STAFF SUMMARY FOR FEBRUARY 8-9, 2023

16. DEPARTMENT UPDATE ON IN-RIVER SALMON

Today's Item **Information ☒** **Action ☐**

Receive Department presentation and discuss in-river salmon needs and threats.

Summary of Previous/Future Actions (N/A)

Background

For decades, California salmon populations have undergone a series of challenges that have resulted in substantial declines. From wildfire and drought to pollutants, migration barriers and now thiamine deficiencies, salmon management presents complex threats that require innovative, unique management strategies.

At the Commission's December 2022 meeting, the Northern California Guide and Sportsman's Association (NCGASA) requested an opportunity for a presentation and a discussion on actions that can be taken to reverse the declines of salmon populations.

Today, the Department will present on salmon needs and current threats, as well as provide an update on some of the actions it is taking to manage salmon stocks (Exhibit 1). NCGASA will then present its assessment of the state of Sacramento River salmon.

Significant Public Comments

1. NCGASA provides a report regarding the state of Sacramento River fall-run salmon (Exhibit 2).

Recommendation (N/A)

Exhibits

1. Department presentation, received February 2, 2023
2. *Sacramento River Fall Run Salmon*, received January 26, 2023

Motion (N/A)

Sacramento Fall Run Salmon Needs Threats, and Department Actions

February 2, 2023

Jay Rowan
Chief, Fisheries Branch

Presentation Overview

- Sacramento fall-run Chinook Salmon Needs
- Threats
- Sacramento fall-run Salmon Status and Trends
- California Department of Fish and Wildlife (CDFW) Actions

Sacramento Fall Chinook Salmon Needs

- Adult Migration
  - Cool Water <65F, Flow

- Egg incubation
  - Cold Water temperatures <53F
  - Clean Gravel, Flow

- Rearing and migration
  - Cool Water<65, Flow, Rearing Habitat, Food

Threats: Habitat loss

- Dam construction
  - Access to spawning habitat
  - Gravel mobilization and transport
  - Flow regimes
- Population increases
  - 1970-2020 2.78 to 7.26 million people
- Land use
  - Loss of flood plain and riparian habitat
  - River Channelization

Threats: Water Quality and Disease

- Temperature
- Flow
- Disease
- Urban and agricultural contaminants
  - Pesticides
  - Stormwater and wastewater treatment plant discharges
    - 6PPD, endocrine disrupters

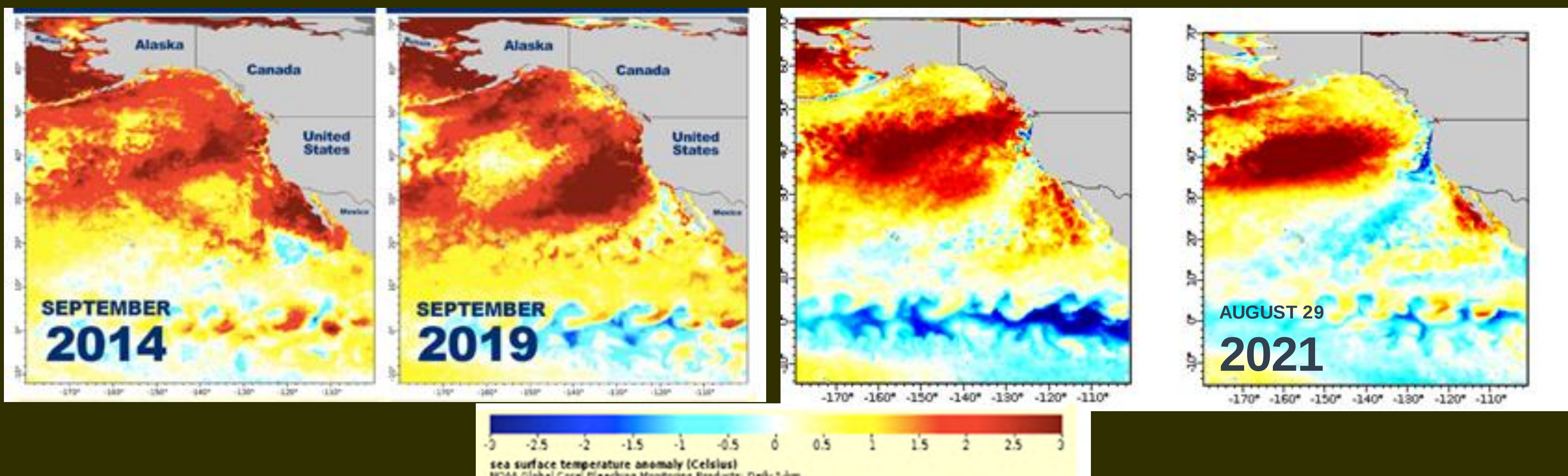
Climate Change Impacts

- Fire
- Harmful Algal Blooms
- Drought
- Ocean Forage shifts and thiamine deficiency

The “Blob” 2014-2021

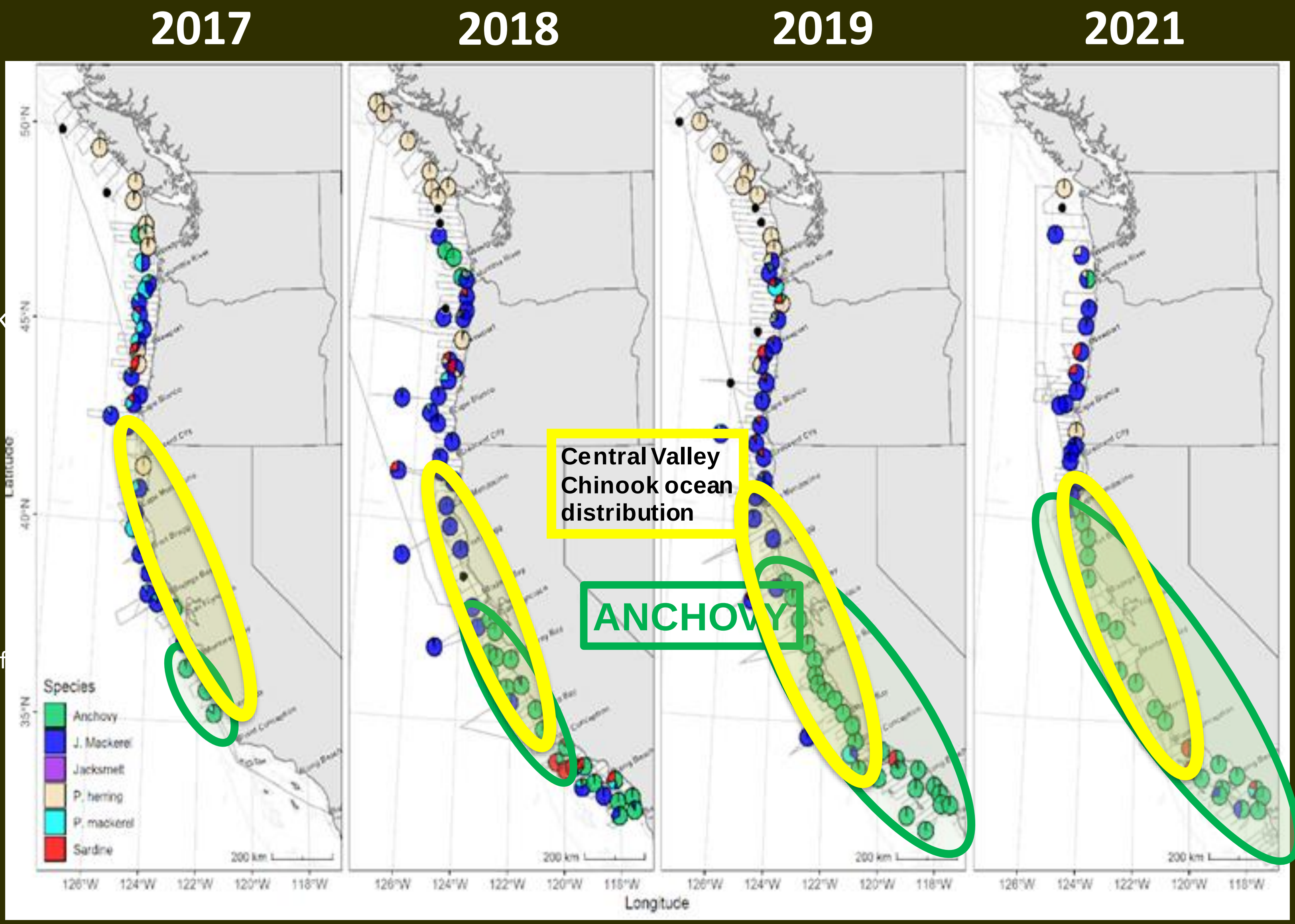
Frequent Marine Heatwaves from 2014-2021?

Extreme and persistent warm periods have affected the northeast Pacific, bringing widespread impacts on marine life and fisheries.



https://www.fisheries.noaa.gov/feature-story/new-marine-heatwave-emerges-west-coast-resembles-blob

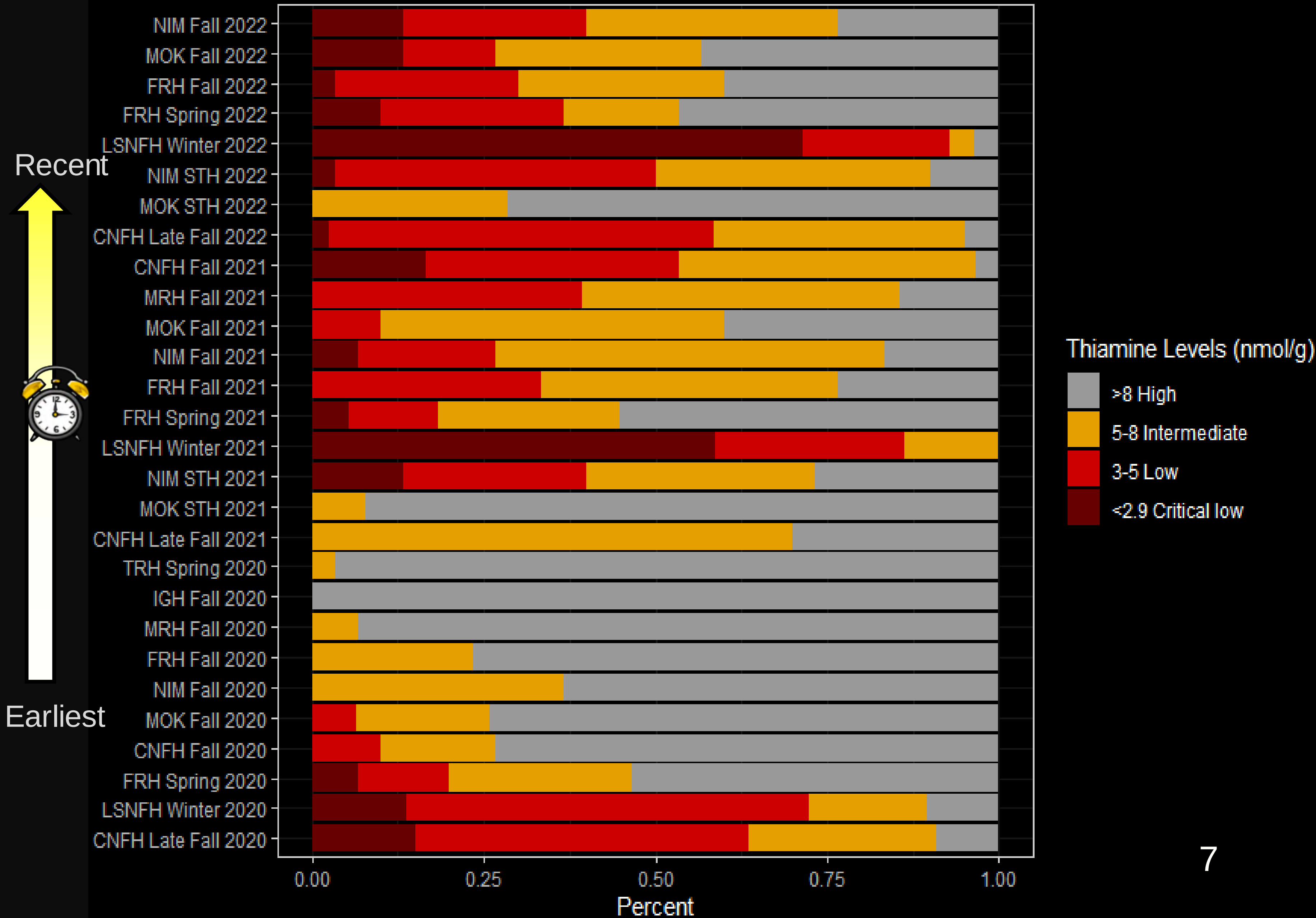
Coastal Pelagic Species from National Marine Fisheries Service (NMFS) Summertime acoustic-trawl surveys



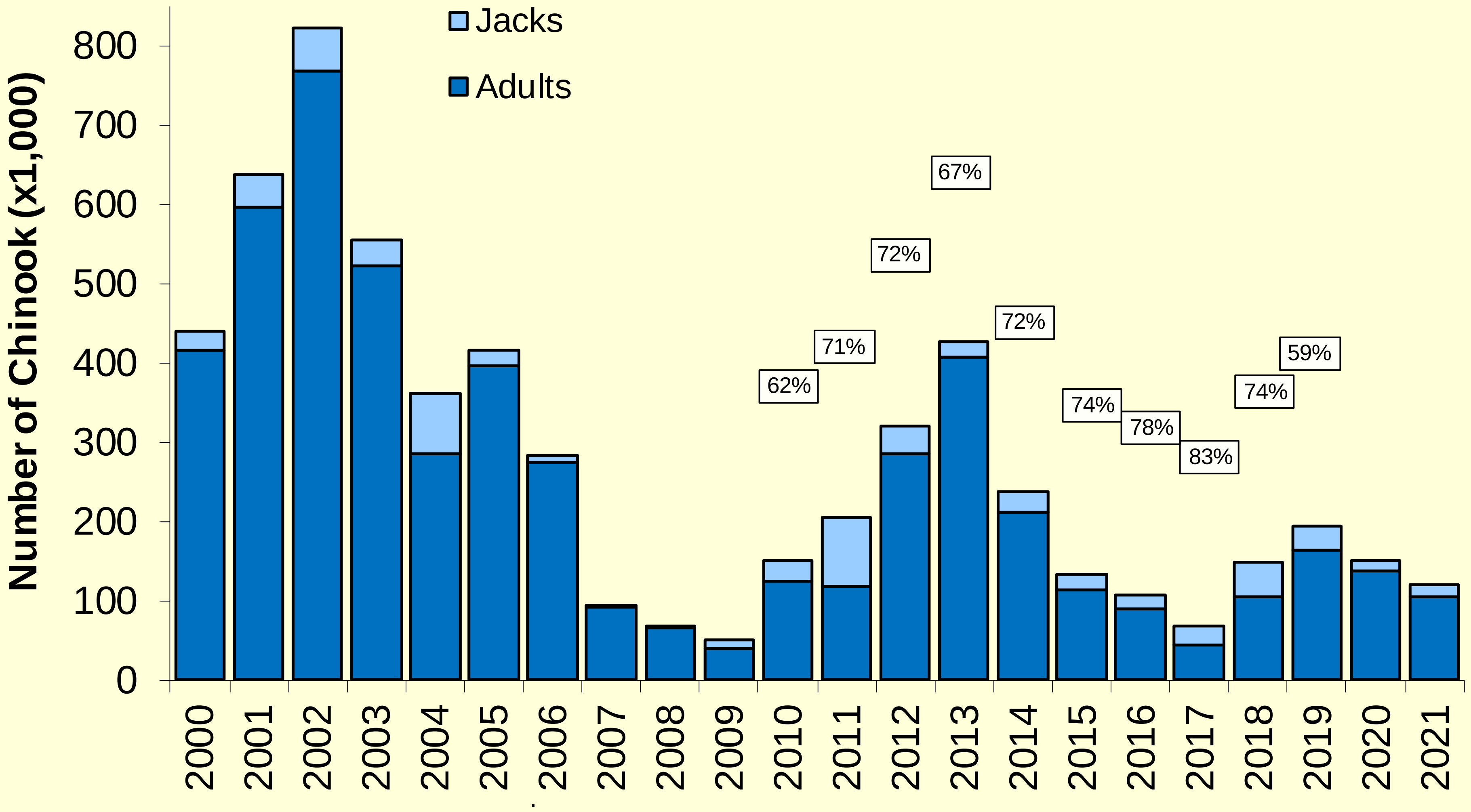
Central California northern anchovy stock biomass and north end of their distribution expanded greatly from 2017-2021.

