seabird productivity (2016)		Reproductive failures	Below/near average	-
Seabird at-sea abundance		Well below average	*Below/near average*	Well above average
Sea lions (2016)		Signs of recovery after the 2013 Unusual Mortality Event		
Whales		Humpback whales distributed shoreward		

Especially bad combinations of extreme warm stream temperature and ocean temperature for the same brood year

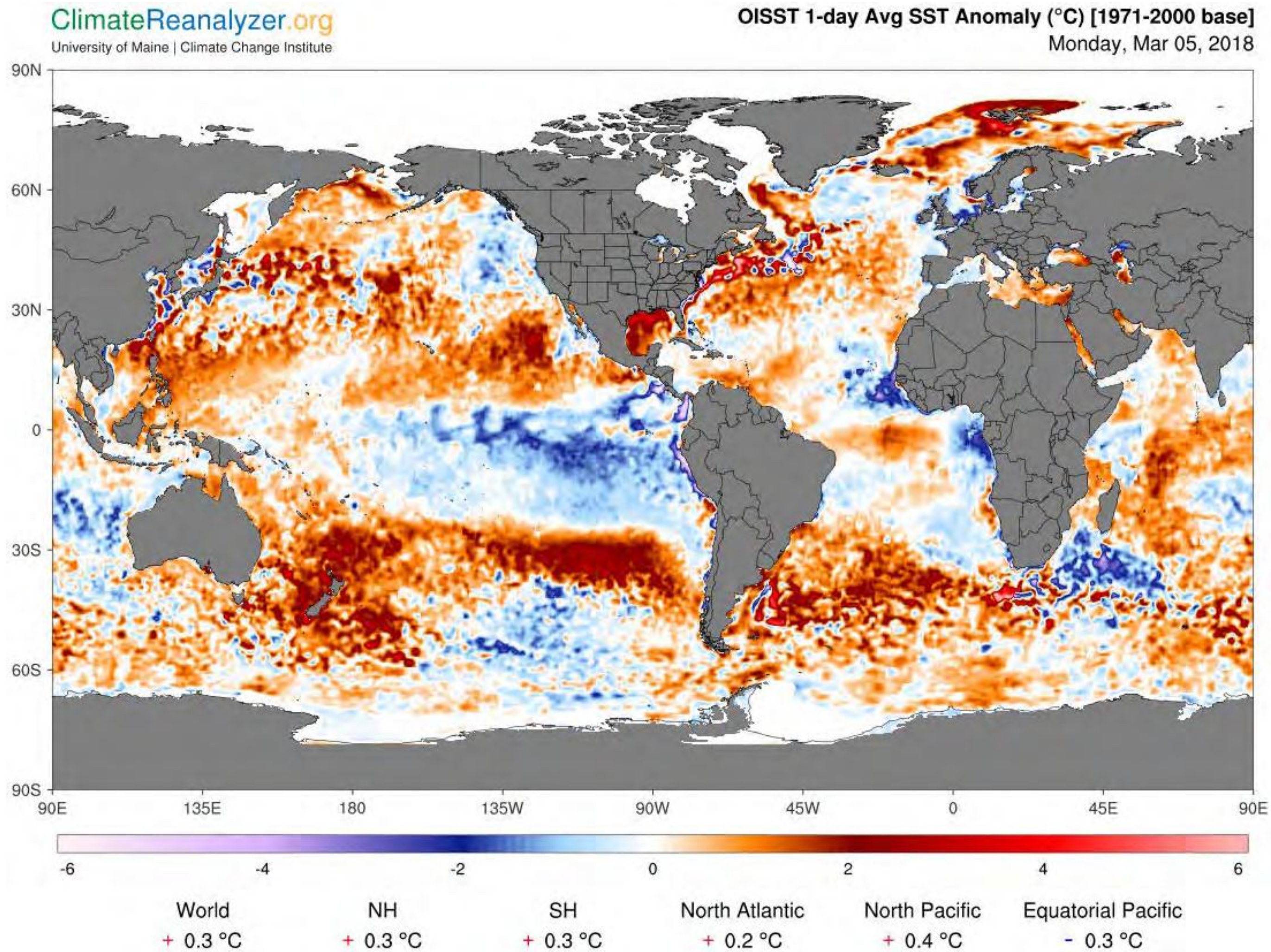


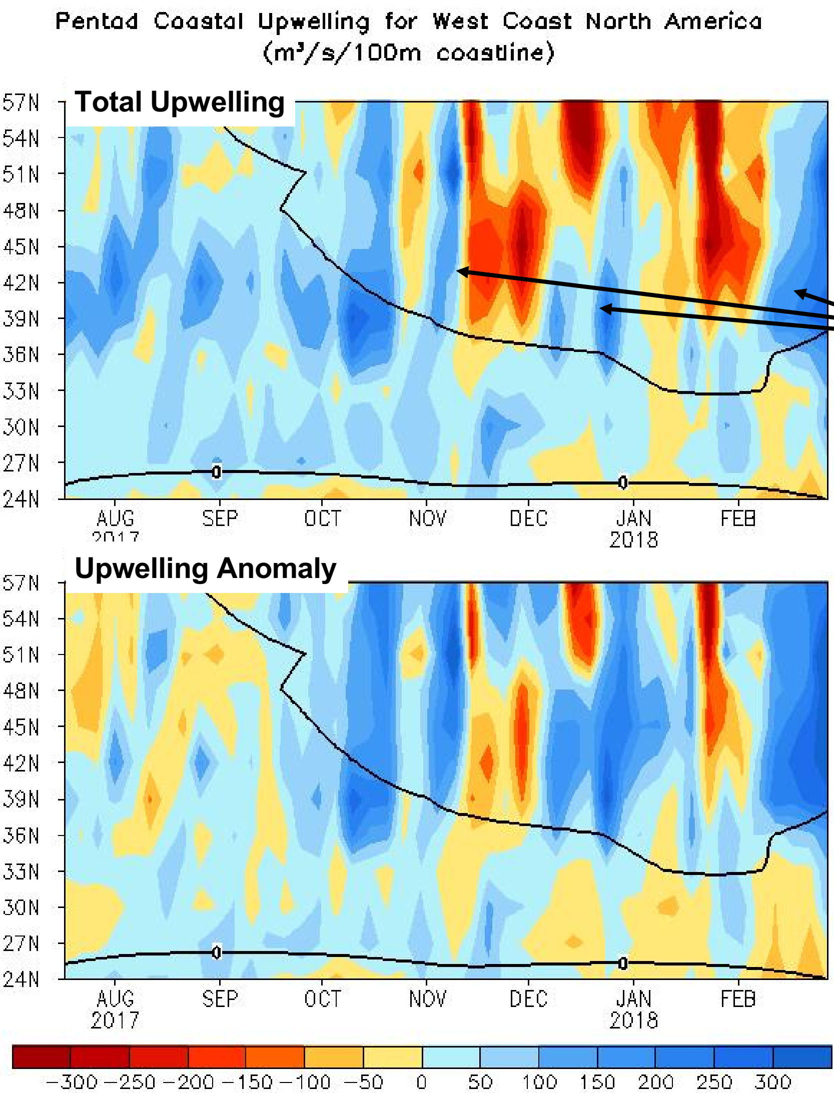
- This plot shows brood year stream temperature between Keswick and Clear Creek for Sept-Oct against January—June ocean entry year SST at the Farallon Islands
- Year labels indicate ocean entry years (Brood Year+1)
- Note the relative lack of extreme Sept-Oct stream temperatures after 1993 (TCD was installed in 1996-97), **until 2014/15**
- **These data suggest that brood years 1991, 1992, and 2014 experienced the 3 worst combined stream/ocean temperature conditions for Central Valley salmon going back to 1990 (when our RAFT-based stream temperature record begins)**

A climate timeline for California's salmon

2013	2014	2015	2016	2017	2018
Yr 2 CA drought, carryover storage	Year 3 CA drought, record heat	West Coast "snow drought" record heat	Near average precip and snowpack but warm w/an early melt	A very wet year with abundant snowpack; refill reservoirs	Extremely warm/dry/low snow; good carryover storage
Cold productive NE Pacific	NEP in transition from good to bad	Record warm SSTs, ecosystem stress	A still warm unproductive NEP, but not as extreme	good productivity south of Mendocino	Near normal SSTs; no info on productivity yet
BY 2013 Chinook	**Smolt migration**	Ocean year 2	Ocean year 3, most return	Ocean year 4	
	BY 2014 Chinook	**Smolt migration**	Ocean year 2	Ocean year 3, most return	Ocean year 4
		BY2015 Chinook	**Smolt migration**	Ocean Year 2	Ocean year 3 Most return

Tropical La Niña has been fading, while persistently strong and cold north winds in late February brought West Coast ocean temperatures back to normal



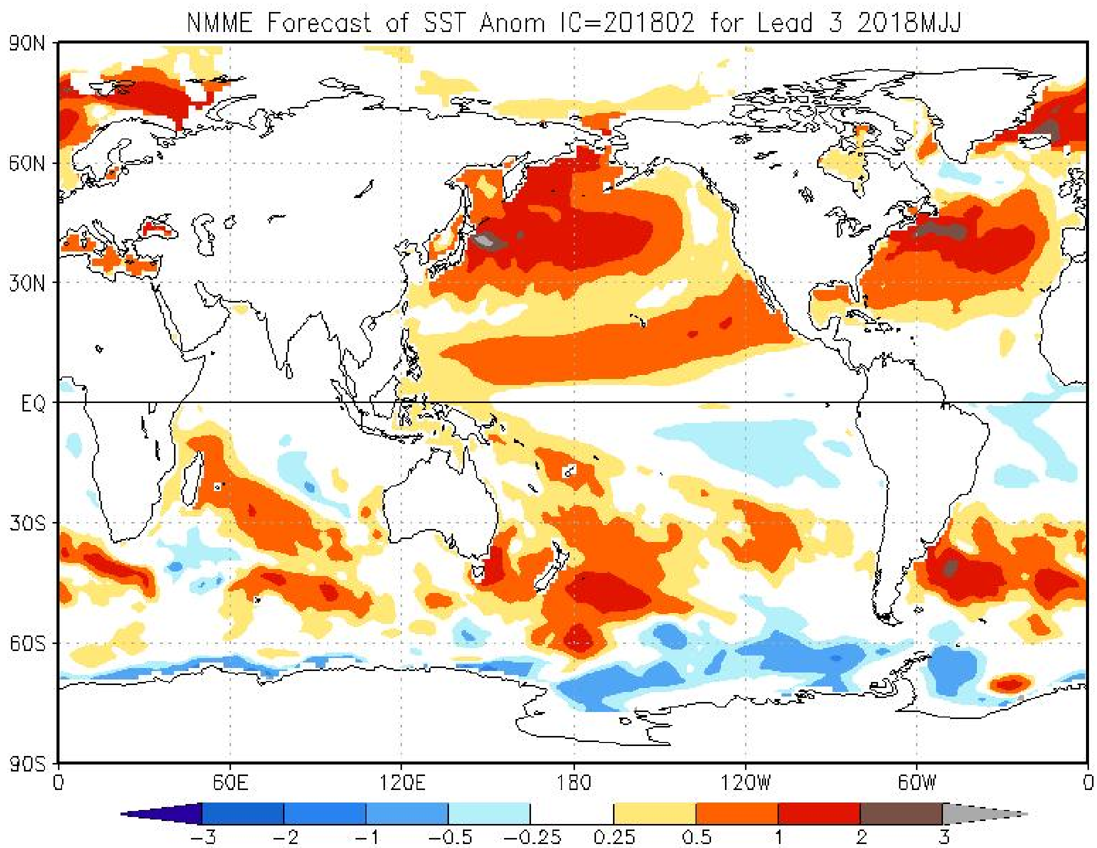


- Fall 2017-Winter 2018 "downwelling" was very weak and intermittent (persistent high pressure ridge blocked storms that come with intense south winds)
- Frequent periods of upwelling along the US West Coast in October, December, and February

- Note the prevalence of blue shading in the upwelling anomaly plot going back to September 2017 – fall/winter downwelling has been weak, while fall/winter upwelling has been unusually strong and frequent

The latest climate model forecasts for North Pacific ocean temperatures are extraordinary: many models are predicting a rapid warming for much of the North Pacific in spring/summer 2018

North American Multi-model ensemble SST forecast for May-June-July 2018



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ARTICLE

Movement and Survival of Wild Chinook Salmon Smolts from Butte Creek During Their Out-Migration to the Ocean: Comparison of a Dry Year versus a Wet Year

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Abstract
California's Central Valley (CCV) Chinook Salmon *Oncorhynchus tshawytscha* stocks have declined substantially since the mid-1800s, with most listed as threatened or endangered or heavily supplemented by hatcheries. As the largest population of CCV wild spring-run Chinook Salmon, Butte Creek fish are an important source for promoting life history diversity in the CCV Chinook Salmon community. However, little information exists on Butte Creek juvenile mortality during out-migration to the ocean, which is considered a critical phase in the overall population dynamics. We used the Juvenile Salmon Acoustic Telemetry System to track the movement of individual fish, and we used a mark–recapture modeling framework to estimate survival of migrating wild Chinook Salmon smolts from lower Butte Creek to ocean entry at the Golden Gate Bridge. Survival and migration varied significantly among years; in 2015, which was a dry year, Chinook Salmon smolts migrated more slowly throughout their migratory corridor and exhibited lower survival than in a wetter year (2016); among locations, fish migrated faster and experienced higher survival in the lower Sacramento River than in the Sutter Bypass and the Sacramento–San Joaquin River Delta. Our data suggest that higher flow at release and larger fish lengths both resulted in increased survival. Our findings shed light on a critical phase of wild spring-run juvenile Chinook Salmon dynamics and could help to inform future restoration and management projects that would improve the survival and abundance of the CCV spring-run Chinook Salmon populations.

Balancing human demands for water with the maintenance of a functioning ecosystem capable of supporting healthy Chinook Salmon *Oncorhynchus tshawytscha* populations has become a central challenge facing natural resource managers in California's Central Valley (CCV). Here, four runs of Chinook Salmon have evolved distinct

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life histories to capitalize on the diversity of habitat available in CCV rivers and streams. The runs are named according to the season in which the adults return to freshwater: fall, late fall, winter, and spring (Healey 1991). Similar to stocks in many large West Coast rivers, Chinook Salmon stocks from the CCV have declined substantially since the mid-1800s, mainly due to the construction of large dams and habitat degradation (Yoshiyama et al. 2001). Spring-run Chinook Salmon were once a major component of CCV Chinook Salmon runs and occupied the headwaters of all major CCV river systems where natural barriers were absent (Williams 2006). Presently, self-sustaining spring-run populations survive only in three tributaries of the Sacramento River: Mill, Deer, and Butte creeks (Lindley et al. 2004). Spring-run fish are reported inconsistently in additional Sacramento River tributaries and are supplemented by stray spring-run adults from the Feather River Hatchery (Yoshiyama et al. 2001). However, these additional stocks are believed to have been hybridizing with fall-run stocks since the 1960s due to dam-created spatial constrictions on previously separate spawning distributions (CDFG 1998). As a consequence of these various stressors, the CCV spring-run Chinook Salmon evolutionarily significant unit (ESU) has been state and federally listed as threatened since 1999 (U.S. Office of the Federal Register 1999).

One of the fundamental objectives for managing spring-run populations for future recovery is ensuring that we are supporting and managing for the full range of life history diversity within the ESU (Beechie et al. 2006). Indeed, spring-run Chinook Salmon populations demonstrate unique juvenile rearing plasticity that is characterized by a wide range of size, timing, and age at which they out-migrate from their natal tributaries to the ocean (e.g., out-migration as subyearling fry, subyearling smolts, or yearlings; CDFG 1998). Such life history diversity has been suggested to convey a stabilizing portfolio effect by providing each population the ability to buffer environmental changes due to anthropogenic forcing or climate, ultimately increasing the resiliency of the entire community (Hilborn et al. 2003; Greene et al. 2010; Schindler et al. 2010). As the largest population of CCV spring-run Chinook Salmon, Butte Creek fish are an important source for promoting diversity in the CCV Chinook Salmon community and have been the focus of considerable investment in the form of population monitoring and restoration efforts. Several restoration actions were implemented in the early 1990s by various state and federal agencies in coordination with water interests and local stakeholders (e.g., CALFED and the U.S. Fish and Wildlife Service's Final Restoration Plan for the Anadromous Fish Restoration Program) in order to restore and maintain CCV spring-run Chinook Salmon populations on a long-term basis. The Lower Butte Creek Project, for instance, was established in 1997 to improve passage for protected fish species while maintaining the viability of commercial agriculture, private wetlands, government lands, and other habitats (ICF Jones & Stokes 2009). Although increases in returning Butte Creek spring-run Chinook Salmon adults have been observed in recent years, the success of those management efforts in enhancing juvenile survival and maintaining population life history diversity has yet to be determined.

Juvenile mortality during out-migration to the ocean is considered a critical phase to overall population dynamics (Healey 1991; Williams 2006). Tagging and tracking of juvenile Chinook Salmon from their freshwater rearing habitats, through riverine systems, and into the marine environment can help to determine survival rates and identify locations where juvenile mortality is greatest during downstream migration. Acoustic tagging technology has become a well-established tool in estimating movement and survival rates of CCV Chinook Salmon juveniles (Perry et al. 2010; Michel et al. 2013, 2015). These studies have mainly focused on hatchery smolts that are easily captured, tagged, and released in large groups, whereas little is known about the survival and movement of the remaining wild spring-run Chinook Salmon populations. Assessing juvenile mortality of wild spring-run Chinook Salmon is challenging in part due to the small size of these populations and the difficulty in capturing them during their out-migration. However, the utilization of survival data from hatchery stocks as a surrogate for wild salmon survival dynamics is often criticized because the two are different in many ways (Kostow 2004). Wild salmon hatch and rear in a completely different environment and face many challenges in their early life that hatchery smolts are able to avoid due to hatchery management and release practices (e.g., predation, water quality). In this paper, we detail an acoustic tagging study—implemented in lower Butte Creek and extending to the Golden Gate Bridge—that was aimed at assessing the movement and survival rates of the largest population of wild CCV spring-run Chinook Salmon smolts during their out-migration to the ocean. We were particularly interested in evaluating potential dissimilarities between survival through (1) the Sutter Bypass, a floodplain that has been suggested to constitute important rearing habitat for juvenile Chinook Salmon (Garman 2013); and (2) the lower Sacramento–San Joaquin River Delta (hereafter, the Delta), which is considered a strongly degraded habitat (Nichols et al. 1986). Moreover, previous studies have demonstrated that CCV juvenile out-migration survival can vary strongly among years due to various anthropogenic and environmental factors (Baker and Morhardt 2001; Brandes and McLain 2001; Michel et al. 2015). Therefore, we compared fish movement and locations of high mortality during out-migration for a hydrologically dry year (2015) versus a hydrologically wetter year (2016). We discuss the implications of our results for the long-term dynamics of the Butte Creek population and the implementation of future recovery actions.