(NMFS Tech Memos; figure from K. Stierhoff NMFS)

Broad Scale Egg Surveillance Chinook and Steelhead Central Valley

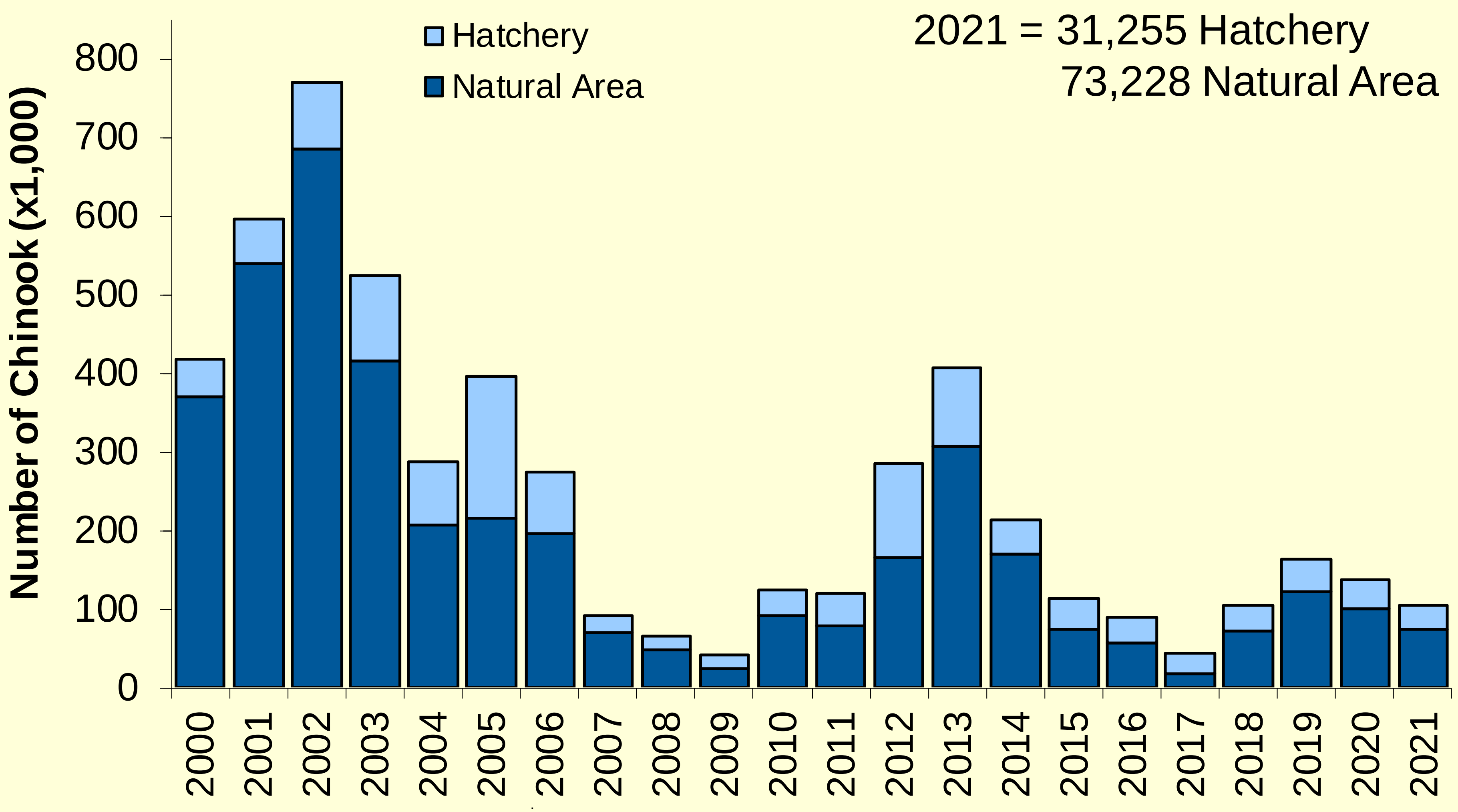


Sacramento River Fall Chinook
Adult & Jack Spawning Escapement, 2000-2021

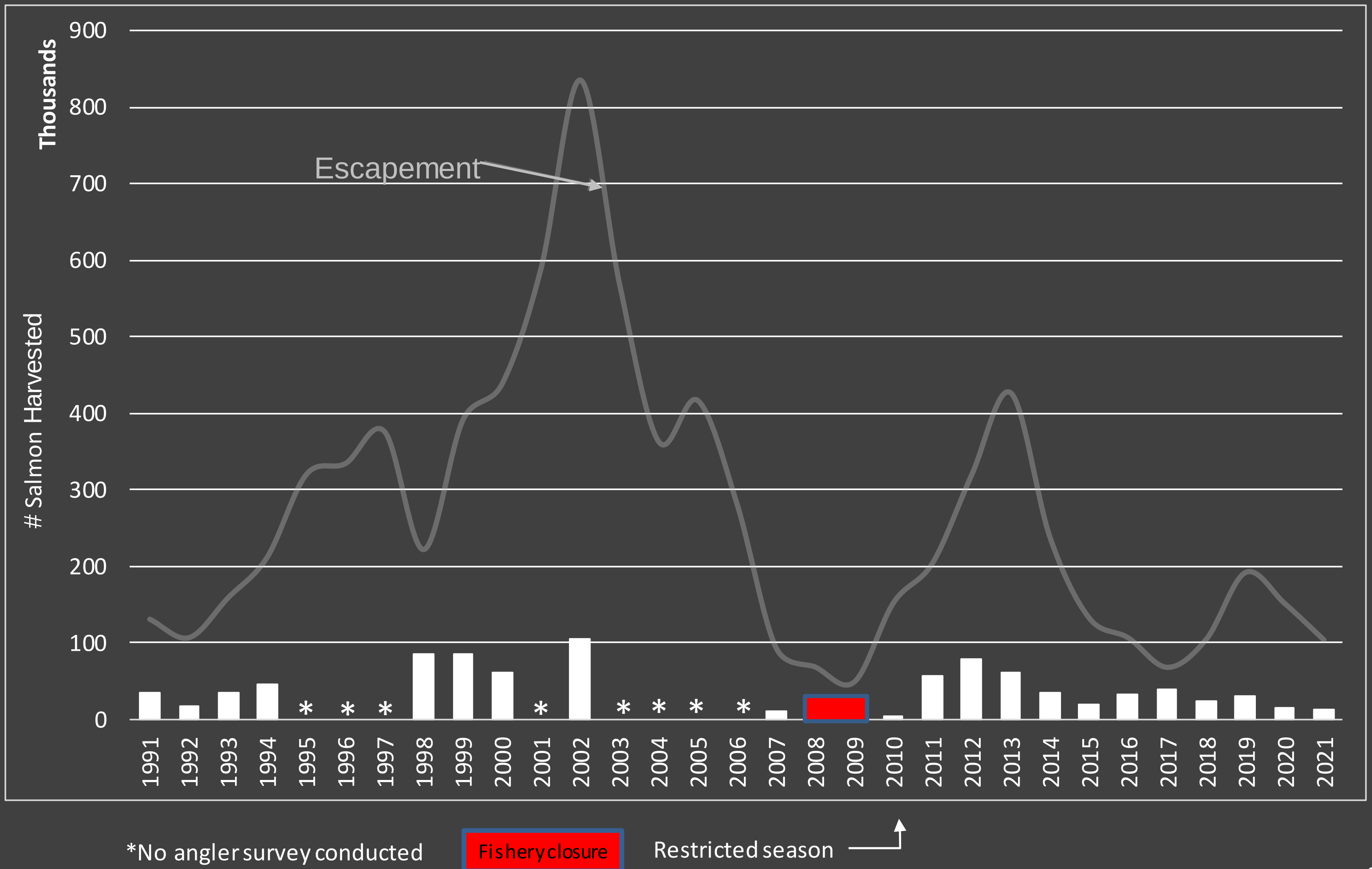


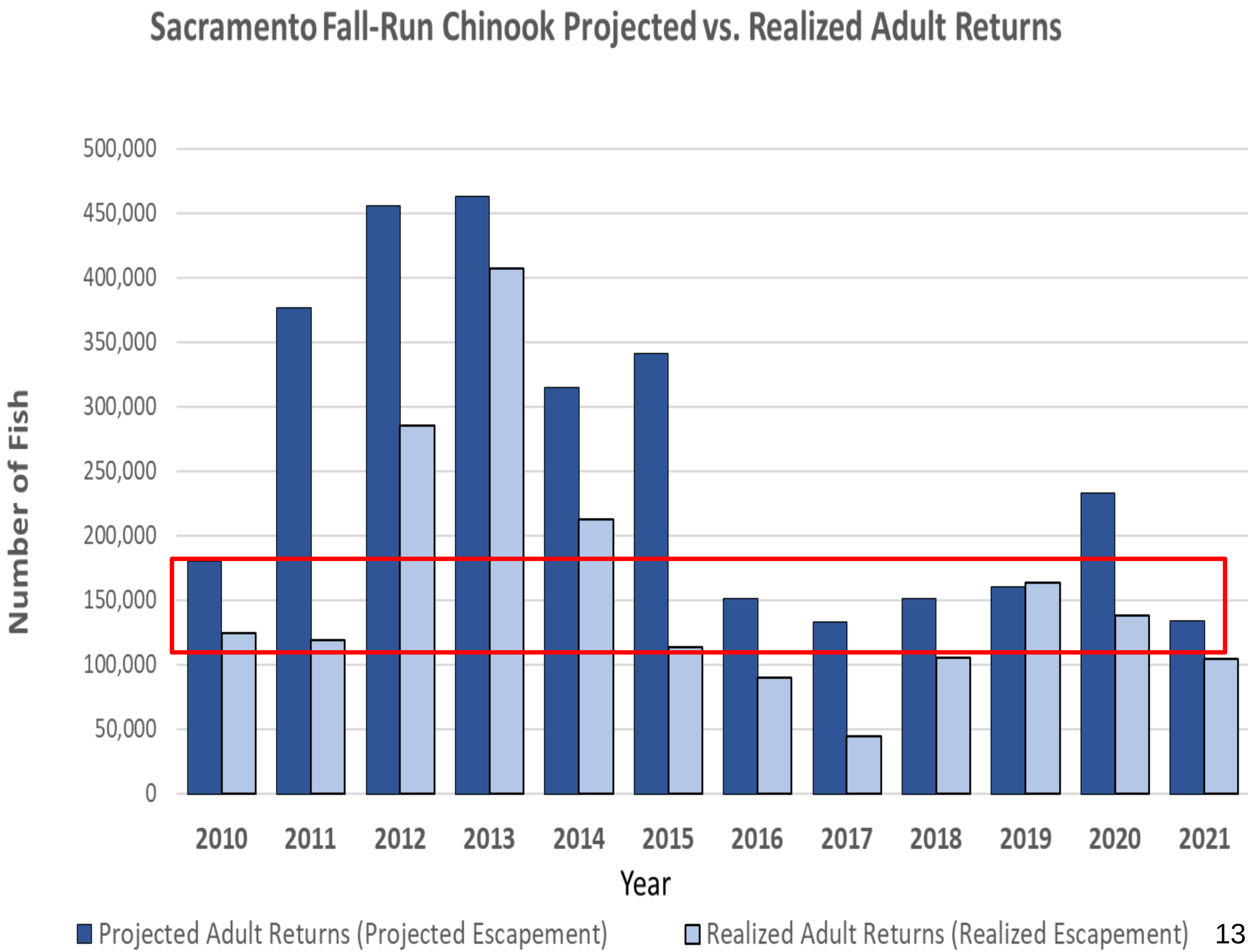
Sacramento River Fall Chinook

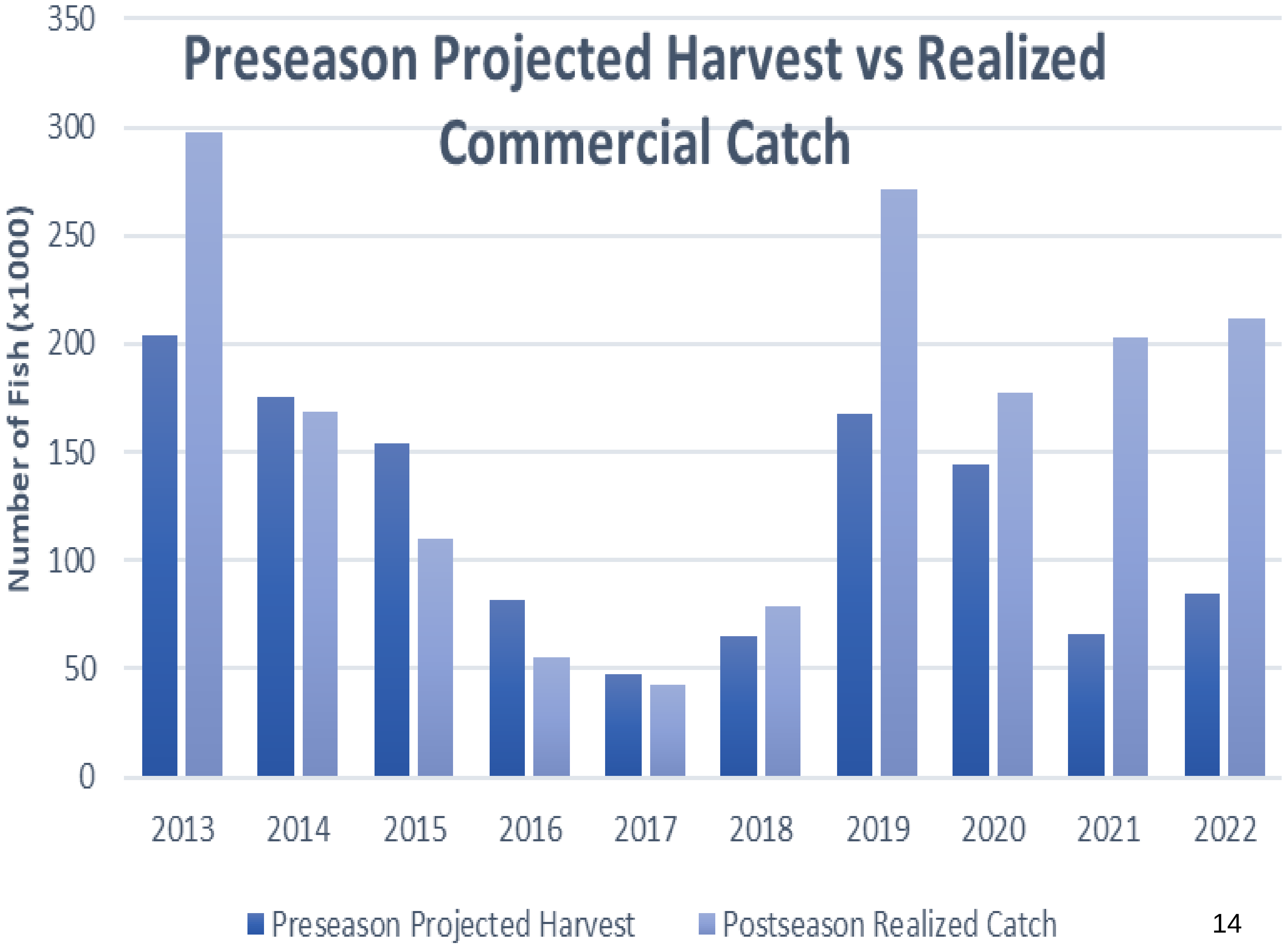
Hatchery & Natural Area Adult Spawning Escapement, 2000-2021



Sacramento River Fall Chinook Harvest Trends 1991-2021




Sacramento Fall-Run Chinook Projected vs. Realized Adult Returns
Number of Fish
500,000
450,000
400,000
350,000
300,000
250,000
200,000
150,000
100,000
50,000
0
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
Year
Projected Adult Returns (Projected Escapement)
Realized Adult Returns (Realized Escapement)


Preseason Projected Harvest vs Realized Commercial Catch
Number of Fish (x1000)
0
50
100
150
200
250
300
350
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
Preseason Projected Harvest
Postseason Realized Catch

What Actions is CDFW taking

- Stakeholder and NGO Coordination and Communication
  - March 1st Annual Salmon informational meeting
  - Salmon Stamp, CAC, Salmon Partners
- Water Operations and directives
- Monitoring and science
- Restoration funding
  - Fisheries Restoration Grant Program, CMP, Prop 1/68, drought, etc.
- Passage above rim dams

CDFW Actions Continued

- Working with NMFS and Pacific Fishery Management Council to address Ocean harvest objectives and inland escapement discrepancy
- Inland Harvest Regulations
- Hatchery Operations
  - Increased Science capacity
  - Increased production- 2.5M additional fish
  - Release Practices-Expand portfolio
  - Hatchery Climate Resilience

Questions?

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Sacramento Fall Chinook Escapement Objectives

Table 1. Preseason-projected vs. postseason actual escapement for SRFC, 2010-2021.

Year	SI Forecast	Postseason SI	Pre / Post	Minimum Escapement Goal for Year	Management Objective for Year (Pre-III, table 5)	Preseason Projected Escapement	Postseason Escapement	Pre / Post
2010	245,483	152,857	1.6	180,000	2010 Council and NMFS guidance for natural and hatchery adult spawners	180,000	124,276	1.45
2011	729,893	199,308	3.7	180,000	2011 Council and NMFS guidance for natural and hatchery adult spawners	377,000	119,342	3.16
2012	819,400	627,900	1.3	245,820	2012 preseason ACL and minimum spawners under default rebuilding plan	455,800	285,429	1.60
2013	834,208	862,525	1.0	250,300	2013 preseason ACL	462,600	406,846	1.14
2014	634,650	554,932	1.1	190,400	2014 preseason ACL	314,700	212,476	1.48
2015	651,985	255,287	2.6	195,600	2015 preseason ACL	341,000	113,468	3.01
2016	299,609	205,023	1.5	122,000	2016 minimum hatchery and natural area adult escapement (FMP control rule)	151,100	89,699	1.68
2017	230,700	139,997	1.6	122,000	2017 minimum hatchery and natural area adult escapement (FMP control rule)	133,200	44,329	3.00
2018	229,432	223,854	1.0	151,000	2018 minimum hatchery and natural area adult escapement (Council guidance)	151,000	105,466	1.43
2019	379,632	505,535	0.8	160,000	2019 minimum hatchery and natural area adult escapement (NMFS guidance)	160,200	163,767	0.98
2020	473,183	351,925	1.3	142,000	2020 minimum hatchery and natural area adult escapement (FMP control rule)	233,200	138,091	1.69
2021	270,958	322,137	0.8	122,000	2021 minimum hatchery and natural area adult escapement (FMP control rule)	133,900	104,483	1.28

Sacramento River Fall Run Salmon

Summary and Conclusions

This report focuses on the escapement failures and escapement data and factors related to escapement failures of Sacramento River Fall Run Chinook Salmon (SRFRCS). Our analysis indicates escapement (recruitment) failure can come quickly (in one year). Recovery may take years or may not occur if stocks become too depressed. The escapement target of 122K is not realistic because escapement can drop to that level quickly in modern times with moderate ocean and inland harvest. Natural spawning stocks are not definable since in-river spawning stocks are predominately hatchery fish or the offspring of hatchery fish. So, the question of what is natural-produced or hatchery-produced is moot. The upper Sacramento in-river (naturally-spawning) stock is greatly depressed and probably headed in the direction of the upper Sacramento spring run stock – extinction at least in the "wild"-genetic stock. Current management[1] does not work well because of the heavy hatchery influence, poor in-river natural-spawning conditions, over- and unequal-harvest, and fishable stocks operating well below their maximum sustainable yield (MSY). Harvest in-river during the SRFR run is often poor because of poor river conditions that delay the run. Salmon must wait to migrate up from the Bay until Delta and lower river waters cool sometime in early fall. Spawners are unhealthy and stressed when they arrive on the spawning grounds – and Thiamine deficient - by the time they can spawn because of poor holding conditions and excessive water temperatures that delay spawning. Summer water allocation from Shasta Reservoir for winter-run salmon leaves nothing for fall-run salmon. The HSRG and the HGMPs attempt to improve the genetics and save the few remaining near-extinct "wild"-genetic fish, and thus do not address the problem of poor stock levels, and low harvests and escapement of remaining natural-born and hatchery-produced stock elements. It really is a "wicked" problem, virtually unsolvable under the present science and management framework. There are so many things that can be done, but only a minimum is tried or accomplished. Trucking hatchery smolts to the Golden Gate and coastal bays dramatically increases adult returns per smolt released but creates a complex straying "problem".[2] Moving fertilized eggs from Coleman-origin salmon back to Coleman seems to be a viable short-term solution if straying is considered a problem. If there is concern that straying will reduce the run up the mainstem Sacramento River, then just fix the real problem – the water is too warm in late summer and fall – forcing delays and straying to refuge waters of the lower tributaries.

Natural River production:

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[1] The combined responsibilities of the federal and state agencies (PFMC, USFWS, NMFS, CDFW, SWRCB, CDWR, etc).

[2] Straying is only a problem if keeping separate genetic hatchery stocks is an objective and securing sufficient eggs for each hatchery is a problem. There is little genetic difference between the various Central Valley fall run stocks because of many decades of straying and inbreeding.

Natural river production of the fall-run and late-fall-run Chinook salmon populations of the mainstem of the Sacramento River that historically spawned in the upper 60 miles of the river between Red Bluff and Keswick Dam made up the largest natural-spawning run of salmon in California for many decades until the populations crashed in the 2007-2009 drought. Numbering near 200,000 natural spawners around the year 2000, escapement declined to less than 10,000 natural spawners in 2009. About two-thirds of the run was natural-origin (not born in a hatchery). However, the vast majority had been descendants of hatchery salmon. The decline is even worse considering 2008 and 2009 had total fishery closers. Ocean and river fishery harvest had totaled near 50% around year 2000. The decline has been attributed to poor ocean and river conditions faced by brood years 2005 and 2006, as well as poor river conditions when they returned in 2008 and 2009. A small recovery to near 40,000 natural spawners occurred after three wetter years (2010-2012) supported by enhanced hatchery production despite 50-60% harvest, only to crash below 10,000 again by the end of the 2013-2015 drought under the burden of 50% harvests. After this drought the population failed to fully recover after four wetter years (2016-2019) reaching less than 30,000 in 2019 and 14,000 in 2021 under 50% harvests. The prognosis for brood years 2019-2021 is grim given the latest 2020-2022 drought.

- Natural-origin SRFRCS suffer from problems in the mainstem river and tributaries - redd dewatering, warm water, turbid, delayed spawning stress, thiamine deficiency, poor spawning habitat, lack of attraction flows, lack of juvenile emigration flows and poor downstream habitats on the route to the ocean.

Hatchery Production:
- Reduced production from poor spawning habitat and poor-quality hatchery and in-river spawning and habitat conditions prior to entering the hatchery.
- Less trucking is not going to solve the problem, but more trucking to the Bay and coast will and quite dramatically (at least for the coastal fishery).
- HSRG has reduced hatchery and natural-origin production. Poor river, Delta, and Bay conditions have done the rest. Trying to separate natural-origin and hatchery spawners per the HSRG will not work.

Genetics Problem:
- Genetic inbreeding over long term has real drawbacks
- Hatchery selection process could be improved.
- Smolt releases could be much better.
- Spawning is delayed by warm reservoir water releases that affects natural selection.

Natural in-river fry and smolt production:
- Declining because of S/R problems (too few spawners), poor habitat conditions, and ineffective HSRG management.
- Taking, culling, and disposal of hatchery fish results in nutrient loss to rivers from loss of carcasses.

Turning production hatcheries into conservation hatcheries:

- Improving genetics (is it too late for that?)
- Reducing production salmon (producing less smolts will make matters worse)

Reducing overall escapement and return (fishery and escapement):

- Problems will worsen with climate change and present management.
- Hatcheries are reducing smolt production and employing less effective release regimes has been a factor in the decline.
- Tailwater spawning habitat continues to degrade, restoration is poorly done and insufficient in quality and quantity.
- Mokelumne Hatchery doing it right.

What has changed since 2000:

- Droughts are more frequent, and stocks cannot rebuild/recover.
- Hatcheries truck less.
- Hatcheries produce fewer smolts.
- River emigration and immigration routes have become much poorer in habitat quality.
- Harvest continues at historical rates despite stock declines.

Introduction

The Sacramento River Fall Run Chinook Salmon (SRFRCS) population is the core-stock of California salmon fishing. The population is made up of natural-spawned (in-river) and hatchery salmon from the mainstem Sacramento River and its tributaries north of the Delta. Most of the adult spawners (75-90%) originate from the five Central Valley fall-run salmon hatcheries. The population is the core of the Central Valley Chinook Distinct Population Segment (DPS) and Evolutionary Significant Unit (DPS), the most important population and the primary population of the CV-ESU/DPS. The SRFRCS population generally reaches into the hundreds of thousands of adult spawners (escapement), numbers that keep it from being listed on state and federal endangered species lists[3]. After reaching record lows in 2008-2009 and 2016-2017 after multiyear droughts (Figure 1; Table 1), and then a measure of recovery in 2013 and 2019, it appears the population is headed for new record lows in 2022-2024 because of the 2020-2022 drought.

The population lows or "stock collapses" are the result of recruitment failures in the three multiyear droughts. Some scientists would blame the population lows on hatchery inbreeding and lack of the population resiliency to such droughts. Some scientists would blame the lows on ocean conditions. But neither are the primary cause. Most scientists would agree that the lows were from overuse of available water supplies in the Sacramento River watershed during the droughts. The fact is if it were not for the hatcheries, few salmon would have returned after three years of drought because there was little water left in the three main Sacramento River reservoirs to sustain smolt production to the ocean. All five Central Valley fall-run salmon hatcheries have resorted to trucking their smolts and releasing them in Bay or coastal waters in drought periods, where percent returns (fisheries and river-hatchery escapement) were 10-100 times greater than concurrent river (near hatchery) smolt releases. As a result, total escapement is now predominantly hatchery fish (>95%) based on hatchery tags returns[4]. After just the first year of the recent-decades multiyear droughts, reservoirs were so depleted from water releases for agriculture and urban use, salmon recruitment had begun to decline. By the third year, both bad conditions and poor numbers of returning spawners from the first-year recruitment failures brought escapement to record low levels. As priorities switched to the endangered winter run salmon, water allocations from the three main Sacramento River reservoir that had benefitted fall-run salmon were virtually eliminated in all the drought years, but especially in the third years of the droughts.

Because of the dominance of hatchery salmon in the three dominant Sacramento Valley FRCS populations (Sacramento River mainstem, Feather River, and American River), the loss of "natural-salmon" genetic inputs into the hatchery populations, the natural-genetic composition

[3] The ESU has been reviewed again for ESA listing but remains "a species of special concern". In recent years, the poor recruitment, and numbers of wild SRFRCS have again created interest in considering the population for listing.

[4] Most of the "Natural Area" or "In-River" counts have also been hatchery fish. Most "natural born" salmon are the offspring of hatchery salmon.

and diversity in each salmon population, and extreme low numbers of the natural-born salmon component of the populations, there is now pressure to "naturalize" the SRFRCS and reduce the proportion of hatchery origin spawners (pHOS) in the natural spawning areas and in the hatcheries. At one extreme a solution to reduce pHOS is eliminating hatcheries, at another is using only natural-origin spawners in hatcheries, while at another is using only hatchery-born spawners in hatcheries and saving the river spawning for natural-origin spawners. Each of these alternatives has their supporters and detractors. This report supplies information for evaluating these alternatives.

In the next two sections, we summarize the status of the SRFRCS population, its population dynamics, and the causes of its decline.

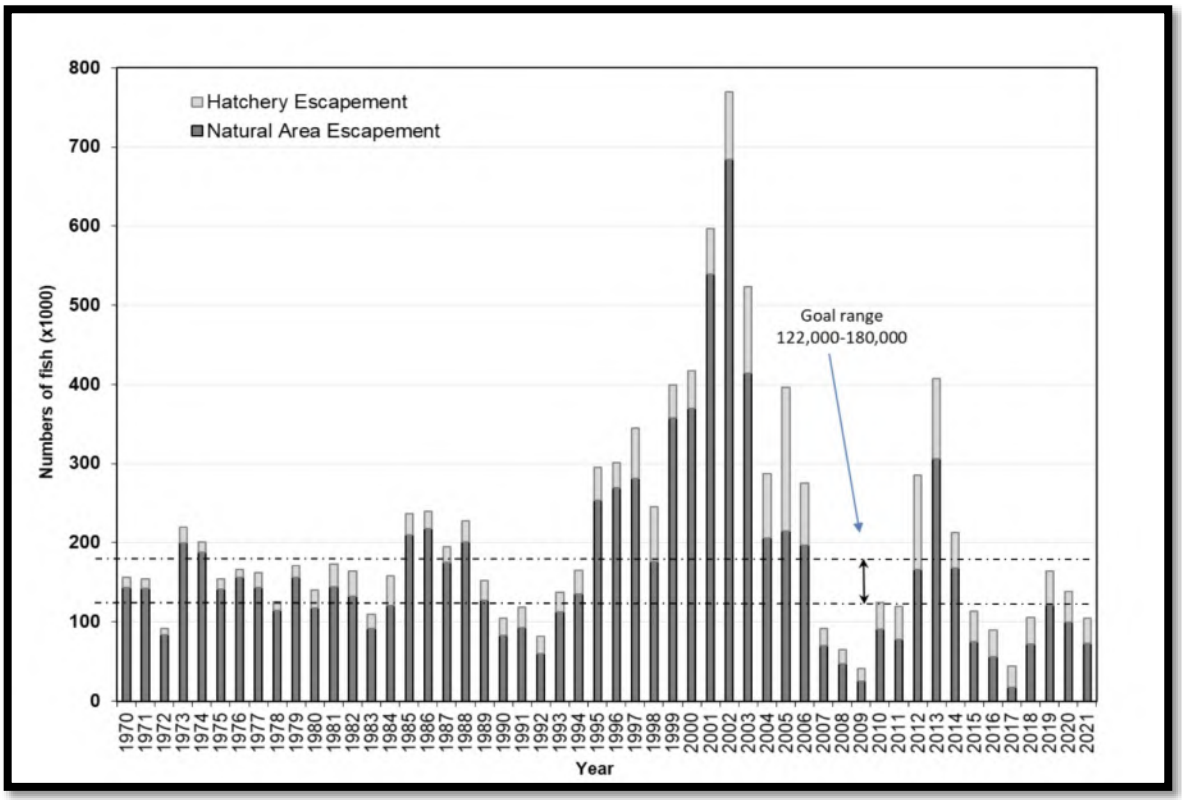


Figure 1. Adult salmon recruitment (escapement to spawn) 1970-2021 breakdown by hatchery and in-river count estimates with target goals. Source: Pacific Fishery Management Council (PFMC).

Table 2. Adult salmon recruitment (escapement to spawn) 1981-2021 breakdown. Source: PFMC.

Year or Average	Upper River[a/] Hatchery	Upper River[a/] Natural[b/]	Upper River[a/] Subtotal	Lower River Hatchery	Lower River Natural[b/]	Lower River Subtotal	Total Hatchery	Total Natural[b/]	Grand Total
1981-85	11,557	57,913	69,470	16,917	81,880	98,797	28,475	139,793	168,268
1986-90	11,507	87,396	98,903	11,521	73,633	85,154	23,028	161,029	184,057
1991-95	11,948	60,151	72,099	16,951	70,691	87,642	28,899	130,842	159,741
1996-00	29,965	153,777	183,742	21,137	137,071	158,207	51,102	290,848	341,949
2001-05	72,122	197,215 [c/]	269,337	30,520	214,652	245,172	102,643	411,867	514,510
2006	56,819	89,933	146,752	21,722	106,556	128,278	78,541	196,489	275,030
2007	11,543	36,079	47,622	9,759	33,993	43,752	21,302	70,072	91,374
2008	10,181	36,274	46,455	7,867	11,042	18,909	18,048	47,316	65,364
2009	5,433	12,277	17,710	10,492	12,671	23,163	15,925	24,948	40,873
2010	8,666	25,688	34,354	24,484	65,438	89,922	33,150	91,126	124,276
2011	19,312	20,466	39,778	22,176	57,388	79,564	41,488	77,854	119,342
2012	77,318	67,190	144,508	41,878	99,043	140,921	119,196	166,233	285,429
2013	67,758	90,119	157,877	33,453	215,516	248,969	101,211	305,635	406,846
2014	17,937	80,407	98,344	25,872	88,260	114,132	43,809	168,667	212,476
2015	13,861	40,696	54,557	25,103	33,808	58,911	38,964	74,504	113,468
2016	8,306	10,563	18,869	25,096	45,734	70,830	33,402	56,297	89,699
2017	1,316	1,526	2,842	25,162	16,325	41,487	26,478	17,851	44,329
2018	8,207	18,317	26,524	25,570	53,372	78,942	33,777	71,689	105,466
2019	13,065	53,706	66,771	29,073	67,923	96,996	42,138	121,629	163,767
2020	12,478	36,447	48,925	25,444	63,722	89,166	37,922	100,169	138,091
2021[d/]	14,555	52,320	66,875	16,700	20,908	37,608	31,255	73,228	104,483
Goal[e/]									122,000

a/ Above the Feather River; 1971-1985 estimates include Tehama-Colusa Spawning Channel.

b/ Fish spawning in natural areas are the result of hatchery and natural production; estimates generally based on carcass surveys.

c/ Estimation methodology for 2002 was changed due to an extremely high Battle Creek escapement.

d/ Preliminary.

e/ Sacramento River fall Chinook S_{MSY}.

Part A - Status of Central Valley and Sacramental River Fall Run Chinook Salmon

The SRFRCS population reached peak recent-historic escapement (spawner numbers) levels of 500-900 thousand in 2003-2005 after a decade of wet years (Figure 2). The peak followed a low period of 100-200 thousand from 1989 to 1991 during the 1987-1992 drought, and a gradual rebuilding period from 1993 to 2002. The recovery occurred during a period of high tributary in-river spawning escapement) and modest increases in returns to the three SRFRCS hatcheries that were due to higher returns from a decade of higher escapement that resulted from wet year smolt releases near the hatcheries and increasing release of smolts to the Bay-Delta. In-river escapement to the upper Sacramento River (mainstem) however showed less improvement except in 1997 and 1999.

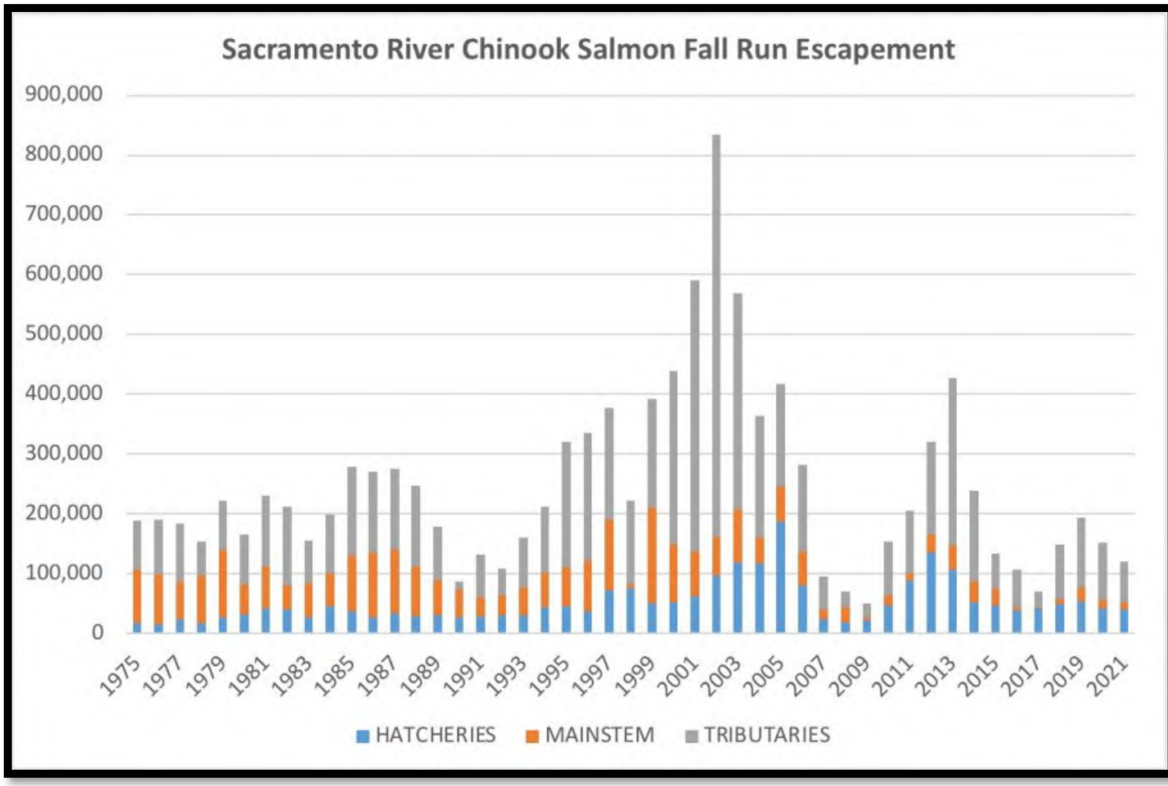


Figure 2. Sacramento River Fall Run Chinook salmon escapement total with breakdown by mainstem in-river returns, total returns to three hatcheries, and total of in-river tributary returns from 1975-2021. Source: GrandTab. Note the GrandTab tabulations are slightly higher than the PRMC totals for adults in Figure 1 and Table 2, because GrandTab totals include a small percentage of early returning precocious "Jacks and Jills" (that have spent only 6 to 18 months or so in the ocean) in addition to adults (ages 3 or more).

Escapement dropped sharply in the 2007-2009 drought in all three groups. Much of the decline has been attributed to poor ocean conditions in 2005 and 2006. Poor river conditions during the summer-fall run up from the Bay are all also likely contributors in each of these three drought years. Other factors included poor in-river and hatchery returns in the mainstem and tributaries during drought years, some of which was due to straying that was not accounted for.

A moderate recovery in escapement occurred from 2010-2014 because of good wet-year adult returns and good smolt production in the wetter 2010-2012 water years. Tributary in-river adult return estimates improved sharply along with strong numbers of hatchery spawners from 2011-2013. Upper river mainstem returns (Figure 4) also improved but less dramatically.