METHODS

Study site.— Butte Creek is a tributary of the Sacramento River that originates at Humboldt Mountain on the western slopes of the Cascade Range at an elevation of more than 2,100 m (Figure 1). The Butte Creek watershed encompasses an area of about 2,900 km^2 and is connected to the Sacramento River at two locations: the Butte Slough Outfall Gates (BSOG); and the downstream end of the Sutter Bypass, a remnant flood basin habitat (Garman 2013). Butte Creek historically entered the Sacramento River at the BSOG but is now diverted away from the Sacramento River for 40 km into the Sutter Bypass (Figure 1). This bypass is composed of two canals as well as the East–West Diversion Weir, which is used to control the flow of water going into the east- and west-side canals of the bypass. Several weirs along both canals divert water for agricultural or managed wetland uses (ICF Jones & Stokes 2009). During high-flow conditions, water from the Sacramento River flows into the bypass through Moulton, Colusa, and Tisdale weirs to prevent flooding of downstream areas.

Once juvenile salmon exit the Sutter Bypass and enter the Sacramento River above the town of Verona, they migrate downstream through the lower Sacramento River, the Delta, and San Francisco Bay before entering the Pacific Ocean. In a wet year, fish could also cross the Sacramento River at the base of the Sutter Bypass and enter the Yolo Bypass through Fremont Weir; however, no water from the Sacramento River spilled into the Yolo Bypass during the 2015–2016 tagging period. The entire migration corridor considered for this study encompassed 249 river kilometers from the release site in the Sutter Bypass to the Golden Gate Bridge.

Freshwater life history.— Central Valley spring-run Chinook Salmon demonstrate a unique diversity in life history among the California stocks of Chinook Salmon. Adult spring-run Chinook Salmon ascend un-dammed tributaries to elevations between 300 and 1,500 m when the spring freshet allows access, and they hold in deep pools over the summer before spawning in the fall. The CCV spring-run juveniles emerge from the gravel between November and March depending on water temperatures, and they spend 3–15 months in freshwater before emigrating to the ocean (CDFG 1998). Spring-run Chinook Salmon juveniles exhibit a wide variety of rearing and out-migration strategies. They can (1) migrate out of the spawning habitat soon after emergence as fry during high flows in the winter; (2) rear in their natal habitat and out-migrate as smolts during the spring; or (3) remain in the stream for an entire year and out-migrate during the following fall, winter, or spring as yearlings (CDFG 1998). Juveniles out-migrating from Butte Creek are assumed to be a mix of fry and smolts, with very few remaining in Butte Creek as yearlings (Clint Garman, California Department of Fish and Wildlife [CDFW], personal communication). Smolt emigration peaks in April and May but can extend from February through June (Ward et al. 2004a, 2004b, 2004c).

Acoustic tagging and receivers.— We used the Juvenile Salmon Acoustic Telemetry System (JSATS; McMichael et al. 2010) to track the movements and estimate the survival of migrating wild spring-run Chinook Salmon smolts from Butte Creek. The transmitters (tags) were manufactured by Advanced Telemetry Systems (ATS): JSATS Model SS300 tags had a weight in air of 300 mg and dimensions of $10.7 \times 5.0 \times 2.8$ mm. The tags emitted a uniquely coded signal at 416.7 kHz with a pulse rate of about 5 s and had an expected life of 32 d at these settings. The tag weight of 300 mg allowed us to tag juvenile Chinook Salmon that weighed at least 6.0 g (approximate FL = 80 mm), resulting in a tag burden no greater than 5%. Laboratory studies comparing growth and survival between acoustically tagged and untagged juvenile salmon have suggested that tag burdens of less than 5% do not significantly affect acoustically tagged fish relative to untagged controls (Brown et al. 2010; Ammann et al. 2013).

To detect the presence of tagged fish, we deployed acoustic receivers at several sites beginning at the capture/release site and ending at the Golden Gate Bridge (Figure 1). We used a combination of receivers manufactured by ATS, Teknologic, and Lotek Wireless. The number of receivers deployed at each location varied from one to five depending on the channel width. Reaches were defined by receiver locations and varied from 0.5 to 100 km in length (Table 1). Each year, we deployed all receivers prior to release of tagged fish and then recovered and downloaded the data at the end of June.

We collected fish by using a 2.44-m-diameter rotary screw trap (RST) installed at Weir 2 in the Sutter Bypass (Table 2). We chose Weir 2 as the trapping site to ensure that fish collected and tagged were actively migrating downstream, as this weir is relatively low in the Butte Creek system. Additionally, this downstream site ensured that the 30-d acoustic tag battery life was utilized efficiently, allowing fish movement through the Sutter Bypass, the Sacramento River, the Delta, and San Francisco Bay to be recorded. The RST was operated continuously (24 h/d) and was emptied of fish each morning. All salmonids were measured (FL; mm), and an acoustic tag was implanted into each fish larger than 80 mm.

On the riverbank adjacent to the RST, we set up a shaded work station to surgically implant the tags before

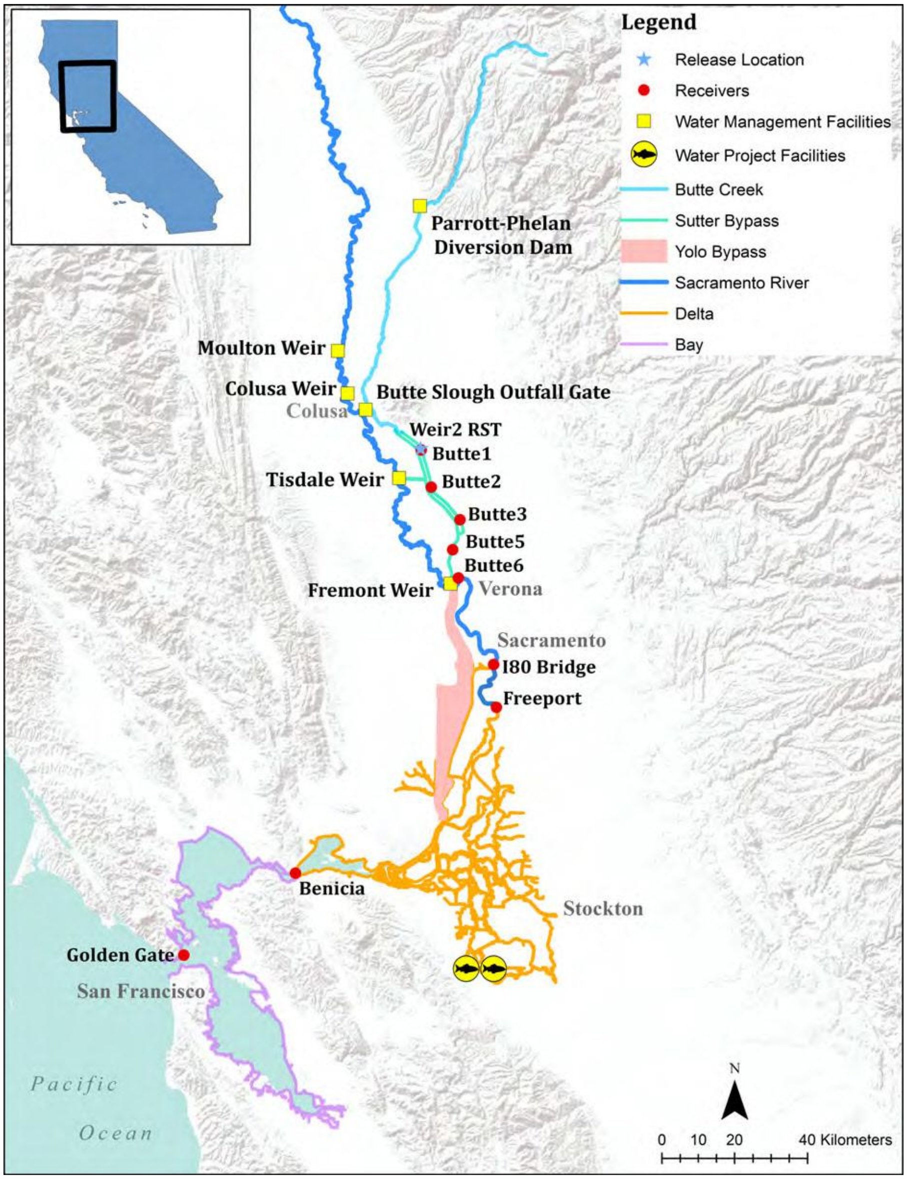

FIGURE 1. Map of California's Central Valley, showing the different regions considered in the study, the release location, and the receiver locations. [Color figure can be viewed at afsjournals.org.]

the sun was overhead and before temperatures became too warm. The same surgeon implanted tags into the coelom of all fish for both years of the study. Fish were anesthetized (tricaine methanesulfonate at a concentration of 90 mg/L), weighed, measured, photographed, and then placed ventral side up in a padded V-channel. During surgery, the fish's gills were irrigated with water containing a maintenance dose of anesthetic (30 mg/L). An incision was made on the ventral side of the fish between the pelvic girdle and pectoral fins with a Sharpoint 3-mm, 15° stabbing blade scalpel. The incision was 6–8 mm long and 3 mm off the ventral midline. The tag was inserted into the coelom and oriented such that the tag transducer was posterior. The incision was closed with a single suture of 6-0 polydioxanone absorbable monofilament, and the suture was tied with a double-wrapped square knot (i.e., surgeon's knot). We placed each tagged fish into a recovery bucket and monitored the fish until it resumed its normal swimming behavior. After surgery, we held the tagged individuals in holding pens just below Weir 2 for 12 h before releasing them at 2200 hours (Pacific Standard Time), primarily to ensure that the fish were fully recovered but also because juvenile salmon tend to migrate at night (Chapman et al. 2013).