In contrast, mainstem in-river spawner estimates showed only limited improvement from the wet period of 2010-2012. The decline in escapement from 2015-2017 generally reflects poor smolt production and survival throughout the watershed in drought years 2013-2015 resulting in the record low returns to the upper Sacramento River in 2017.

The modest escapement increases from 2018-2020 reflects the benefits of the wetter years to returning adults to tributary spawning grounds (Figure 3). There were slight increases to upper mainstem (Figure 4) or Coleman hatchery returns (see Appendix A, Figures A-1 and A-2).

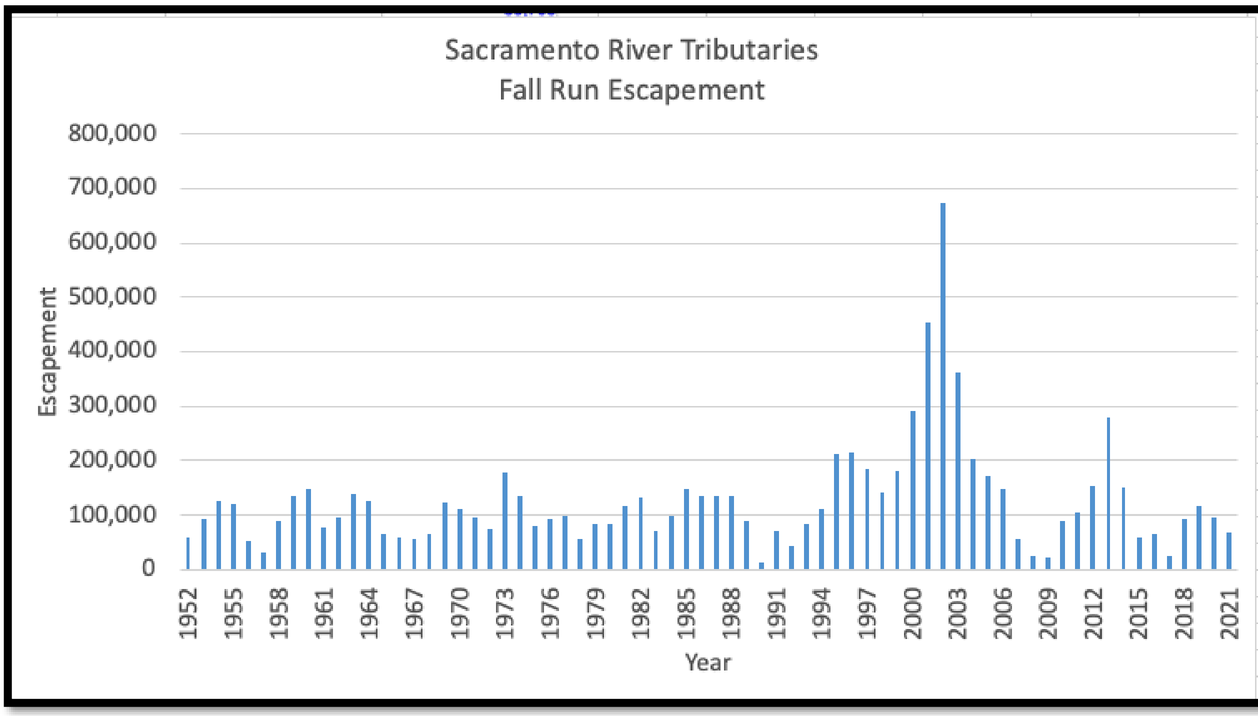


Figure 3. Sacramento River tributaries fall-run salmon escapement 1952-2021.

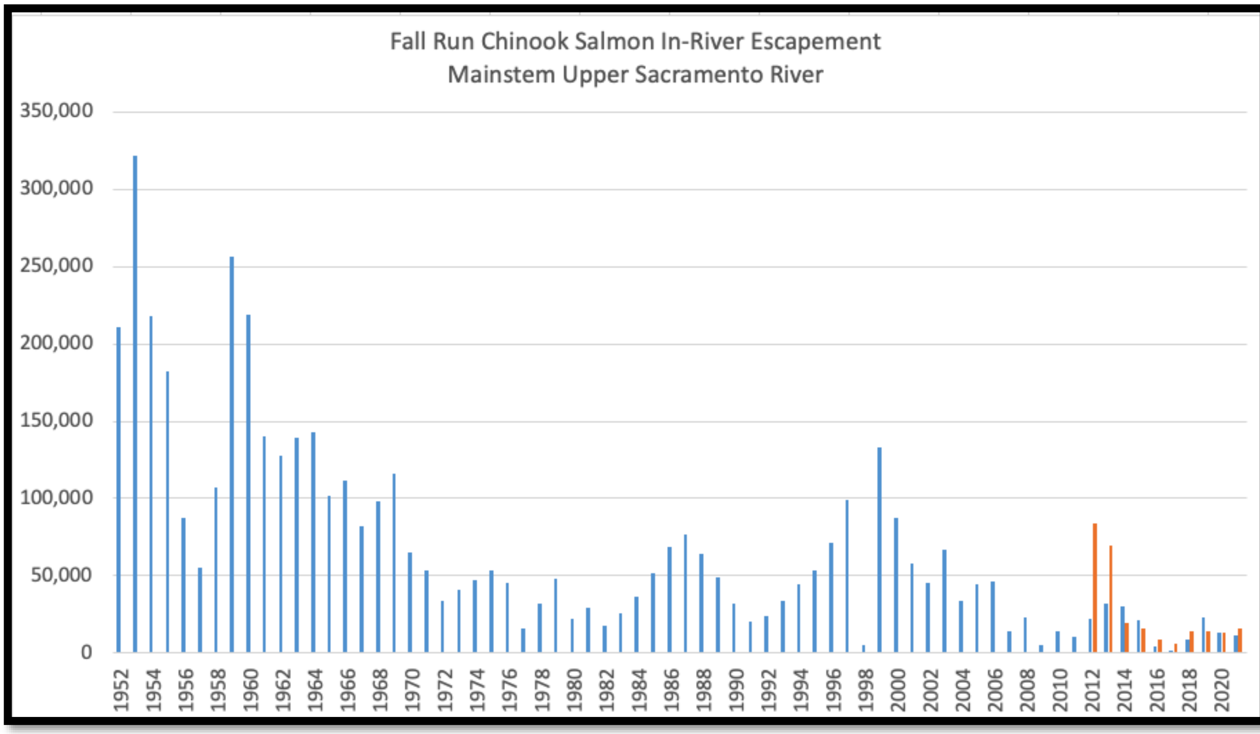


Figure 4. Upper Sacramento River mainstem fall-run salmon escapement 1952-2021. Orange data points are Coleman Hatchery returns for 2012-2021 for comparison. Source: GrandTab.

More discussions of the above patterns and their causes are in Part B. For more detailed breakdown of the escapement data by river see Appendix A.

Part B – Population Analyses

Spawner/Recruit Analyses

The mainstem fall run escapement decline over the past six decades (Figures 2 and 4) is a major feature in the overall decline of the Sacramento River fall run salmon. Tributary escapement (Figures 2 and 3) in contrast has remained relatively stable except for the sharp increase in the late 1990s and early 2000s and sharp drops during or after multiyear droughts (90-92, 07-09, and 15-17). The spawner-recruitment (S/R) relationships (Figures 5 and 6) reflect these patterns with the in-river upper Sacramento River fall-run escapement S/R relationship being strongly positive except for poor recruitment per spawner after extended droughts. In contrast, the tributary S/R is nearly flat reflecting recruitment is more a function of environmental conditions and hatchery contribution than spawning stock size. Hatchery production dominates the tributaries with less difference because tributary hatcheries transport most of their production to the Bay (resulting in high %survival rates) whereas the Coleman Hatchery generally releases their smolts in the upper river (with poor %survival rates). Poor drought survival results in sharp drops in the upper Sacramento in-river escapement because the Coleman Hatchery does not pick up the slack as the hatcheries do on the Feather and American Rivers.

A closer look at the Sacrament River fall-run in-river escapement (Figure 7) shows a poor recruitment year occurred in 2009 despite a strong parent population in 2006. Poor conditions in the river in 2007, poor ocean conditions in the ocean from late 2007 into early 2009, and poor river conditions during the spawning run in 2009 all contributed to the very poor number of returns (harvest and escapement) in 2009. However, good conditions helped brood year 2009 recover to a modest level of recruits in 2012. More discussion on the 2009 and 2016-17 recruitment failures (crashes) follows.

A closer look at the S/R relationship for the mainstem fall run (Figure 8) shows some capacity to recover, but that capacity may be waning. Despite very low spawner numbers in 2009 and 2016-17, subsequent good conditions led to the moderate 20,000-30,000 mainstem recruitment levels. However, brood year 2018 brought only slightly higher recruitment in 2021 despite a wet year in 2019.

The overall S/R relationship for the entire Sacramental River fall-run salmon stock (Figure 9, Figure E-1) as expected is somewhat between its two major components depicted in Figures 5 and 6. The following section focuses on the likely causes related to years with recruitment levels below 100,000 including the population recruitment failures of 1990, 2009, and 2017.

Cause of Recruitment Failures

Each of the recruitment failures is exemplified by escapement falling below 100,000 spawners. Each occurred because of multiyear droughts 1987-1992, 2007-2009, and 2013-2015. Each resulted in a downward (and leftward) shift in the S/R relationship (Figures 7 and 8).

1990-1992 Population Crash

The 1990-1992 period of recruitment failure was the consequence of six years of drought 1987-1992. The spawning population declined from 200,000 in 1987 to under the targeted 122,000 in 1990-92 (Figure 1). The population had grown over the previous five years of good wet year conditions prior to 1987. Brood year 1987 and their offspring were immediately faced with drought water year 1988, which likely took a toll on spawning, egg incubation, and fry and juvenile survival, that led to reduced numbers of smolts entering the ocean, which led to the very low 1990 returns.

Coleman Hatchery and Feather River Hatchery fall-run smolt release returns (Figures 10 and 11) started dropping beginning with the 1987 releases, which contributed to lower escapement in 1989 and 1990. The practice of summer advanced smolt Bay releases from the Feather River Hatchery that generally brought high return rates ended in 1986. Summer Delta smolt releases from the Feather Hatchery in 1987-1989 yielded poor returns (Figure 12), thus contributing to the population decline.

2007-2011 Population Crash

The 2007-2011 recruitment minimums were the consequence of three years of drought 2007-2009. The spawning population declined from nearly 300,000 in 2006 (Figure 1) after building from over a decade of good wet year conditions. Brood year 2006 offspring were immediately faced with drought water year 2007, which likely took a toll on spawning, egg incub`ation, and fry and juvenile survival, that led to reduced numbers of smolts entering the ocean, all of which led to reduced 2009 returns. Poor 2007 and 2008 returns were likely due to poor river conditions for returning adult spawners and poor smolt production from winter floods in 2005 and 2006. Poor smolt production in critical drought years 2008 and 2009 led to poor returns in 2010 and 2011.

Coleman Hatchery and Feather River Hatchery fall run smolt release returns (Figures 10-12) started dropping beginning with the 2007 releases, which led to lower escapement in 2009 despite fishery closures in 2008 and 2009. The poor returns of Bay released Feather River and American River hatchery smolts is an indication of potentially poor ocean conditions as hypothesized by Lindley et al (2009). However, low Delta outflow (<10,000 cfs) and high water temperatures (17-20°C) in the hatchery smolt release area likely contributed to poor survival/return of 2007 May-June Bay smolt releases from the Feather and American River Hatcheries.

2012-2013 Recovery

Analyzing crashes also requires a close look at the recovery periods. The 2012 recovery-level return was quite dramatic despite being from the near record low 2009 escapement. The recovery was likely the consequence of a series of very strong factors that overcame the low number of spawners. First, BY 2009 young survival in winter-spring 2010 was high based on several positive factors. The peak hatchery and wild smolt migration from the American, Feather, and upper Sacramento River mainstem in early spring 2010 came during a strong natural pulse flow, that in combination with a closed Delta Cross Channel allowed the juvenile salmon to be carried straight through the Delta into the Bay, evidenced by few juvenile salmon being collected at the south Delta export pumps fish facilities (Figure 17). Other indications of good natural and hatchery production in the upper Sacramento River are presented in Figures 18 and 19 that showed in in-river and hatchery returns for 2012 that carried over into 2013 (Figure 4). Populations responses (especially hatchery release returns from BY 2009) were generally strong in 2012 and 2013 (Figures 1-5, 10, and 12). Second, the fishery closure in 2008 and 2009 probably led to increased escapement in years 2009-2012. Third, the resumption of regular harvest in 2011 and 2012 (Figure E-1) did not appear to hinder the recovery[5].

2015-2018 Population Crash

> *"Chinook that will be harvested in ocean fisheries in 2017 hatched two to four years ago and were deeply affected by poor river conditions driven by California's recent drought. CDFW and federal fish agency partners have expended millions of dollars on measures to minimize the impacts of the drought. These efforts have included trucking the majority of hatchery salmon smolts to acclimation pens in the lower Delta, improving hatchery infrastructure to keep juvenile fish alive under poor water quality conditions and partnering with sport and commercial fishermen to increase smolt survival. Though all of these efforts helped, other environmental factors – such as unusually warm water conditions in the ocean – were beyond human control." (USFWS, CDFW)*

While the statement is true for the most part, and efforts were commendable, there are additional factors that also were important:

1. River conditions especially in main rivers (upper Sacramento, lower Feather, and lower American) were also greatly affected by water management strategies that benefitted water supply not salmon. In-river fall-run spawners and egg/embryo survival were compromised by warm and sharply dropping flows below the three large dams in the fall.
2. Many of the hatchery trucks released their smolts in the Delta near Rio Vista rather than the Bay (Figures 10 and 12). Many smolts were also released near the hatcheries. Both measures led to higher predation on smolts in the warm, low river flows characteristic of the drought years, leading to fewer smolts reaching the ocean.
3. There were many factors that were within human control that also contributed to poor salmon survival and production. Chief among these was the inability to maintain prescribed flow and water temperature standards in the rivers below dams. Flow and water temperature prescriptions to protect fish were relaxed during the 2013-15 critically dry water years. Water allocated from Shasta Reservoir's cold-water pool for summer spawning of winter run salmon resulted in a limited supply remaining for fall run spawning in the fall.

[5] Some might like to attribute the recovery to the fishery closure (2008-2010), however the recovery is primarily the consequence of good survival of BY 2009 in winter-spring 2010 and good conditions in 2012 when the adults returned.

There was ample evidence and known circumstances that another population collapse was possible or even likely. Such evidence included the limited recovery during the wetter 2010-2012 sequence and the effects of the 2013-2015 drought had begun to show (Figure 1). Most notable was the sharply lower number of spawners returning in 2015, and brood ye ar 2014 spawners produced very low numbers of young[6] in the winter-spring of 2015.

A close look at recruitment per spawner in the population over the past 40 years (Figure 9, Figure E-1) shows strong evidence that recruitment suffers in dry winter-spring rearing years or dry fall spawning years. These factors overwhelm the background relationship between spawners and recruits three years later. Patterns in Figure E-1 indicate:

1. Recruitment is significantly depressed if the two years prior (rearing and emigration years) were drier years. The major contributing factor is likely poor survival in winter-spring of juveniles in their first year.
2. Recruitment is severely depressed for brood years rearing in winter-spring of critical years and returning as adults two years later in critical years (e.g., 88-90, 07, 13).
3. Recruitment can be depressed for brood years with good winter-spring juvenile rearing conditions but poor conditions when adults return (e.g., 05, 06).
4. Recruitment can be enhanced for brood years with poor winter-spring young rearing conditions if there are very good fall conditions for adults returning (e.g., 94).
5. Generally higher numbers of spawners produce higher numbers of recruits. However, despite this underlying positive spawner/recruit relationship, it is overwhelmed by the huge effect on recruitment by poor flow-related habitat conditions.
6. Poor ocean conditions in 2005-2006 likely contributed to poor recruitment.
7. The increase in the relative contribution of hatchery fish is a concern[7] as is the declining contribution of mainstem spawners (see Figure 1). With estimates of up to or above 90 % of the spawning population being fish of hatchery origin, and very little evident genetic diversity, the population is already nearly totally dependent on hatcheries. California sport and commercial salmon fisheries, which depend for the most part on the fall run salmon, will remain dependent on fall run hatcheries well into the future.

Habitat enhancement efforts will help sustain the population and fisheries by increasing wild and hatchery smolt recruitment to the ocean, and escapement of adults to spawning grounds and hatcheries. Habitat restoration and improved spawning-rearing-migration conditions (flows, water temperatures, and physical habitat) will help increase survival and smolt production. Hatchery contributions could be improved with upgraded infrastructure, improved transport (i.e., trucking and barging), and hatchery fry floodplain rearing. Improving hatchery and natural population genetic diversity will help further toward sustaining a healthy population into the future.

[6] https://www.fws.gov/redbluff/RBDD%20JSM%20Biweekly/2017/Biweekly20170226-20170311.pdf
[7] http://fishbio.com/field-notes/the-fish-report/the-road-to-salmon-collapse-is-paved-with-good-intentions

The reason the ocean collapse hypothesis is supportable is that bay-coast salmon release returns went down too, but there are questions – how does Delta outflow affect Bay releases or even ocean coast smolt survival? Floods (high fall flood control dam releases) may be important in late fall and early winter (e.g., 05-06).

Perhaps the most compelling reason to accept the premise that ocean conditions are important is the difference in returns of Bay releases in some years (Figure 13). Normal year returns (fishery catch plus escapement) were on average 50 times higher for normal water year 2010 compared to critical water year 2007. While some part of the difference was likely due to the Bay conditions in the two years, most is likely due to ocean conditions outlined in Lindley et. al. (2009) and other studies.

What is remarkable is the federal government repeating this debacle with 2015 Coleman releases (Figure 14), and even worse releasing over ten million of their fall run smolts at Rio Vista in the Delta and only 820,000 in the Bay. The Bay releases had on average 5 times the returns per smolt released as the Delta smolt releases.

2022-2024 Population Crash (predicted)
All indications are that there will be a population crash from 2022-2024. The first indicator is the critical drought conditions in 2021 and 2022, which likely reduced in-river, natural-born smolt production to near zero. The second is the Coleman Hatchery releasing 90% of their shortened supply in drought year 2021 near the hatchery and only 10% to the Bay (Figure 15), albeit much closer to the Golden Gate (San Quentin). The difference in returns in the coming years between the hatchery and Bay locations will likely be substantial (50-100 times), which could mean a paper-loss of 100,000-200,000 adult salmon to the fishery and escapement. Granted, returning Coleman adults from Bay releases will likely be spread all over the Valley with a shortage of returning spawners to Coleman, but recovery of eggs at the Nimbus and Mokelumne hatcheries (implemented last year and this year) would potentially mitigate for that problem. Such mitigation could be expanded to the Feather and Merced hatcheries if need be. The third is very poor conditions for returning adults in 2021 and 2022, which leads to excessive pre-spawn mortality and stress on adults. Thiamine deficiency is a contributing factor[8].

Conclusion

There is really no reason the Coleman Hatchery cannot begin achieving the management response success achieved by the modern Mokelumne Hatchery (Figure 16), which has many of the same problems if not more difficult problems to overcome. For most of the past decade including the 2013-2015 and 2020-2022 droughts, the Mokelumne Hatchery has achieved the upper right part of the S/R curve and become a major contributor to the Central Valley Fall-Run Salmon DPS.

[8] https://californiawaterblog.com/2022/10/30/spawning-of-the-living-dead-understanding-how-salmon-pass-thiamine-deficiency-to-their-young/

Each of the three population crashes described above were anticipated once the droughts began. Mitigative responses were available but often not employed because of lack of will, funding, or betting on a wet year. Escapement in 2021 was already below the 122,000 target (Figure 1). Strong measures this year and next, including fishery closures, are necessary to bring recruitment/escapement up regardless of what happens in water year 2023.

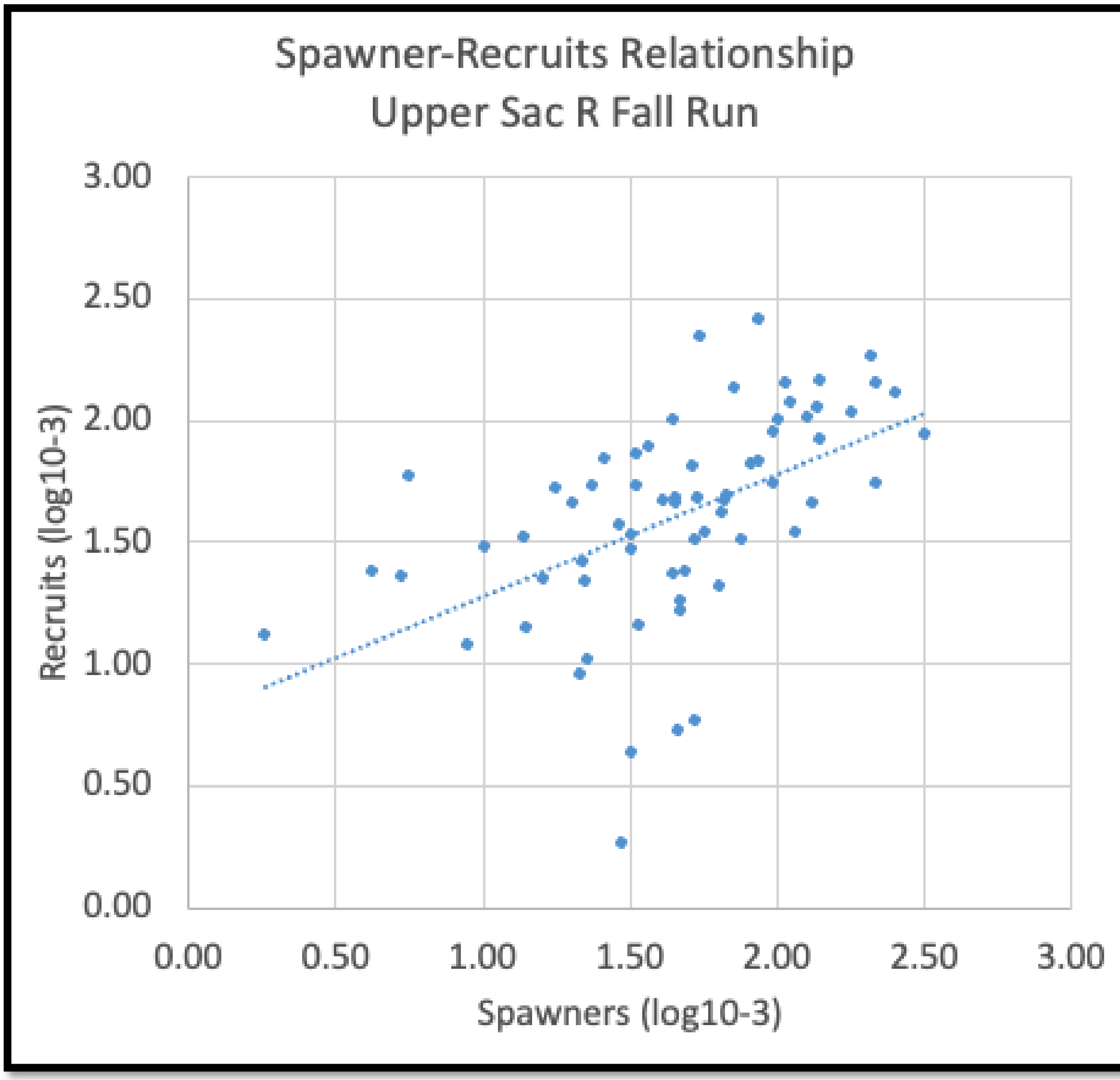


Figure 5. Spawner-recruit relationship for in-river escapement estimates for the Upper Sacramento River fall-run salmon population. Dots are transformed (log_{10} – 3) number of recruits versus spawners three years earlier.

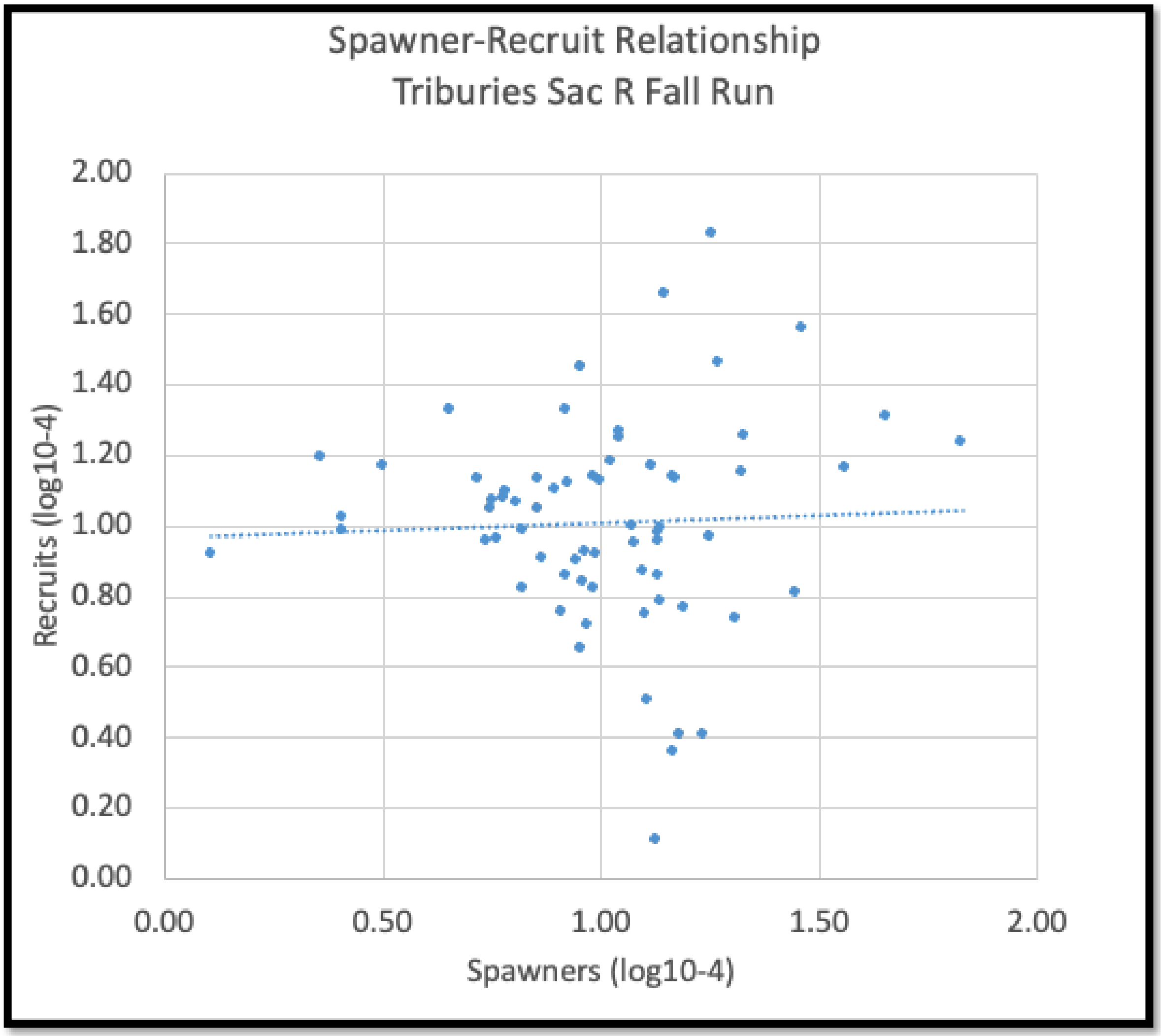


Figure 6. Spawner-recruit relationship for in-river escapement estimates for the Sacramento River tributary fall-run salmon populations. Dots are transformed ($\log_{10}$ – 4) number of recruits versus spawners three years earlier.

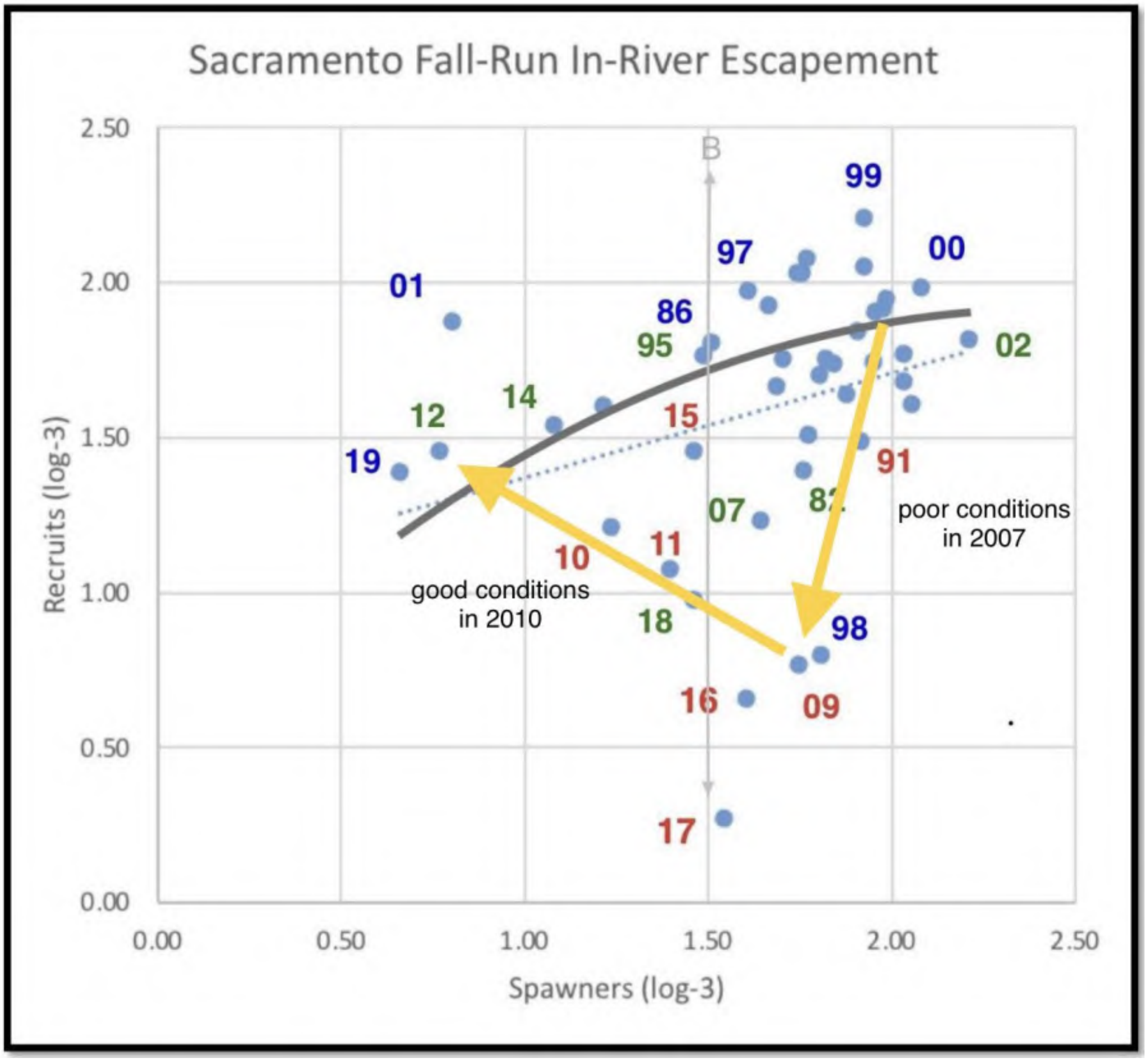


Figure 7. Spawner-recruit relationship for the Sacramento River mainstem fall-run Chinook salmon. Number is that year's escapement (recruits) transformed (log_{10} – 3). Spawners are the recruits from three years prior. Numbers are log_{10} minus 3 transformed. A red number indicates a dry water year two years prior during in-river rearing and emigration to the ocean. A blue number indicates a wet year two years prior. A green number indicates a normal water year two years prior. For example: red 17 represents the 2017 record-low escapement level on the y-axis that reared and emigrated in drought year 2015. Note the yellow arrows depict recruit numbers for 09 and 12 from their origin spawners three years earlier. Spawner numbers in 2009 and 2016 were so low that wetter year returns in 2012 and 2019 were weak.

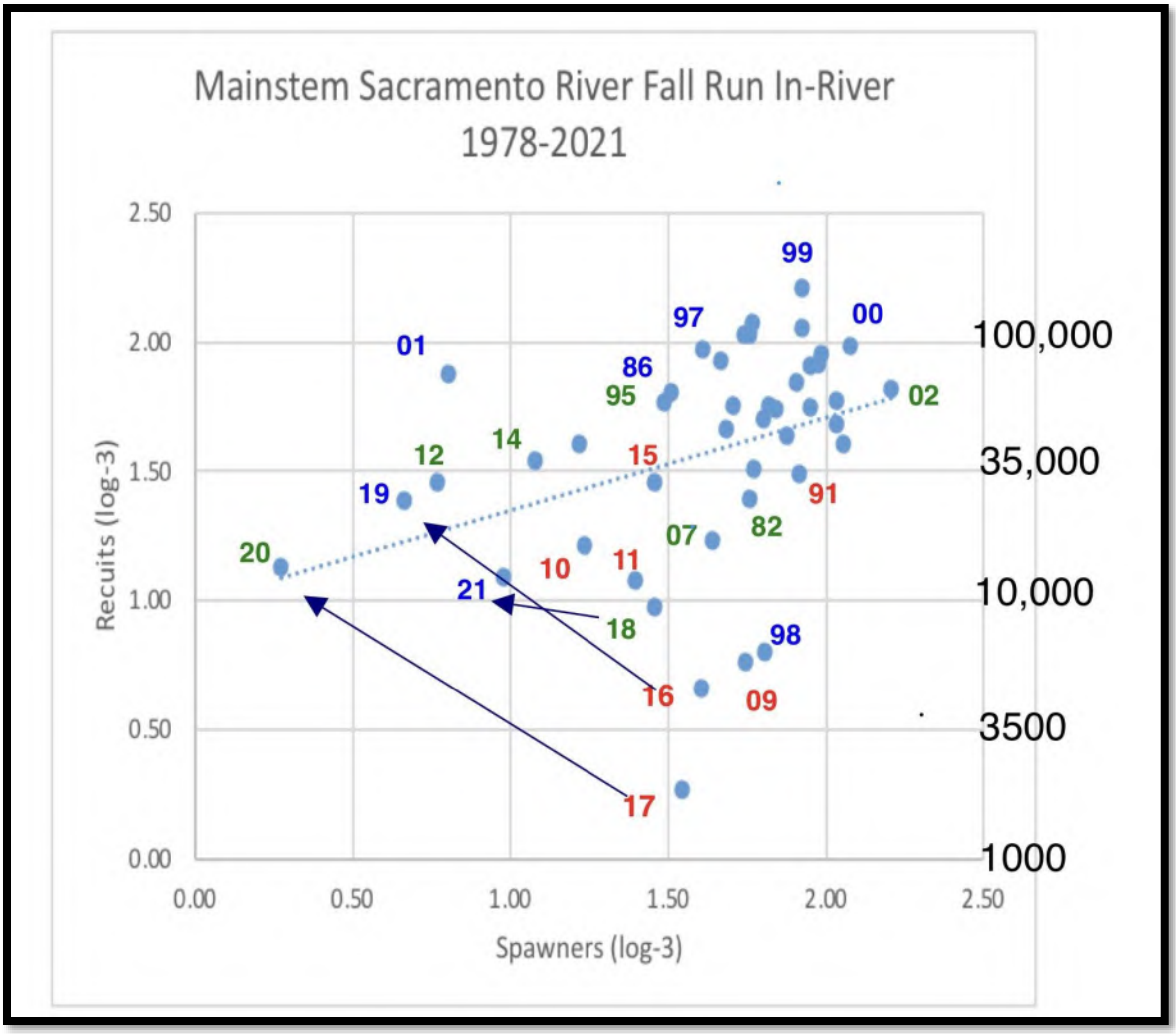


Figure 8. Spawner-recruit relationship for the Sacramento River mainstem fall-run Chinook salmon as shown in Figure 7. The three black arrows have been added to show the capacity to recover in recent years under good conditions. Note there is only partial recovery because the population crash in 2016 and 2017 was unable to fully recover despite good conditions.