We collected tissue samples from all tagged fish to identify their origin by using genetic stock identification

TABLE 1. Study reach locations where out-migrating Chinook Salmon from Butte Creek (California) were tracked, the distance of each reach from the Golden Gate Bridge (river kilometers [rkm]), the individual reach lengths, and the total region length (km). Weir2_RST represents the rotary screw trap installed at Weir 2 in the Sutter Bypass; Butte1–Butte6 and additional receiver locations are depicted in Figure 1.

Region	Reach	Distance from ocean (rkm)	Reach length (km)	Region length (km)
Sutter Bypass	Weir2_RST to Butte1	249.54–249.05	0.49	
	Butte1 to Butte2	249.05–238.46	10.59	
	Butte2 to Butte3	238.46–226.46	12.00	
	Butte3 to Butte5	226.46–216.98	9.48	
	Butte5 to Butte6	216.98–206.48	10.50	43.06
Sacramento River	Butte6 to I-80 Bridge	206.48–170.74	35.74	
	I-80 Bridge to Freeport	170.74–152.43	18.31	54.05
Sacramento–San Joaquin River Delta	Freeport to Benicia	152.43–52.04	100.39	100.39
San Francisco Bay	Benicia to Golden Gate Bridge	52.04–0.80	51.24	51.24

TABLE 2. Weight (g) and FL (mm; mean, minimum [min], and maximum [max]; SDs in parentheses) of juvenile Chinook Salmon that were captured, tagged, and released at the rotary screw trap in the Sutter Bypass during 2015 and 2016 (CCV = California Central Valley; n = sample size). Group assignment is shown only for fish with genetic stock assignment posterior probabilities exceeding 75%.

Year	Group	n	Mean (SD) weight	Mean (SD) FL	Min FL	Max FL
2015	CCV fall run	6		112.67 (16.85)	84	135
	CCV spring run	125		104.00 (11.73)	80	136
	All	141	13.47 (5.36)	104.75 (12.28)		
2016	CCV fall run	121		114.60 (6.82)	98	128
	CCV spring run	65		103.51 (6.88)	85	122
	All	200	16.68 (7.68)	110.02 (10.93)		

(Clemento et al. 2014). For each fish, we calculated the posterior probability that it originated from a given stock, and we assigned the fish to the stock with the highest posterior probability. Based on Satterthwaite et al. (2014) and communication with John C. Garza (National Marine Fisheries Service [NMFS], Southwest Fisheries Science Center [SWFSC], Santa Cruz), we considered assignments of fish with a maximum posterior probability exceeding 75% as robust stock assignments for purposes of this study. We did not assign a stock to fish with posterior probabilities less than 75%. The genetic analysis was performed at the NMFS-SWFSC.

Data analysis.— Tagged fish either completed their migration out of the study reaches or completed a partial migration and died before exiting the detection arrays. We used a spatial form of the Cormack–Jolly–Seber model (Cormack 1964; Jolly 1965; Seber 1986) to estimate the reach-specific survival rate (φ_i) and detection probability (p_i). We considered the initial tag location as a "mark" and subsequent detections at downstream receivers as "recaptures." We used the method of maximum likelihood to estimate survival and detection probabilities along with their 95% confidence intervals (Lebreton et al. 1992).

For consistency between tagging years and due to the low number of fish migrating through the Delta, we selected a subset of receiver locations for the survival analysis, thus creating a total of nine separate reaches for which survival and detection probabilities were estimated (Table 1; Figure 1). Furthermore, because the lengths of reaches along the migratory path were not identical, we standardized survival estimates per 10 km in order to allow inter-reach survival comparisons. Finally, we estimated regional survival (Sutter Bypass, Sacramento River, the Delta, and San Francisco Bay) and overall survival (from the release site to the Golden Gate Bridge) for both years using methodology described by Michel et al. (2015).

To evaluate year and location effects on out-migrating smolt survival and detection probabilities, we compared the constant model (i.e., constant survival and detection rates through space and time) to models that included parameters allowing year and/or reach to vary (e.g., φ[~reach × year]; see Appendix Table A.1 for a list of models). Because it is impossible to measure or estimate all potential factors that influence salmon survival, we hypothesized that the fully parameterized model (full model) that included year and reach as factors would have the best fit to the data and would provide the best estimates of reach survival by year. We therefore used this model to generate reach-specific, regional, and overall survival estimates. However, to gain a better understanding of the underlying mortality mechanisms, we also looked at models that included fish characteristics (i.e., FL and Fulton's condition factor *K*) and environmental variables (i.e., Sutter Bypass flow and water temperature at release). We used flow data from Butte Slough near Meridian (California Data Exchange Center [CDEC] station BSL, http://cdec.water.ca.gov/cgi-progs/stationInfo?station_id=BSL), located downstream of the BSOG (the closest flow gauge to the Sutter Bypass release site), and we used temperature data from the Buttel acoustic receivers (postcalibrated at the NMFS-SWFSC). All continuous covariates were standardized by subtracting the mean and dividing by the SD.

To facilitate our ability to partition the influence of each covariate of interest on survival variability through time, we used the base model, φ(~reach), and included covariates in an additive framework (see Table 3 for a list of models). We deliberately excluded the year variable from all covariate models because the inclusion of this variable would have accounted for the majority of interannual variability in survival, thereby masking any influence of the individual/environmental covariates and providing no information on mechanisms. However, we compared the φ(~reach + year) model to the models including covariates in order to assess how much interannual variability explained by the year variable could be explained by these covariates instead. Once the relative importance of covariates had been determined from the model selection exercise, we extracted the standardized β parameter coefficients for these covariates to identify the relationship direction between the covariates and fish survival. These β parameter coefficients allowed for comparison of the influence of covariates between models; they can be interpreted as the predicted change in survival for a 1SD increase in the covariate. Model selection was conducted by using Akaike's information criterion corrected for small sample sizes (AIC_c; Akaike 1973; Burnham and Anderson 2002). We performed this analysis in the RMark package (Laake 2013) within R version 3.1.1 (R Development Core Team 2013).

Finally, to obtain additional information on the movements of the tagged fish during their out-migration and relate that to their survival, we estimated the average migration rates for the different regions along the migration pathway. We did this by considering the movement rate of each fish between its last detection in one reach to its first detection at the next reach.

TABLE 3. Comparison of the ~reach + year survival (φ) model versus models that included reach and individual or environmental covariates (fish length, Fulton's condition factor *K*, Sutter Bypass flow at release, and water temperature at release). The detection probability (*p*) was set as a constant for each model (N_{par} = number of model parameters; AIC_c = Akaike's information criterion corrected for small sample size; ΔAIC_c = difference in AIC_c score between the given model and the most parsimonious model). Models are ordered from lowest to highest AIC_c. Lower AIC_c scores indicate greater relative model parsimony. The β parameter estimates (defined in Methods) are shown for the two covariate models with substantial support over the reach-only model.

Model	N_{par}	AIC_c	ΔAIC_c	β
φ(~reach + year), *p*(~1)	11	1,394.074	0.00	
φ(~reach + release flow), *p*(~1)	11	1,396.929	2.85	0.24
φ(~reach + fish length), *p*(~1)	11	1,402.226	8.15	0.17
φ(~reach + release temp), *p*(~1)	11	1,404.477	10.40	
φ(~reach), *p*(~1)	10	1,405.719	11.64	
φ(~reach + *K*), *p*(~1)	11	1,406.765	12.69	

RESULTS

In 2015, we deployed the RST on April 1 and tagged Chinook Salmon for 11 d between April 6 and April 16. During that period, we tagged and released a total of 141 smolts. In 2016, we started tagging on April 14, and we were able to tag and release our target of 200 juvenile Chinook Salmon by April 18. In 2015, the mean FL of tagged fish was 104.75 mm and the mean weight was 13.47 g, whereas the averages in 2016 were 110.02 mm and 16.68 g, respectively (Table 2).

Genetic Assignment

The genetic analysis suggested that the smolts tagged in the Sutter Bypass were a mix of CCV fall-run and spring-run origin. In 2015, 6 smolts were confidently identified as CCV fall-run fish, and 124 smolts were identified as CCV spring-run fish; in 2016, a higher proportion of tagged individuals were genetically classified as CCV fall-run fish (121 fall-run versus 65 spring-run fish; Table 2). Although fall-run smolts were slightly larger in both years, fall-run and spring-run smolts appeared to exhibit similar size ranges (Table 2; Appendix Figure A.1). We performed an *F*-test ("var.test" function in R) to compare fall-run versus spring-run smolt length variances for each year and found no statistical difference between their length distributions (2015: $P = 0.1489$; 2016: $P = 0.9086$). This implied that no length cutoff could be robustly applied to these two runs and that visual distinction based on length is problematic. Therefore, although not all of the tagged fish were spring-run Chinook Salmon, we assumed that due to their overlapping size range and migration timing, fall-run juveniles served as a good proxy for the purpose of this study.