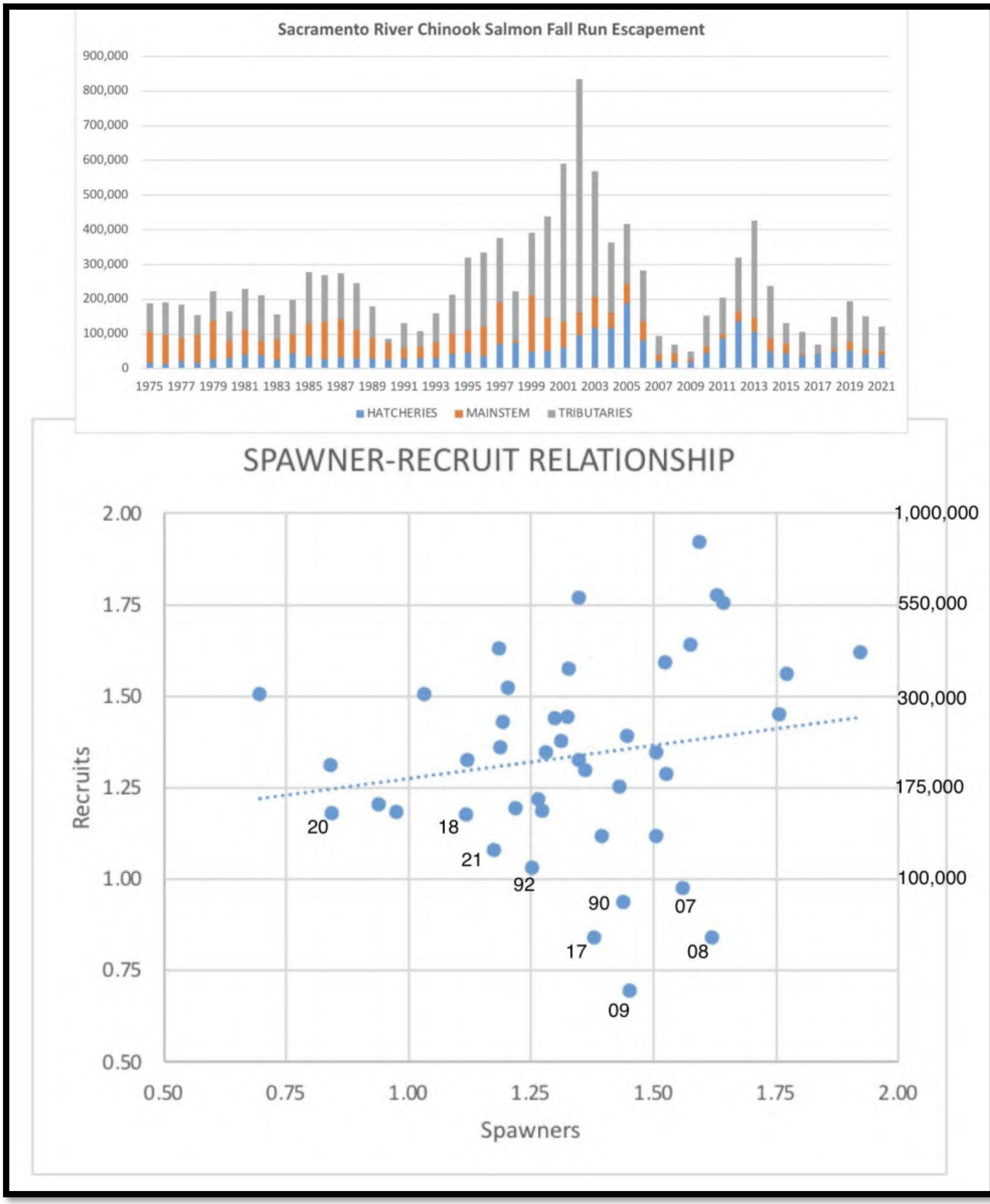


Figure 9. Spawner-recruit relationship for the Sacramento River fall-run Chinook salmon as shown in Figure 2 (also shown here for ease of reference). The black numbers are specific years. For example, 09 recruit (escapement) year. The 09 level of spawners is the recruits from 2006.

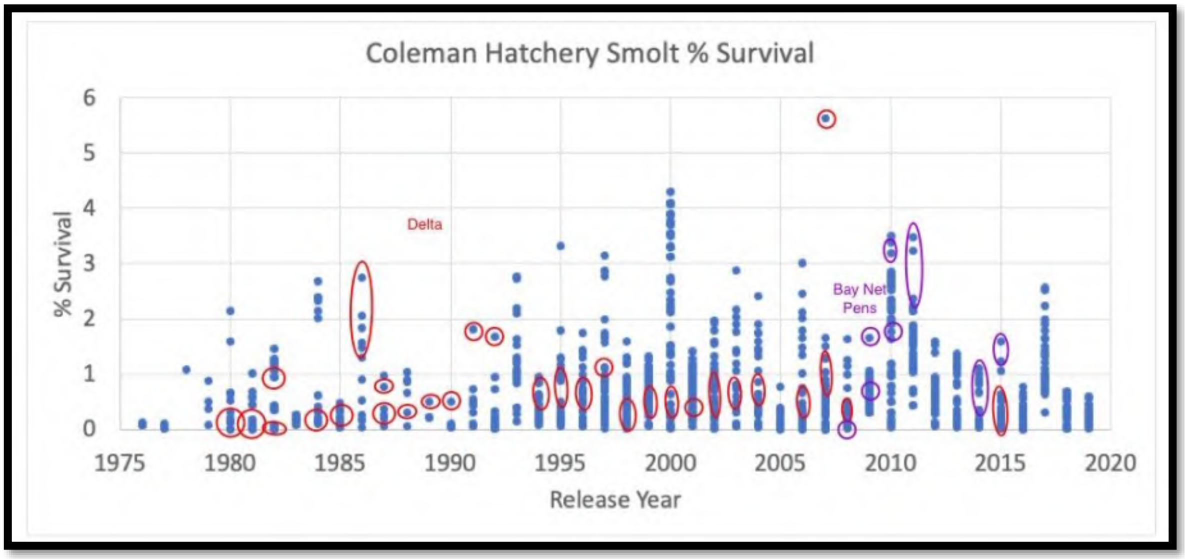
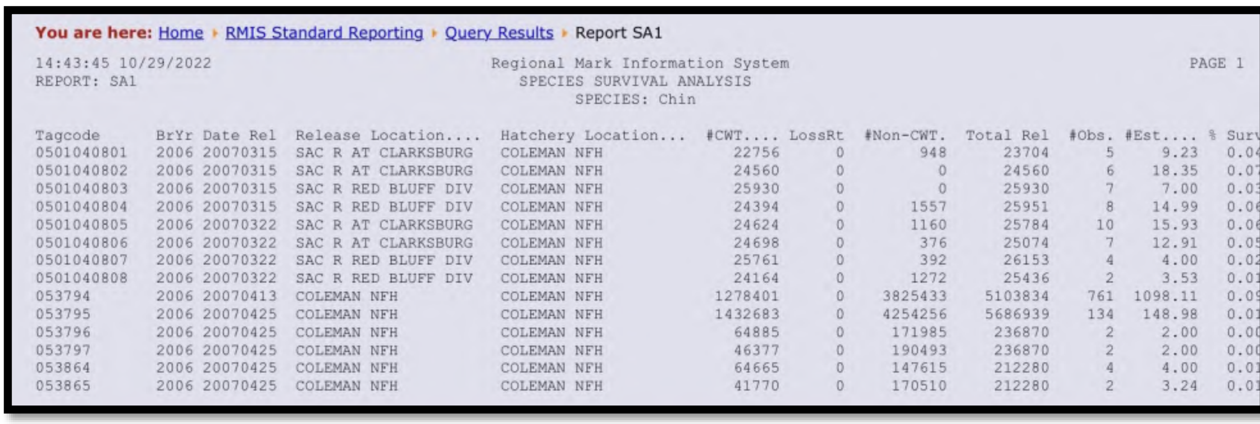


Figure 10. Percent survival (harvest plus escapement return rate estimates) for cwt Coleman Hatchery release groups 1976-2019. (Note 2019 return have not all been processed.) Red circled points were Delta releases. Purple circled releases are Bay pen releases. All others are river releases. Data source: https://www.rmpc.org..



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REPORT: SA1 SPECIES SURVIVAL ANALYSIS
SPECIES: Chin

Tagcode	BrYr	Date Rel	Release Location....	Hatchery Location...	#CWT....	LossRt	#Non-CWT.	Total Rel	#Obs.	#Est....	% Surv
0501040801	2006	20070315	SAC R AT CLARKSBURG	COLEMAN NFH	22756	0	948	23704	5	9.23	0.04
0501040802	2006	20070315	SAC R AT CLARKSBURG	COLEMAN NFH	24560	0	0	24560	6	18.35	0.07
0501040803	2006	20070315	SAC R RED BLUFF DIV	COLEMAN NFH	25930	0	0	25930	7	7.00	0.03
0501040804	2006	20070315	SAC R RED BLUFF DIV	COLEMAN NFH	24394	0	1557	25951	8	14.99	0.06
0501040805	2006	20070322	SAC R AT CLARKSBURG	COLEMAN NFH	24624	0	1160	25784	10	15.93	0.06
0501040806	2006	20070322	SAC R AT CLARKSBURG	COLEMAN NFH	24698	0	376	25074	7	12.91	0.05
0501040807	2006	20070322	SAC R RED BLUFF DIV	COLEMAN NFH	25761	0	392	26153	4	4.00	0.02
0501040808	2006	20070322	SAC R RED BLUFF DIV	COLEMAN NFH	24164	0	1272	25436	2	3.53	0.01
053794	2006	20070413	COLEMAN NFH	COLEMAN NFH	1278401	0	3825433	5103834	761	1098.11	0.09
053795	2006	20070425	COLEMAN NFH	COLEMAN NFH	1432683	0	4254256	5686939	134	148.98	0.01
053796	2006	20070425	COLEMAN NFH	COLEMAN NFH	64885	0	171985	236870	2	2.00	0.00
053797	2006	20070425	COLEMAN NFH	COLEMAN NFH	46377	0	190493	236870	2	2.00	0.00
053864	2006	20070425	COLEMAN NFH	COLEMAN NFH	64665	0	147615	212280	4	4.00	0.01
053865	2006	20070425	COLEMAN NFH	COLEMAN NFH	41770	0	170510	212280	2	3.24	0.01

Figure 11. Tabular data for 2007 fall run salmon cwt groups of Coleman Hatchery smolts from https://www.rmpc.org. Last column is estimated percent return (harvest plus escapement) for the tag release group. The very low return rate (<0.1 %) is highly unusual (see Figure 13) and indicative of poor ocean condition during the period from 2007-2009.

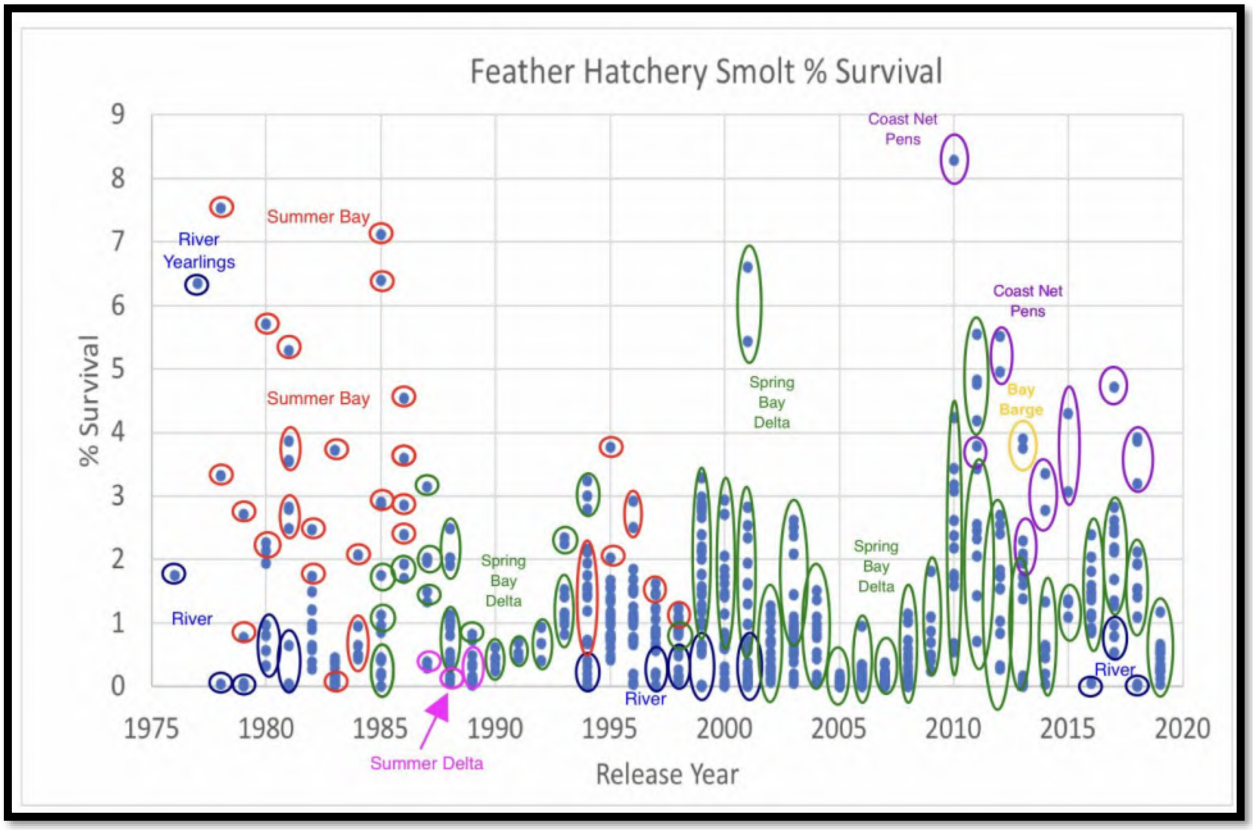

Figure 12. Percent survival (harvest plus escapement return rate estimates) for cwt Feather River Hatchery release groups 1976-2019. (Note 2019 return have not all been processed.) Red circled points represent summer Bay-Delta releases. Purple circled releases are Coast releases. Green circles represent spring Bay-Delta release groups. Blue circles represent river releases. Yellow circle represents groups barged to Golden Gate. Data source: https://www.rmpc.org..

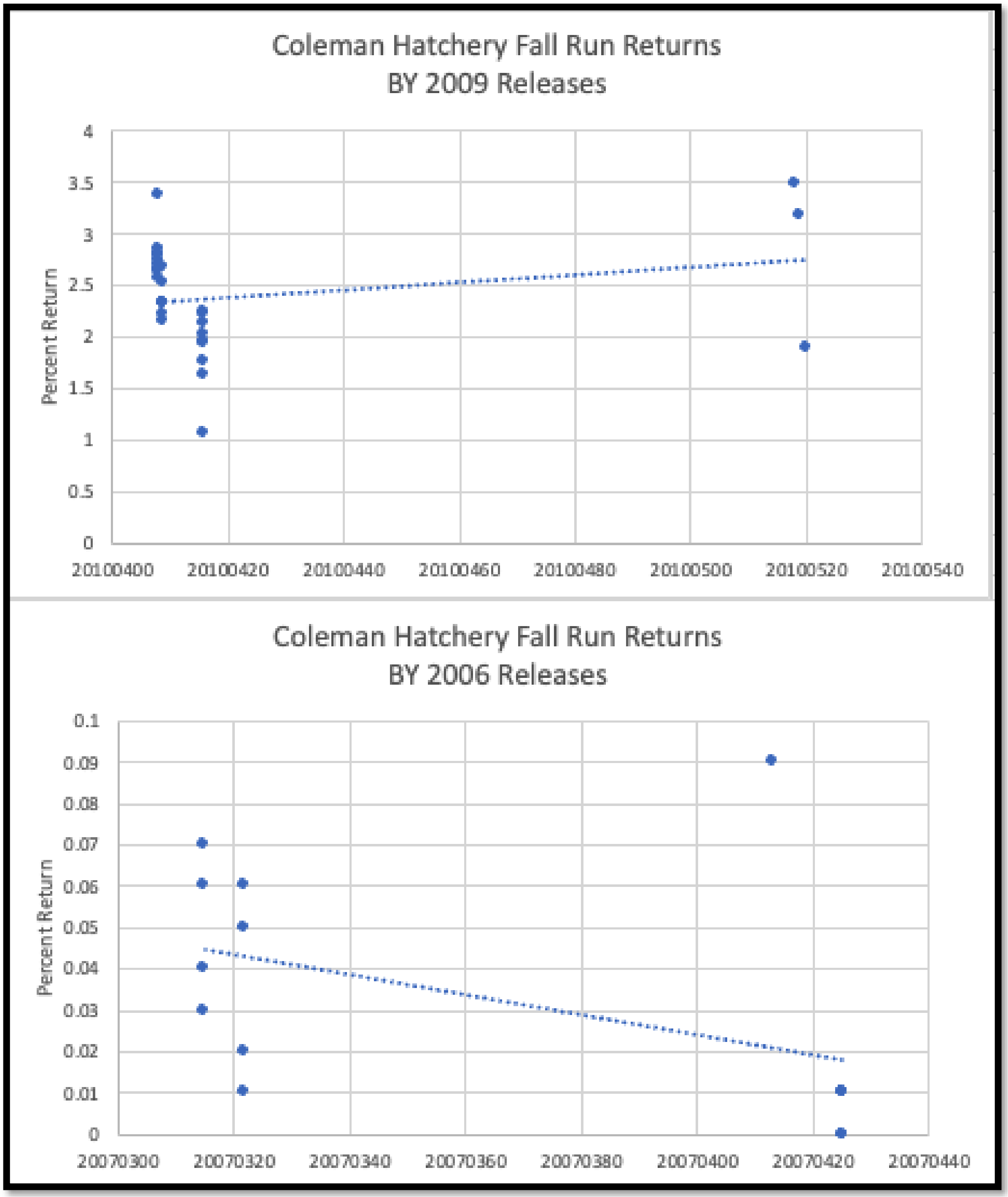

Figure 13. Comparison of Coleman Hatchery spring Bay release group survival (by date of release) for critically dry year 2007 and normal year 2010.