The RST was located below the spawning habitat of the Butte Creek fall run; it is therefore likely that many of the captured fall-run smolts were wild Butte Creek fall-run Chinook Salmon. In addition, because Sacramento River water spilled into the lower Butte Creek watershed via Moulton, Colusa, and Tisdale weirs several times before the tagging experiment took place, it is also possible that some of the tagged fall-run fish originated from the mainstem Sacramento River or another tributary and used the Sutter Bypass as a migratory corridor.

Hydrological Conditions

During the 2015 water year, California experienced an extreme drought that was classified as "critical," whereas the 2016 water year was considered "below normal" by the California Department of Water Resources (CDWR; CDEC data). Although 2016 was not considered a wet year, a series of rain events leading to the flooding of the Sutter Bypass occurred during the CCV spring-run smolts' out-migration period. Therefore, the hydrological conditions experienced by the migrating smolts changed considerably between the 2 years of the study. In spring 2015, likely because of very dry winter conditions, the flow recorded in the lower Butte Creek system had already dropped substantially and stayed very low during the entire study period, averaging 4.03 m^3/s at the BSL station (Figure 2A). In 2016, we tagged and released fish after a flood event, and although the flow decreased throughout the study period, it remained substantially above the maximum flow value recorded during the same period in 2015. The 2016 BSL flow averaged 12.91 m^3/s. The same pattern was observed in the Sacramento River reach, with an average flow of 160.29 m^3/s in 2015 and an average of 381.53 m^3/s in 2016 (CDEC station at Verona, http://cdec.water.ca.gov/cgi-progs/stationInfo?station_id=VON; Figure 2A).

In 2015, water temperatures in the Sutter Bypass and the Sacramento River increased throughout the tagging experiment (Figure 2B). Water temperature at the Buttel receiver peaked at 18.5°C during the tagging period, then kept increasing and reached 21°C by the end of April. Similarly, water temperature in the Sacramento River increased from 14°C to 22°C during April 2015 (CDEC station at Verona, http://cdec.water.ca.gov/cgi-progs/stationInfo?station_id=VON). In 2016, water temperature in the Sutter Bypass during the tagging period varied between 18°C and 19.5°C. The peak water temperature at the Buttel receiver was 21°C on April 21, 2016. The Sacramento River water temperature in 2016 slowly increased throughout the month of April but never exceeded 18°C.

Fish Movement

In 2015, 27 (19.1%) of the 141 tagged fish were detected as entering the Sacramento River, 14 fish (9.9%) were detected as entering the Delta, and only 1 fish (0.7%) was detected at the Golden Gate Bridge. In 2016, 71 (35.5%) of the 200 tagged fish were detected as entering the Sacramento River, 49 fish (24.5%) were detected in the Delta, and 4 fish (2%) were detected at the Golden Gate Bridge. Although some variability in movement rates among fish was observed each year, especially in the Sacramento River, most of the tagged smolts moved quickly throughout the migration corridor (Figure 3). On average, fish took 6 d in 2015 versus 2 d in 2016 to transit the Sutter Bypass, and they took 2 d in 2015 versus 1 d in 2016 to transit the Sacramento River (Table 4). The single fish that survived to the Golden Gate Bridge in 2015 migrated through the Delta in less than 5 d and migrated from the release site to the Pacific Ocean in 27 d. In 2016, it took an average of 5 d for fish to migrate through the Delta and 18 d for them to migrate from the release site to the ocean (Table 4).

Tagged fish migration rates were higher in the Sacramento River compared to the Sutter Bypass and the Delta during both years (Figure 3; Table 4). Based on a Tukey's honestly significant difference test ("TukeyHSD" function in R), the migration rate in 2016 was significantly higher than that in 2015 within the Sacramento River ($P < 0.001$) and the Sutter Bypass ($P < 0.001$); migration rates were significantly higher in the Sacramento River compared to the Sutter Bypass during both years (2015: $P = 0.0$; 2016: $P = 0.0$). We calculated mean migration rates of 10.24 km/d in the Sutter Bypass and 33.21 km/d in the Sacramento River during 2015 versus estimates of 22.13 and 56.83 km/d, respectively, during 2016 (Table 4). Since only one fish was successfully detected at Benicia (the Delta exit location) and the Golden Gate Bridge in 2015, it was not possible to estimate Delta and San Francisco Bay travel rate statistics for that year. However, more fish were detected in 2016, and the average movement rate through the Delta was estimated at 22.48 km/d.

Survival Estimates

The full model, which was strongly supported as the single best model ($AIC_c = 1{,}383.726$; the difference in AIC_c value [ΔAIC_c] between the best model and the second-best model was greater than 8; Table A.1), included

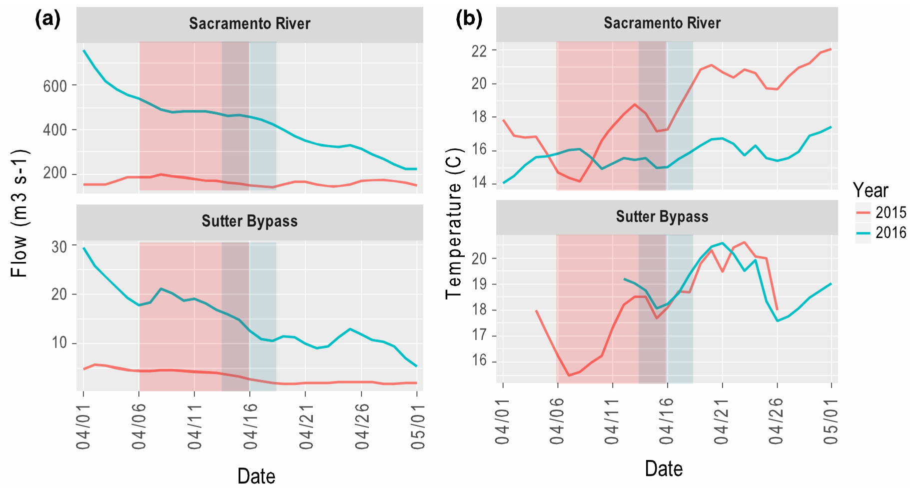

FIGURE 2. **(A)** Mean daily flow (m^3/s) in April 2015 and 2016 for the Sacramento River (California Data Exchange Center [CDEC] Verona station: http://cdec.water.ca.gov/cgi-progs/stationInfo?station_id=VON) and Sutter Bypass (CDEC station BSL [Butte Slough near Meridian]: http://cdec.water.ca.gov/cgi-progs/staMeta?station_id=BSL); and **(B)** mean daily water temperature (°C) during April 2015 and 2016 for the Sacramento River (CDEC Verona station) and Sutter Bypass (Butte1 site; Advanced Telemetry Systems receiver thermistor). The shaded rectangles indicate the tagging and release time periods in Sutter Bypass for 2015 (in red) and 2016 (in blue). [Color figure can be viewed at afsjournals.org.]

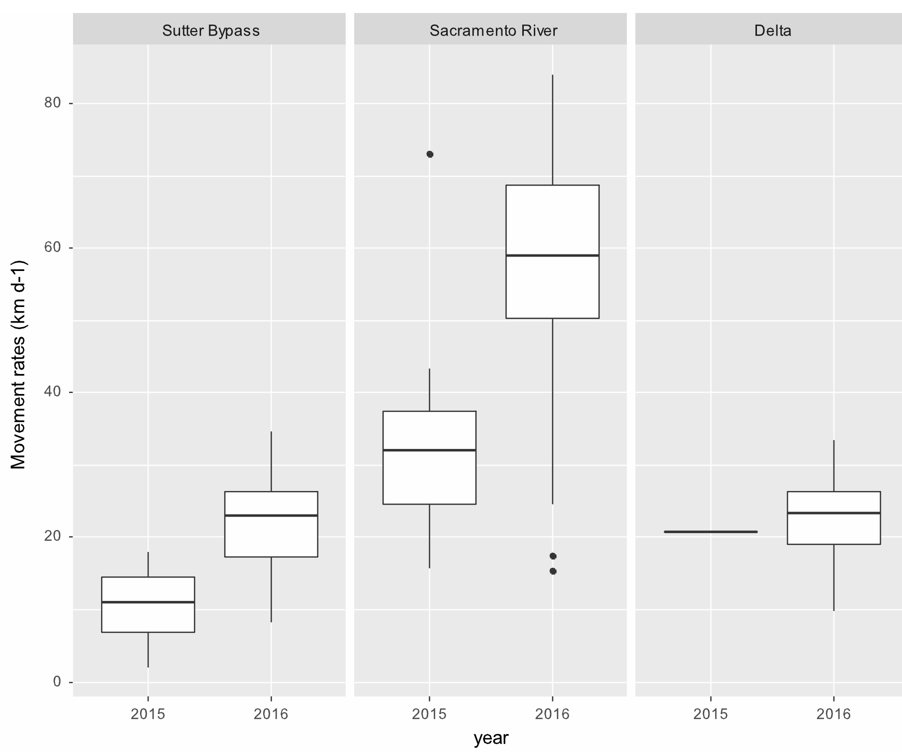

FIGURE 3. Box plot of region-specific movement rates (km/d) for out-migrating Chinook Salmon in 2015 and 2016 (Delta = Sacramento–San Joaquin River Delta). The horizontal bold line represents the median value; vertical whiskers represent the 95th percentiles; and dots denote extreme values.

survival as a function of reach × year and a constant detection probability. This suggested that out-migrant smolt survival varied by location and year. Additionally, although the best model supported a constant detection probability, the spatially explicit models (i.e., p[~reach]) suggested that detection rates throughout the migratory

TABLE 4. Overall and region-specific percent survival, mean migration rate (km/d), and mean migration time (d), along with SE or SD (in parentheses), for juvenile Chinook Salmon tagged during each year (NA = not applicable).

Year	Region	Percent survival (SE)	Mean (SD) migration rate (km/d)	Mean (SD) migration time (d)
2015	All	0.7 (0.7)	NA	NA
	Sutter Bypass	19.1 (3.3)	10.24 (4.61)	5.75 (4.28)
	Sacramento River	51.8 (9.6)	33.21 (14.31)	1.88 (0.73)
	Sacramento–San Joaquin River Delta	7.1 (6.9)	NA	NA
2016	All	3.0 (1.2)	33.69 (15.32)	18.44 (3.93)
	Sutter Bypass	35.5 (3.4)	22.13 (6.21)	2.15 (0.81)
	Sacramento River	69.0 (5.5)	56.83 (16.26)	1.09 (0.57)
	Sacramento–San Joaquin River Delta	12.2 (4.7)	22.48 (8.03)	5.18 (2.59)

corridor were consistently high, ranging from 0.851 to 1.000. For all model exercises presented in this paper, detection probability was therefore set to be constant through space and time and was estimated at 0.993.

After including individual and environmental variables in the analysis, the φ(~reach + year) model was selected as the best model, emphasizing the strong year effect on smolt survival (Table 3). The model that incorporated Sutter Bypass flow at release as a covariate was substantially better supported ($\Delta AIC_c > 3$) over the base model φ(~reach). Furthermore, it shared similar support ($\Delta AIC_c < 3$) relative to the φ(~reach + year) model (which benefited from a free parameter), suggesting that the flow model explained much of the variation in interannual survival. The model including fish length also had substantial support over the base model ($\Delta AIC_c < 6$) and suggested a positive influence of fish length on survival. However, the models including water temperature at release and Fulton's K were not better supported than the base model, indicating that these covariates had no detectable influence on survival.

We used the full model (i.e., φ[~reach × year]) to estimate survival per 10 km, per region, and cumulatively. Overall, survival through the entire migratory corridor (from the release site to the Golden Gate Bridge) was better in 2016 (3.0%) than in 2015 (0.7%; Table 4). At the regional level comparing 2015 to 2016, survival increased in the Sutter Bypass from 19.1% to 35.5%, in the Sacramento River from 51.8% to 69.0%, and in the Delta from 7.1% to 12.2% (Figure 4; Table 4). For both years, the highest regional survival was observed in the lower Sacramento River, while the lowest estimate was for the Delta region. However, the length of each region varied considerably (the Delta region was about twice as long as the Sutter Bypass and Sacramento River regions; Table 1), and survival often decreases proportionally with increasing region length.

Rates of survival per 10 km varied dramatically between reaches within the Sutter Bypass, the Sacramento River, and the Delta, and some similar survival patterns were observed between years (Figure 5). In the Sutter Bypass, relatively low survival was observed between the release site (the RST at Weir 2 ["Weir2_RST" in Table 1]) and the first receiver (Butte1; 27.1% in 2015) and between the Butte3 and Butte5 receivers (39.3% in 2015; 65.1% in 2016). Survival was higher in the other reaches of the Sutter Bypass, ranging from 72.5% to 94.0% in 2015 and from 79.8% to 84.7% in 2016. In the Sacramento River for 2015, survival decreased from the first reach (Butte6 to the I-80 Bridge; 91.9%) to the second reach (I-80 Bridge to Freeport; 82.5%), whereas it increased in 2016 (92.6% and 95.1%, respectively). Survival in the Delta was lower than in the Sacramento River for both years (76.8% in 2015; 81.1% in 2016). Finally, due to the low number of tagged fish surviving to the Golden Gate Bridge ($n = 1$ in 2015; $n = 4$ in 2016), the 2015 survival rate in the San Francisco Bay could not be estimated, and the 2016 San Francisco Bay survival rate should be used for discussion purposes only.

DISCUSSION

This is the first study to investigate the survival and migration rates of wild Butte Creek spring-run Chinook Salmon smolts during their out-migration to the Pacific Ocean. The acoustic telemetry system used in this study had high detection probabilities (>85%) at all receiver locations. The mark–recapture models provided estimates of survival at fine spatial scales during a dry water year and a wet water year. We showed that Chinook Salmon smolts migrated faster throughout their migratory corridor

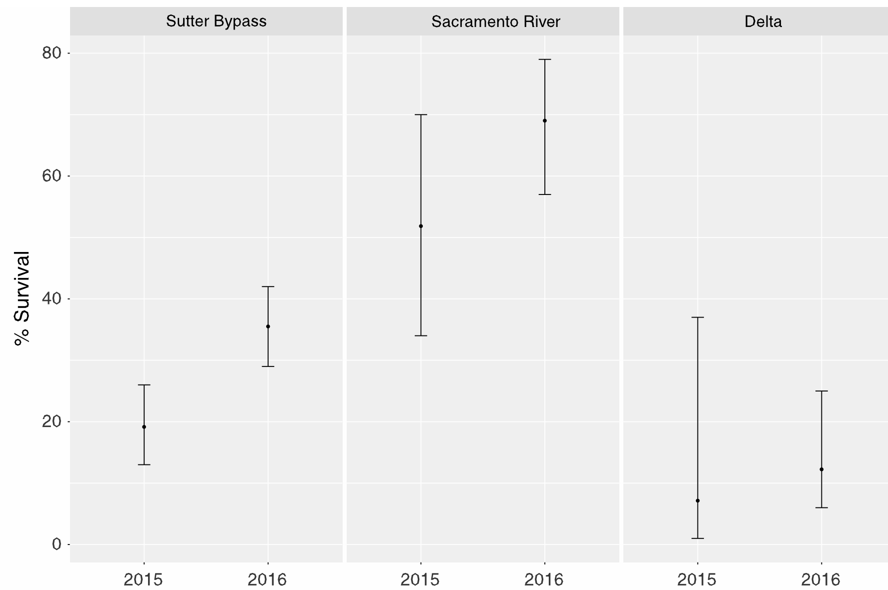

FIGURE 4. Region-specific survival rates (%; mean ± 95% confidence interval) for out-migrating Chinook Salmon in 2015 and 2016 (Delta = Sacramento–San Joaquin River Delta).

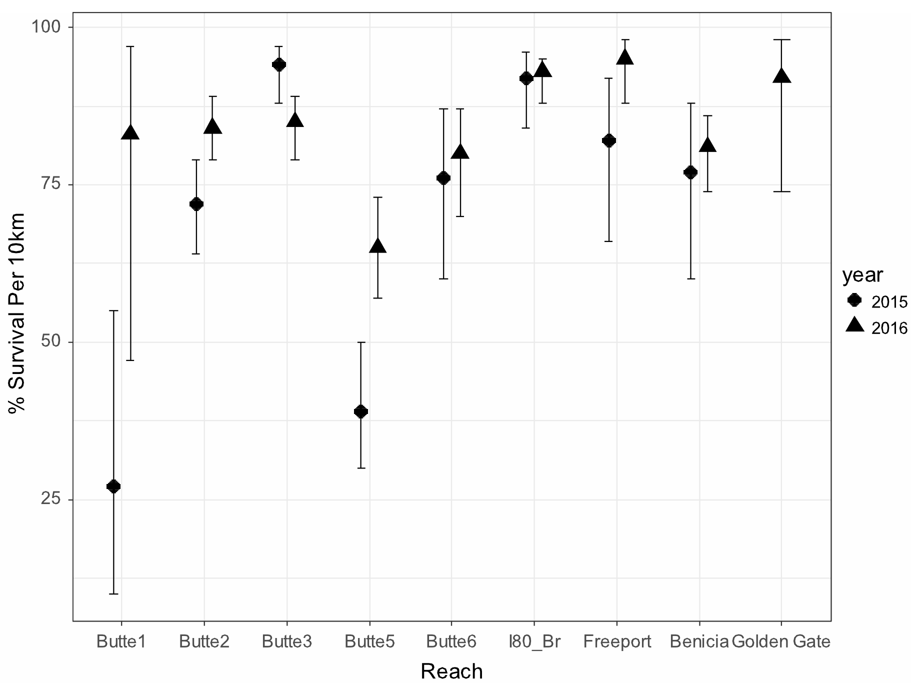

FIGURE 5. Reach-specific rates of survival per 10 km (%; mean ± 95% confidence interval) for out-migrating Chinook Salmon in 2015 and 2016.

in 2016 (a wetter year) than in 2015 (a dry year). This difference is likely due to higher flow velocities, both in the Sutter Bypass and in the Sacramento River, during 2016 compared to 2015. The mean migration rate to the ocean (Golden Gate Bridge) was 33.7 km/d for 2016, which is faster than the total mean migration rate reported for Sacramento River late-fall Chinook Salmon (14.3–23.5 km/d in 2007–2009) by Michel et al. (2013).