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REPORT: SA1 SPECIES SURVIVAL ANALYSIS
SPECIES: Chin

Tagcode	BrYr	Date Rel	Release Location....	Hatchery Location...	#CWT....	LossRt	#Non-CWT.	Total Rel	#Obs.	#Est....	% Surv
055780	2014	20150325	SAC R AT RIO VISTA	COLEMAN NFH	105927	0	318086	424013	103	385.17	0.36
055781	2014	20150325	SAC R AT RIO VISTA	COLEMAN NFH	103366	0	310332	413698	127	658.68	0.64
055782	2014	20150327	SAC R AT RIO VISTA	COLEMAN NFH	103407	0	310363	413770	82	311.60	0.30
055783	2014	20150327	SAC R AT RIO VISTA	COLEMAN NFH	111208	0	333948	445156	44	159.50	0.14
055784	2014	20150328	SAC R AT RIO VISTA	COLEMAN NFH	105129	0	315643	420772	127	532.18	0.51
055785	2014	20150329	SAC R AT RIO VISTA	COLEMAN NFH	111112	0	333666	444778	81	262.38	0.24
055786	2014	20150330	SAC R AT RIO VISTA	COLEMAN NFH	86765	0	260551	347316	39	186.30	0.21
055787	2014	20150331	SAC R AT RIO VISTA	COLEMAN NFH	114685	0	344419	459104	45	134.77	0.12
055788	2014	20150331	SAC R AT RIO VISTA	COLEMAN NFH	96479	0	290745	387224	72	237.81	0.25
055789	2014	20150402	SAC R AT RIO VISTA	COLEMAN NFH	109417	0	328546	437963	38	163.09	0.15
055790	2014	20150410	SAC R AT RIO VISTA	COLEMAN NFH	106614	0	320240	426854	173	644.39	0.60
055791	2014	20150411	SAC R AT RIO VISTA	COLEMAN NFH	106009	0	318235	424244	158	582.22	0.55
055792	2014	20150412	SAC R AT RIO VISTA	COLEMAN NFH	103126	0	309526	412652	108	398.01	0.39
055793	2014	20150412	SAC R AT RIO VISTA	COLEMAN NFH	111213	0	333823	445036	106	311.22	0.28
055794	2014	20150413	SAC R AT RIO VISTA	COLEMAN NFH	107111	0	321584	428695	23	47.83	0.04
055795	2014	20150413	SAC R AT RIO VISTA	COLEMAN NFH	115207	0	345862	461069	50	107.52	0.09
055796	2014	20150414	SAC R AT RIO VISTA	COLEMAN NFH	91680	0	275419	367099	43	119.30	0.13
055797	2014	20150414	SAC R AT RIO VISTA	COLEMAN NFH	102470	0	308724	411194	18	47.56	0.05
055798	2014	20150415	SAC R AT RIO VISTA	COLEMAN NFH	114111	0	343839	457950	21	49.41	0.04
055799	2014	20150415	SAC R AT RIO VISTA	COLEMAN NFH	113039	0	339408	452447	59	213.54	0.19
055804	2014	20150416	SAC R AT RIO VISTA	COLEMAN NFH	109600	0	330401	440001	56	189.91	0.17
055805	2014	20150417	SAC R AT RIO VISTA	COLEMAN NFH	108834	0	333040	441874	90	349.70	0.32
055806	2014	20150417	SAC R AT RIO VISTA	COLEMAN NFH	100863	0	302962	403825	81	305.04	0.30
055807	2014	20150418	SAC R AT RIO VISTA	COLEMAN NFH	107068	0	322767	429835	107	324.41	0.30
055808	2014	20150418	SAC R AT RIO VISTA	COLEMAN NFH	102282	0	308212	410494	129	352.20	0.34
055809	2014	20150419	SAC R AT RIO VISTA	COLEMAN NFH	103877	0	314141	418018	82	242.47	0.23
055810	2014	20150513	SAN PABLO BAY NET PE	COLEMAN NFH	103856	0	314946	418802	557	1663.51	1.60
055811	2014	20150514	SAN PABLO BAY NET PE	COLEMAN NFH	100179	0	302889	403068	396	1239.75	1.24

Figure 14. Tabular data for 2015 fall run salmon cwt groups of Coleman Hatchery smolts from https://www.rmpc.org. Last column is estimated percent return (harvest plus escapement) for the tag release group.

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Tag Code or. Release ID..	Tag Typ	Run.	Spec	BdYr	Release. Agency	Hatchery Location...	Release Location....	First. Release	Last.. Release	......CWT Count	..Loss Rate	...Non-CWT Mrk Count
056542	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210310	210310	102,396		308,806
056543	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210310	210310	105,244	0.0026	318,274
056544	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210318	210318	107,520		323,417
056545	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210318	210318	116,268		349,153
056546	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210310	210310	113,219		341,092
056547	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210318	210318	117,930		354,065
056548	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210318	210318	110,621		332,339
056549	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210318	210318	115,033	0.0025	346,519
056550	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210318	210318	116,471		349,706
056551	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210318	210318	111,183	0.0025	335,017
056552	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210318	210318	114,713	0.0026	345,602
056553	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210318	210318	113,466	0.0049	344,102
056554	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210318	210318	111,184	0.003	336,453
056555	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210318	210318	110,906	0.0025	334,077
056556	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210408	210408	114,008		342,341
056557	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210408	210408	109,411		329,806
056558	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210408	210408	109,022		328,464
056559	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210408	210408	112,760	0.0027	340,956
056560	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210408	210408	105,787	0.0025	319,867
056561	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210408	210408	117,589		354,312
056562	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210408	210408	112,979		340,366
056563	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210408	210408	103,437		311,742
056564	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210408	210408	120,923		364,168
056565	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210408	210408	105,095		316,618
056566	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210408	210408	122,137		366,820
056567	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210408	210408	109,302		328,105
056568	12	Fall	Chin	2020	USFWS	COLEMAN NFH	PT SAN QUENTIN NET P	210504	210504	111,159	0.0049	337,106
056569	12	Fall	Chin	2020	USFWS	COLEMAN NFH	PT SAN QUENTIN NET P	210517	210518	108,591	0.0109	332,026
056570	12	Fall	Chin	2020	USFWS	COLEMAN NFH	COLEMAN NFH	210324	210324	92,718		0
056571	12	Fall	Chin	2020	USFWS	COLEMAN NFH	SAC R AT BUTTE CITY	210326	210326	90,774	0.015	1,382
056572	12	Fall	Chin	2020	USFWS	COLEMAN NFH	SAC R AT BUTTE CITY	210326	210326	93,823	0.005	471

Figure 15. Tabular data for 2020 fall run salmon cwt groups of Coleman Hatchery smolts from https://www.rmpc.org.

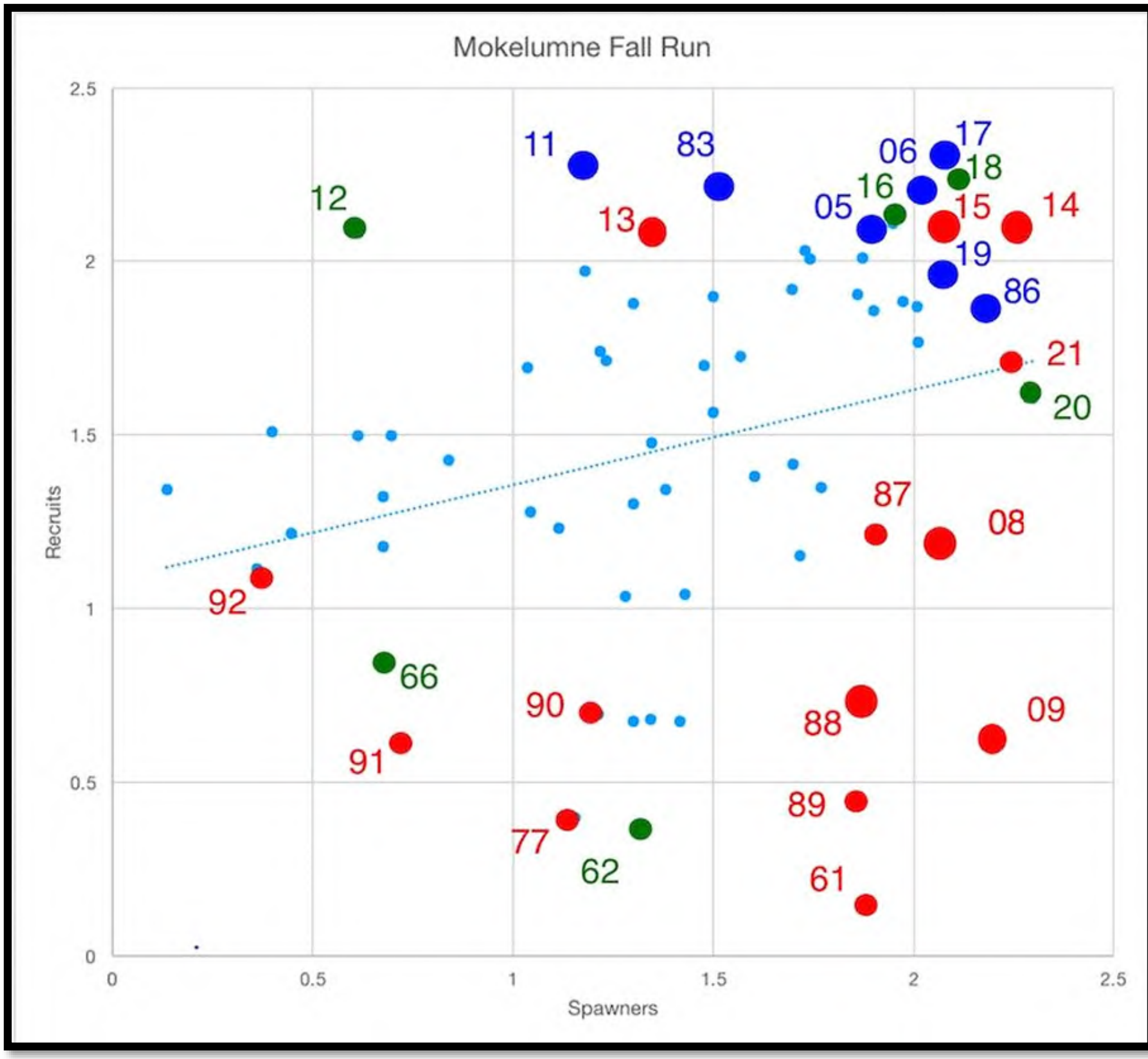

Figure 16. The spawner-recruit relationship for Mokelumne River fall-run salmon. Number is for recruit year with spawners being recruits three years earlier. Red number is critical water year type. Blue is wet year type. Green is normal year type.

Appendix A – Breakdown of GrandTab escapement data for SRFRCS.

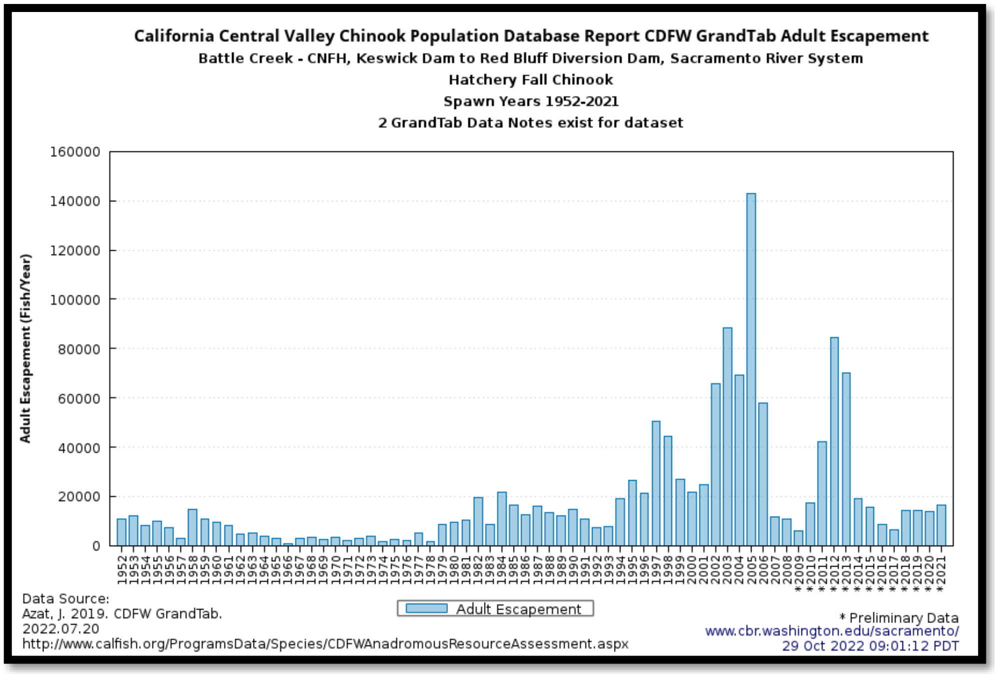

Figure A-1 Coleman Hatchery Fall Run escapement to Coleman NFH on Battle Creek 1952-2021. Source: GrandTab.

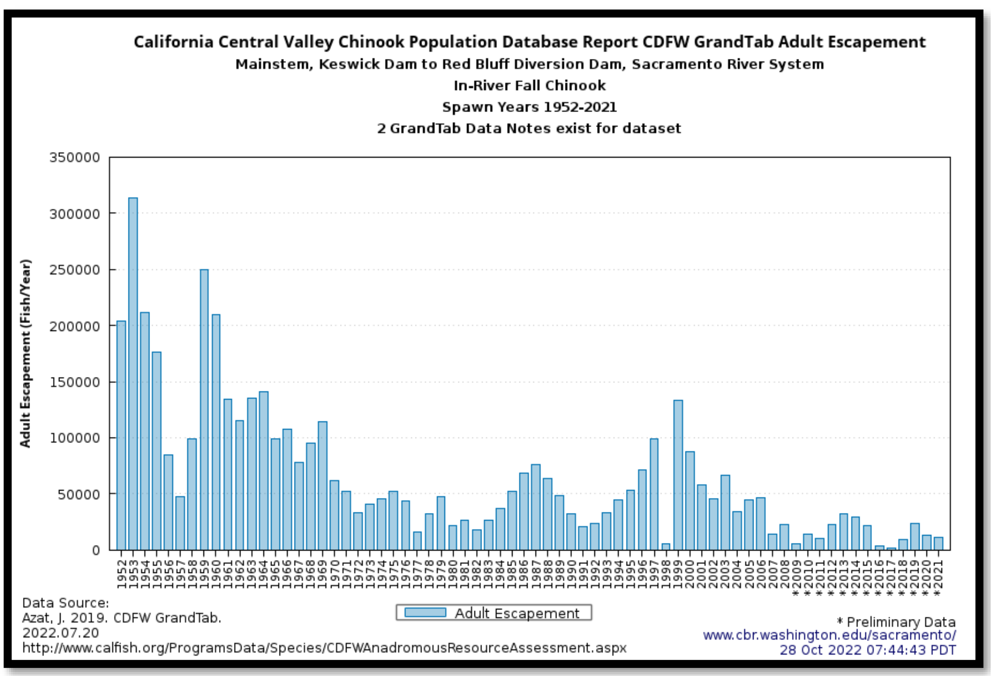

Figure A-2 Upper Sacramento River mainstem in-river escapement 1952-2021. Source: GrandTab.

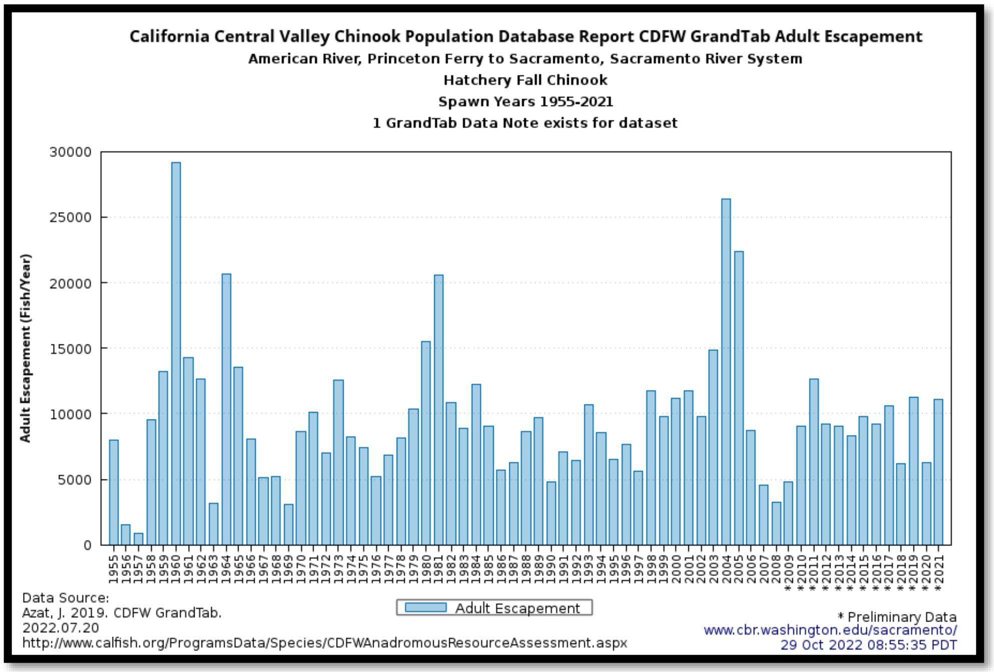

Figure A-3. American River (Nimbus) Hatchery escapement.