Survival to the ocean was also higher in 2016 (3.0%) than in 2015 (0.7%; Table 4). However, these survival rates are lower than most of the survival estimates obtained by Michel et al. (2015) for acoustic-tagged late-fall-run Chinook Salmon yearlings (survival per year ranged from 2.8% to 15.7%). The survival rates we report are also low in comparison with the 2015 and 2016 survival rates estimated by Faulkner et al. (2016, 2017) for populations of wild spring/summer Chinook Salmon from the Snake River (a tributary of the Columbia River) migrating through a much longer watershed than in our study (mean survival rates through the entire 910-km watershed = 38.3% in 2015 and 33.0% in 2016). However, the fish tracked by Michel et al. (2015) and Faulkner et al. (2016, 2017) were larger in size than the fish we tagged in the Sutter Bypass, and we have shown that fish length influences out-migrant survival. Similar to our study, Notch (2017) found very poor survival (0.3%) to the ocean for acoustic-tagged, wild-caught smolts from Mill Creek, an upper Sacramento River tributary. This suggests that out-migration survival of spring-migrating wild Chinook Salmon smolts can be very low and may represent a bottleneck to the recovery of these populations.

In the Sutter Bypass, there were two reaches with substantially lower survival than the other reaches: (1) from the release site to Butte1 during 2015; and (2) between the receivers Butte3 and Butte5 in both years. These two reaches had the lowest survival per 10 km among all reaches in 2015, and the Butte3–Butte5 reach had the lowest survival per 10 km among all reaches in 2016. Common to both these reaches are in-river diversion weir structures (i.e., at the start of Weir2_RST–Butte1 reach and in the middle of Butte3–Butte5 reach). Studies have shown that Striped Bass *Morone saxatilis* and Sacramento Pikeminnow *Ptychocheilus grandis*—both of which are considered major predators of juvenile salmon in the CCV—tend to congregate below in-river diversion weirs and are effective at preying upon disoriented salmon smolts that pass over these structures (Brown and Moyle 1981; Tucker et al. 2003; Sabal et al. 2016). Various nonnative (e.g., Largemouth Bass *Micropterus salmoides*, Striped Bass, and Channel Catfish *Ictalurus punctatus*) and native (e.g., Sacramento Pikeminnow) predators of salmon have been reported in the lower Butte Creek watershed (ICF Jones & Stokes 2009). These predators were also caught in the RST during the present study in both years. If predators are generally concentrated below these diversion weirs, and furthermore if predator concentrations were enhanced during the low-flow conditions in 2015, this may explain the lower survival of juvenile Chinook Salmon in these two reaches.

Similarly, predation could play an important role in the Sacramento River and Delta reaches, as spring-run smolt out-migration timing overlaps with the Striped Bass spawning season. Adult Striped Bass migrate into the San Joaquin and Sacramento rivers in large numbers during the spring to spawn, and they are likely to prey on juvenile out-migrants during that time (Turner 1976; Tucker et al. 2003). The increase in survival observed for 2016 in the Sutter Bypass and the Sacramento River corroborates the assumption that an increase in flow induces an increase of fish transport as well as a potential increase in turbidity, which could both reduce spatiotemporal exposure to predation (Gregory and Levings 1998; Michel et al. 2013 and references therein). The higher flow observed in the Sacramento River in comparison to the Sutter Bypass could explain the higher survival and faster migration rate observed in this region.

On the contrary, the relatively low survival and slower migration rates observed in the Delta could be explained by the complex network of natural and man-made tidally influenced channels that salmon smolts must navigate on their journey to the ocean, thus increasing their exposure to potential predators (Nichols et al. 1986). Perry et al. (2010) demonstrated that survival through the Delta was dependent on the fish route selection, which depends strongly on natural flow conditions and the amount of water exported for state and federal water projects. Poor Delta water quality has also been suggested to influence the survival of out-migrating Chinook Salmon smolts by decreasing their swimming performance and presumably their predator evasion capabilities (Lehman et al. 2017).

It is important to note that our study focused on a single rearing and out-migration life history strategy in which spring-run and fall-run juveniles leave the tributaries as smolts. The results of this study might not be representative of other life history strategies where juveniles out-migrate as fry, parr, or yearlings. Smolts evolved to out-migrate with spring snowmelt freshets during April and May; however, various human-induced and environmental constraints, such as the homogenization of hydrology due to dams, elevated water temperatures associated with dams, and water diversions in the Delta peaking during the spring, are now likely diminishing the benefits of this life history strategy and leading to lower out-migration survival. Given these constraints, life histories that are characterized by earlier out-migration (fry or parr) might exhibit higher relative survival. However, due to their small size, which precludes acoustic tagging, very little is known about these earlier out-migrant life histories. Studies that aim to quantify the proportion of returning adults with the different out-migration life histories (e.g., Sturrock et al. 2015) would be needed to place the smolt out-migration life history studied here into a broader context.

Our results have strong implications for the management of threatened CCV spring-run Chinook Salmon populations. Butte Creek currently supports the most abundant population of spring-run Chinook Salmon in the CCV and provides a key component for the diversity and viability of the spring-run stock. The Sutter Bypass has been designated by National Oceanic and Atmospheric Administration (NOAA) Fisheries as a critical habitat for CCV spring-run Chinook Salmon and is considered an important rearing habitat and migratory corridor (Johnson and Lindley 2016). Therefore, to clearly identify the effects of fish characteristics and environmental variables in relation to juvenile movement and survival, a longer time series with increased sample size is necessary. Moreover, further investigation on salmon predation (especially at in-river structures) and improved water quality monitoring in the Sutter Bypass (i.e., water temperature, flow, and turbidity along the bypass) are critical to facilitate a clear assessment of the reasons for low survival in some of the reaches. This type of information will help target restoration and management projects on specific areas within the Sutter Bypass that could improve spring-run juvenile survival and ultimately lead to increased abundances of adults returning to spawn in Butte Creek. This information could also benefit other runs of CCV Chinook Salmon that use the lower Butte Creek system as a nursery and migratory corridor when accessible and would ultimately promote CCV Chinook Salmon stock diversity and stability.

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Appendix

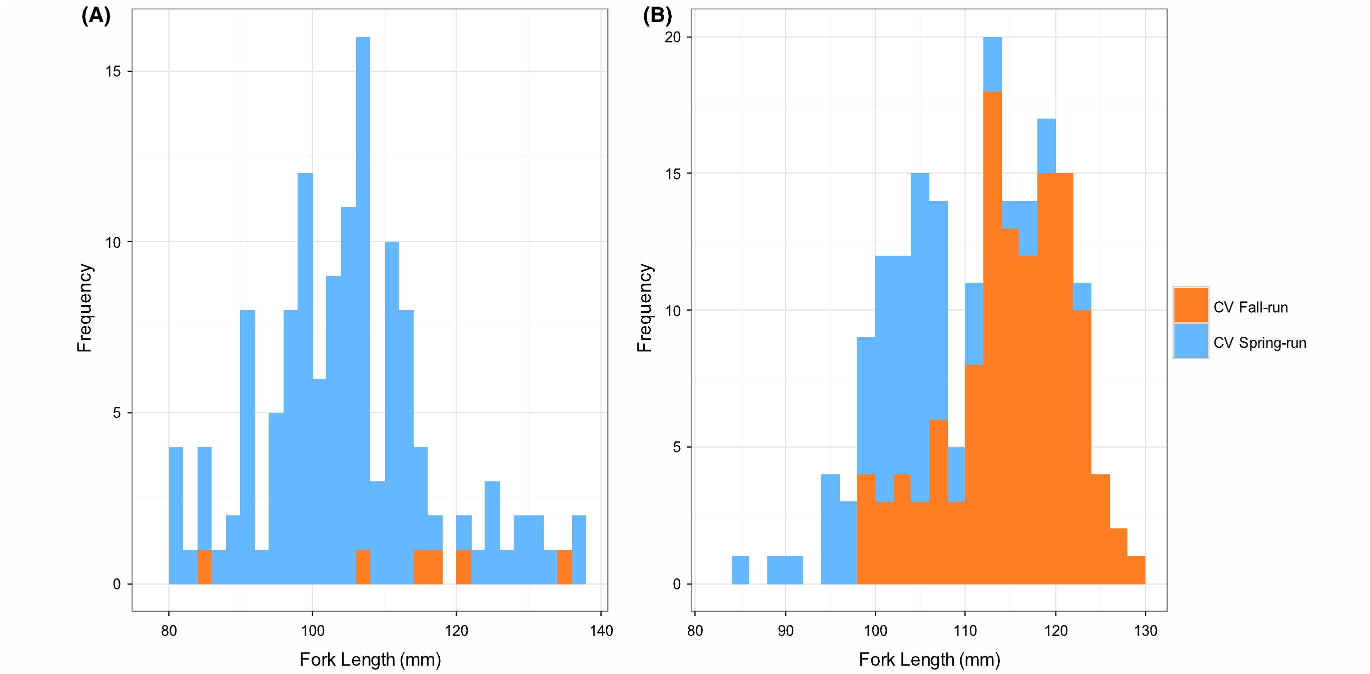

FIGURE A.1. Length frequency histograms of out-migrating Chinook Salmon with genetic distinction that were tagged in the Sutter Bypass during **(A)** 2015 and **(B)** 2016. CV = Central Valley. [Color figure can be viewed at afsjournals.org.]

TABLE A.1. Comparison of constant versus year- and/or reach-varying survival (φ) and detection (p) models for out-migrating Chinook Salmon (N_{par} = number of model parameters; AIC_c = Akaike's information criterion corrected for small sample size; ΔAIC_c = difference in AIC_c score between the given model and the most parsimonious model). Models are ordered from lowest to highest AIC_c. Lower AIC_c scores indicate greater relative model parsimony.

Model	N_{par}	AIC_c	ΔAIC_c
φ(~reach × year), p(~1)	19	1,383.726	0.00
φ(~reach × year), p(~reach)	27	1,392.249	8.52
φ(~reach + year), p(~1)	11	1,394.074	10.35
φ(~reach × year), p(~reach + year)	28	1,394.997	11.27
φ(~reach + year), p(~reach)	19	1,402.255	18.53
φ(~reach + year), p(~reach + year)	20	1,403.608	19.88
φ(~reach), p(~1)	10	1,405.719	21.99
φ(~reach × year), p(~reach × year)	36	1,409.928	26.20
φ(~reach), p(~reach + year)	19	1,416.271	32.55
φ(~reach), p(~reach)	18	1,416.436	32.71
φ(~reach + year), p(~reach × year)	28	1,420.496	36.77
φ(~reach), p(~reach × year)	27	1,429.291	45.56
φ(~year), p(~reach)	11	1,568.503	184.78
φ(~year), p(~reach + year)	12	1,570.401	186.67
φ(~1), p(~reach)	10	1,577.198	193.47
φ(~year), p(~reach × year)	20	1,586.445	202.72
φ(~1), p(~reach × year)	19	1,594.144	210.42
φ(~1), p(~reach + year)	11	1,658.943	275.22
φ(~year), p(~1)	3	1,678.890	295.16
φ(~1), p(~1)	2	1,682.151	298.43

Obegi, Doug

From: Hilts, Derek <derek_hilts@fws.gov>
Sent: Friday, March 29, 2019 8:21 AM
To: Obegi, Doug
Subject: Re: [EXTERNAL] CALSIM modeling questions

Doug,
I think another reason critical year average Shasta storage is higher in the LTO COS than in the CWF NAA is the change in COA sharing percentages. That seems to be supported by the other run results you included in your table. Conversely, Oroville critical year average storage is 124 TAF lower in the COS than the CWF NAA.

FYI, the combination of the new COA percentages, no TUCPs, ELT hydrology and the model's reservoir-delivery balancing caused Oroville to drop to the unrealistic level of 139 TAF in 1977 in the COS simulation.

Derek Hilts M.S., P.E.
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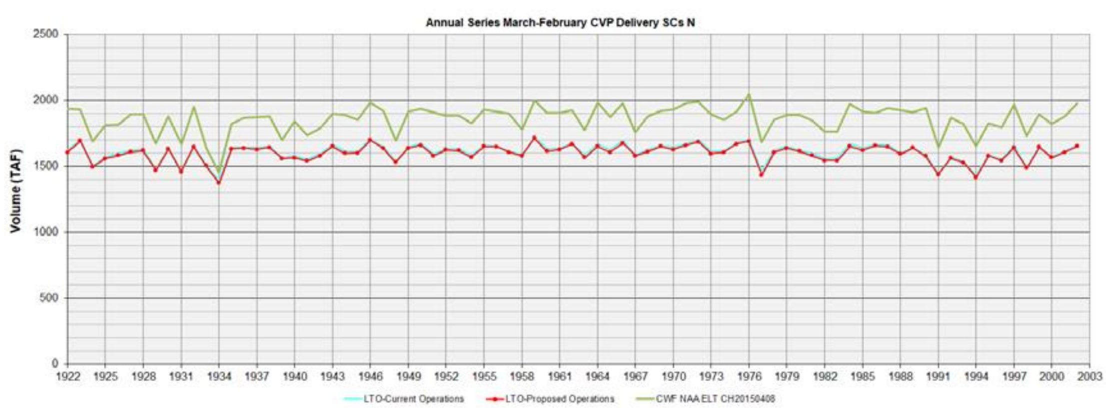
Sacramento, California 95814
Work desk phone 916.930.5633

On Thu, Mar 28, 2019 at 3:33 PM Hilts, Derek <derek_hilts@fws.gov> wrote:

> Doug,
> The chart below shows the annual delivery volume to the Settlement Contractors. As we discussed, the basis for delivering water to them was updated since the CWF modeling. That should at least partially help explain the dry & critical year storage improvements.
> Derek
>
> 
>
>
> Derek Hilts M.S., P.E.
> US Fish and Wildlife Service
> 650 Capitol Mall Room 8-300
> Sacramento, California 95814
> Work desk phone 916.930.5633
>
> On Thu, Mar 28, 2019 at 3:18 PM Obegi, Doug <dobegi@nrdc.org> wrote:
>
> > Ok, so then is that code only turned on in the Proposed Project CALSIM runs?

From: Hilts, Derek <derek_hilts@fws.gov>
Sent: Thursday, March 28, 2019 3:16 PM
To: Obegi, Doug <dobegi@nrdc.org>
Cc: Matt Nobriga <matt_nobriga@fws.gov>; Kaylee Allen <kaylee_allen@fws.gov>
Subject: Re: [EXTERNAL] CALSIM modeling questions

Doug,

Hold the presses! After we talked I went into the code further. The relaxation logic we discussed is NOT turned on in the LTO runs. I'm very sorry to have misled you. I will now look to see if I can unearth why the critical year Shasta Storage is improved in the COS relative to the CWF NAA.

Derek

Derek Hilts M.S., P.E.

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On Thu, Mar 28, 2019 at 8:31 AM Obegi, Doug <dobegi@nrdc.org> wrote:

> Thanks Derek. I'll call that number today. And that is super helpful detail.
>
> Sent from my iPhone
>
> On Mar 28, 2019, at 8:09 AM, Hilts, Derek <derek_hilts@fws.gov> wrote:
>
>> Hi Doug,
>>
>> My apologies, but due to Kaylee's fluid schedule I need to change the phone number for our call this afternoon, again.
>>
>> Please call 916.930.2643
>>
>> Thanks.

By the way, regarding your first concern, I believe the improved critical-year carryover in 2nd, 5th & 6th columns of your table are due to Reclamation's adding logic to those CalSimII runs to reflect SWRCB TUCPs during the seven driest years of the 82 year simulation period. If you or a coworker there can read CalSimII's WRESL code, search for "@jmg" to find all the places the logic has been implemented. I'm attaching one wresl file in particular, but @jmg occurs several other places.

Derek Hilts M.S., P.E.

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---------- Forwarded message ---------
From: **Obegi, Doug** <dobegi@nrdc.org>
Date: Tue, Mar 26, 2019 at 11:51 AM
Subject: RE: [EXTERNAL] CALSIM modeling questions
To: Hilts, Derek <derek_hilts@fws.gov>

Thanks Derek. Below are four of the modeling issues I'm struggling to understand and wanted to talk with you about:

1. Significant changes in carryover storage under the baseline conditions between this BA and the WaterFix BA and other CALSIM studies.

When I reviewed the BA, I noticed that Shasta EOS carryover storage seems to be several hundred thousand acre feet higher under the COS scenario in this BA than in the NAA scenario in the WaterFix BA, as well as in some other CALSIM modeling runs. See below.

	ROC BA (Current Operations)	**WaterFix BA (NAA)**	**2015 ROC EIS (No Action Alternative)**	**USBR 2018 COA EA (NAA)**	**USBR 2018 COA EA (PP)**
Shasta EOS Storage					
Wet	2989	2985	2985	3090	3076
Above Normal	2833	2835	2834	3013	2982
Below Normal	2729	2615	2608	2833	2808

Dry	2611	2459	2462	2460	2504
Critically Dry	1225	914	937	1333	1430

I can't make heads or tails of why there is this significant increase in carryover storage in dry and critically dry years in this BA compared to WaterFix and the 2015 reinitiation EIS. I've only done spot checks but there are number of pretty substantial changes in CALSIM modeling results from these two baseline runs including total exports (e.g., December, April, and July), Delta outflow in certain months (e.g., August under 70%-90% exceedences), river flows (SJR Vernalis flows in March and April), New Melones EOS storage in dry and critically dry years, etc.

2. <u>Modeling assumptions about OMR and storm waivers:</u>

I'm struggling to reconcile the project description (e.g., BA at 4-51 to 4-54) with the modeling assumptions for OMR (e.g., Appendix D at page 35 of the pdf). Curious if you read this similarly to me.

3. <u>Modeling assumptions regarding level of diversions and demands </u>(See Appendix D at 45, 46).

4. <u>Climate change modeling assumptions regarding air temperatures</u>

Does the BA incorporate increased air temperatures in the modeling for temperature dependent mortality? In some places the BA suggests that it doesn't, in others that it does. How does air temperature modeling in the BA for dry and critically dry years compare to observed air temperatures in the recent drought, for instance? *(I'm not sure if you know the answer to this question since its not squarely a CALSIM modeling question)*

Look forward to talking on Thursday at 2 pm.

Thanks again,

Doug

<TUCP_est.wresl>