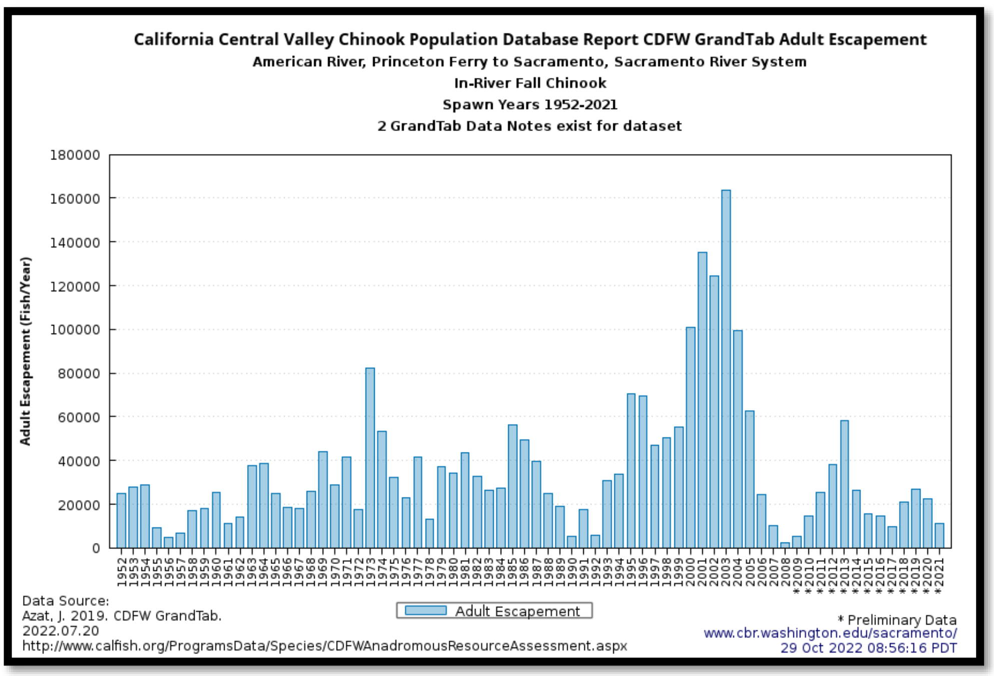

Figure A-4. American River in-river escapement.

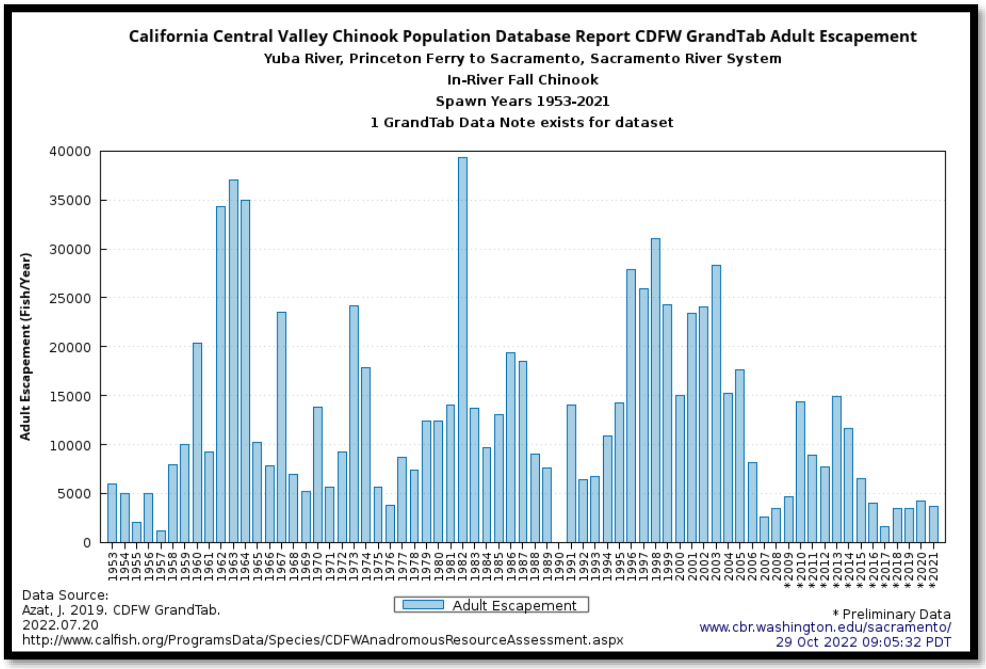

Figure A-5. Yuba River in-river returns 1953-2021. Source: GrandTab.

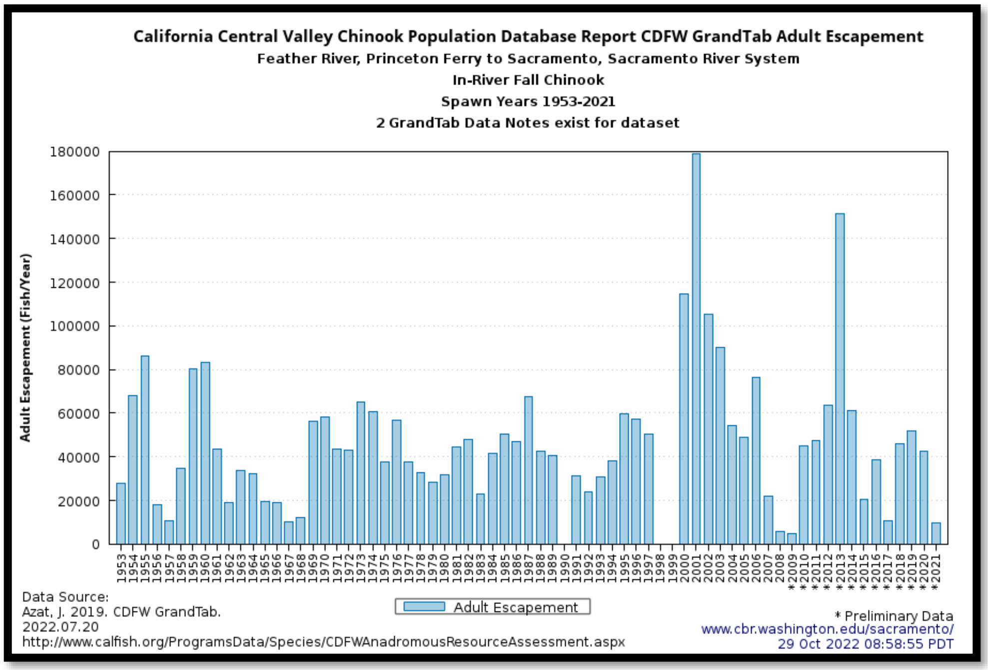

Figure A-6. Feather River in-river escapement.

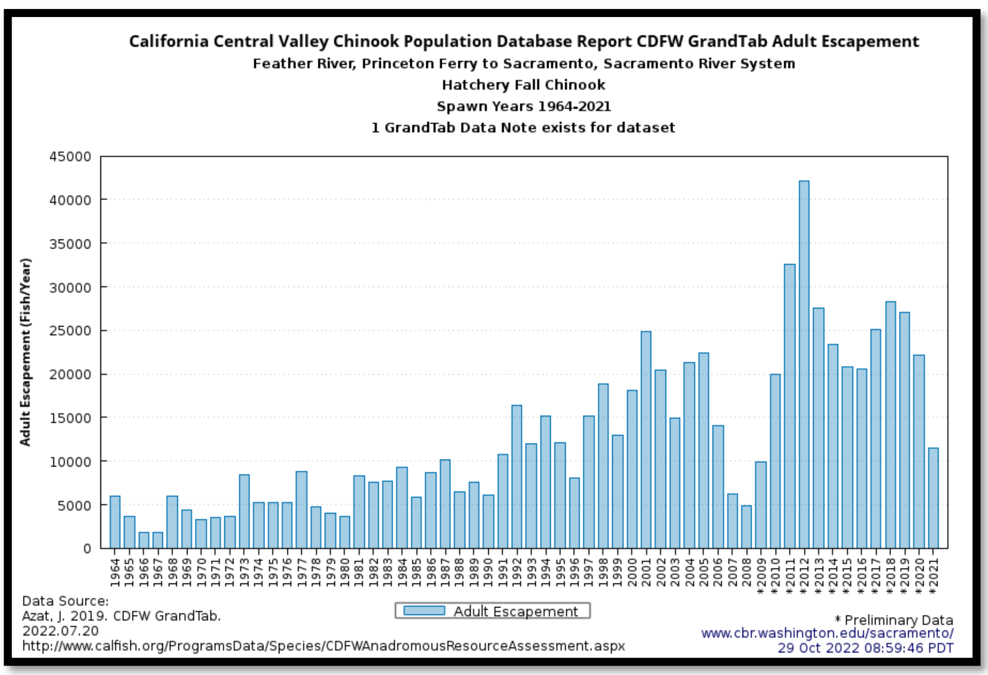

Figure A-7. Feather River hatchery escapement.

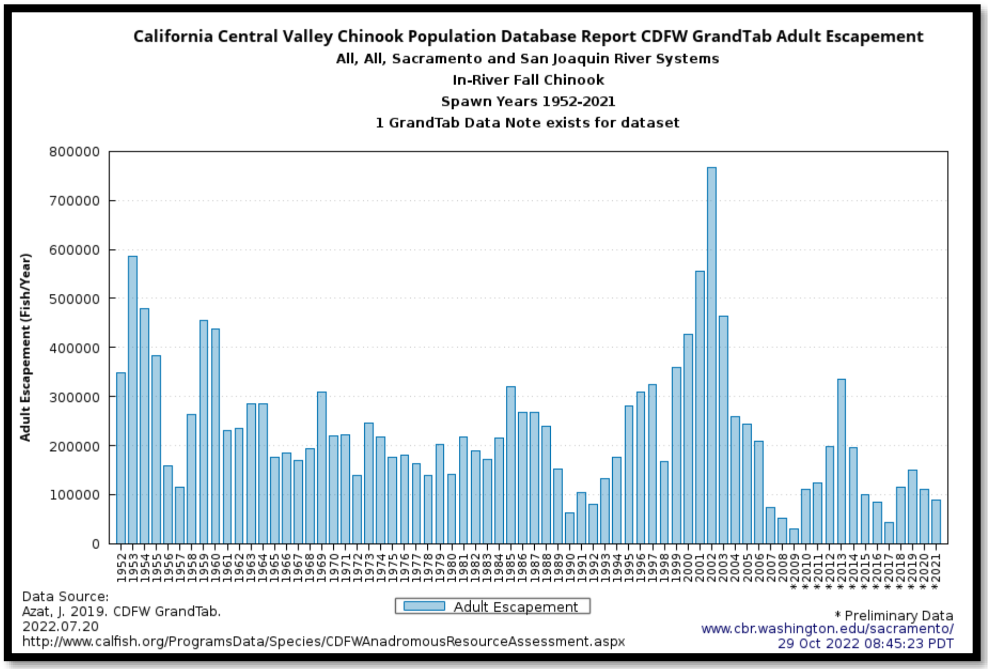

Figure A-8. Central Valley in-river total escapement.

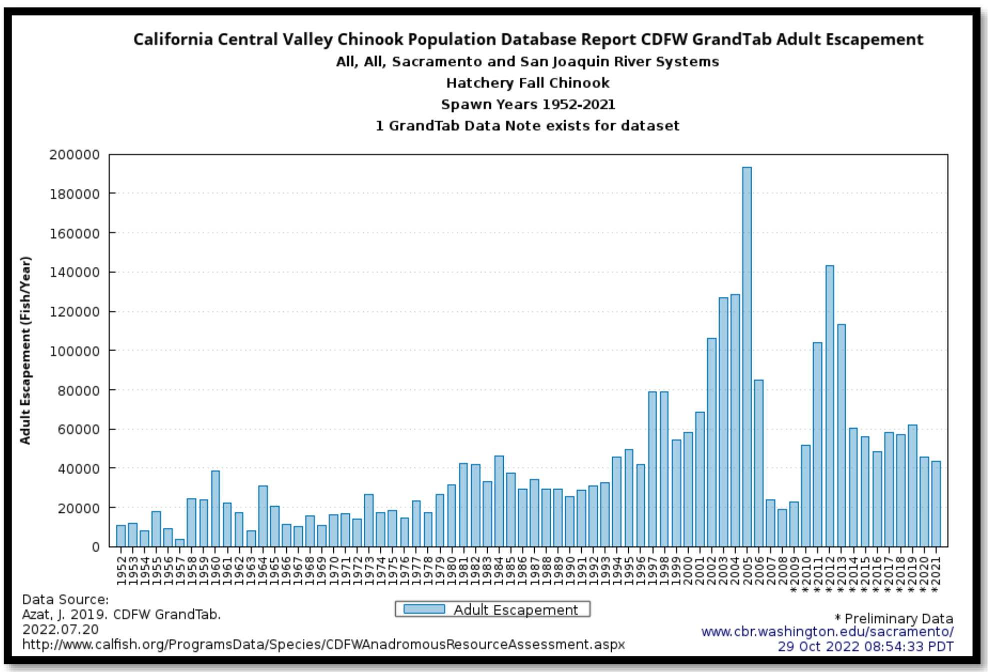

Figure A-9. Central Valley hatchery total escapement.

Appendix B - PFMC Management Plans[9]

Each year the PFMC forecasts the number of fish available for harvest and then sets quotas/regs to control harvest and escapement. Crude at best and subject to bias it is what it is. The problem is that it has led to over-fishing. At a minimum, the quotas and regulations should be more conservative until stocks recover to reasonable levels (at least 200-300 thousand escapement).

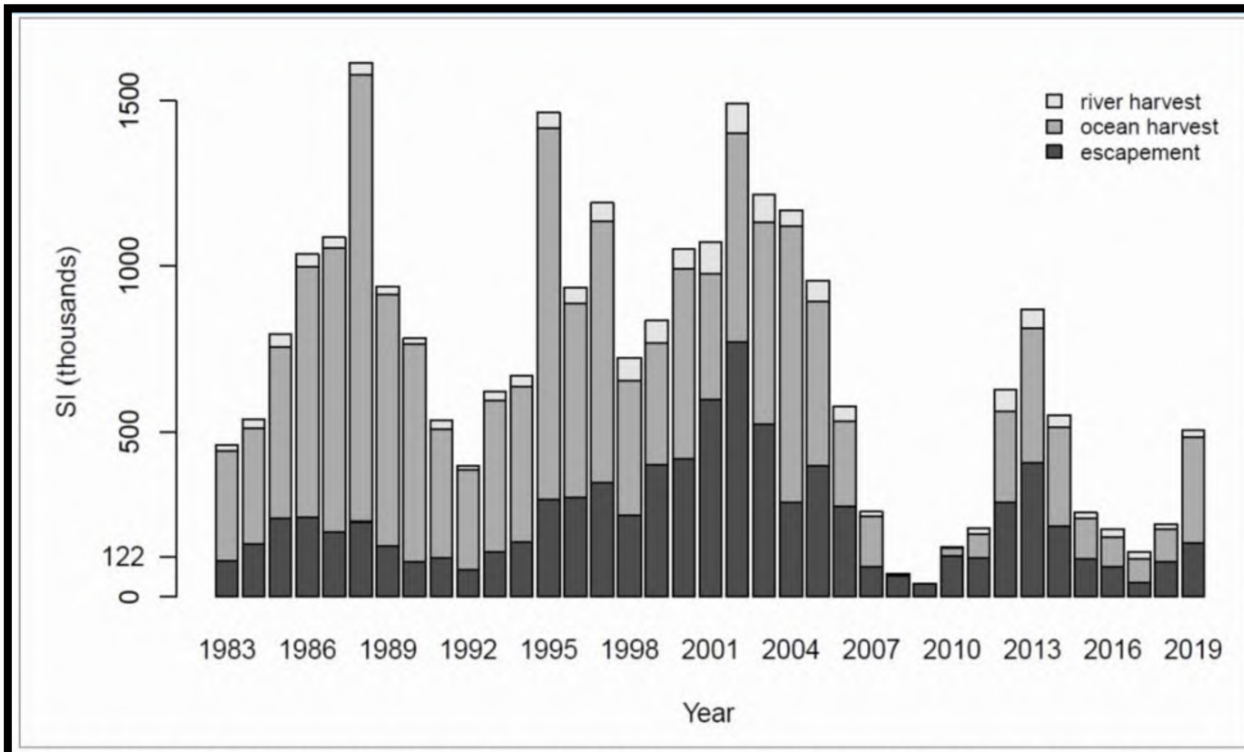

FIGURE II-1. The Sacramento Index (SI) and relative levels of its components. The Sacramento River fall Chinook S_{MSY} of 122,000 adult spawners is noted on the vertical axis.

- *Forecast for 2019: Sacramento River fall Chinook spawning escapement of 160,159 hatchery and natural area adults. Sacramento Index exploitation rate of 57.8%.*

Comment: Their forecast was about 33% too high (actual was about 120,000). Harvest was also high (about two-thirds).

- *Forecast for 2020: Sacramento River fall Chinook spawning escapement of 233,174 hatchery and natural area adults. . Sacramento Index exploitation rate of 50.7%.*

Comment: their forecast was about 50% too high (actual 150,000). If harvest reached 50% of forecast it would have been 118,000 or nearly 80%. However, restrictive regulations kept the harvest rate below expectations.

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[9] *https://www.pcouncil.org/managed_fishery/salmon/*

- *Forecast for 2021: Sacramento River fall Chinook spawning escapement of 133,913 hatchery and natural area adults. Sacramento Index exploitation rate of 50.6%.*
- *Under the terms the salmon FMP, SRFC are considered rebuilt when the 3-year geometric mean spawning escapement exceeds the level associated with MSY (S_{MSY}) of 122,000 hatchery and natural area adults. SRFC met this criterion and were determined to be rebuilt in 2021. The geometric mean of adult spawning escapement for years 2019-2021 is 133,192 and therefore SRFC should not be considered overfished. SRFC are considered to have been subject to overfishing if the estimated exploitation rate exceeds their maximum fishing mortality threshold (MFMT) of 0.78.*
- *Late-fall Chinook spawning escapement in 2021 was estimated to be 3,637 adults and 269 jacks. These Chinook returned primarily to the Coleman National Fish Hatchery and the upper Sacramento River. These numbers also include late-fall Chinook that returned to upper Sacramento River tributaries and those captured in the Keswick trap for use as broodstock at Coleman National Fish Hatchery.*

TABLE II-1. Sacramento River natural area and hatchery adult fall Chinook escapement in numbers of fish.

Year or	Upper River[a/]			Low er River			Total		
Average	Hatchery	Natural[b/]	Subtotal	Hatchery	Natural[b/]	Subtotal	Hatchery	Natural[b/]	Grand Total
1981-85	11,557	57,913	69,470	16,917	81,880	98,797	28,475	139,793	168,268
1986-90	11,507	87,396	98,903	11,521	73,633	85,154	23,028	161,029	184,057
1991-95	11,948	60,151	72,099	16,951	70,691	87,642	28,899	130,842	159,741
1996-00	29,965	153,777	183,742	21,137	137,071	158,207	51,102	290,848	341,949
2001-05	72,122	197,215 [c/]	269,337	30,520	214,652	245,172	102,643	411,867	514,510
2006	56,819	89,933	146,752	21,722	106,556	128,278	78,541	196,489	275,030
2007	11,543	36,079	47,622	9,759	33,993	43,752	21,302	70,072	91,374
2008	10,181	36,274	46,455	7,867	11,042	18,909	18,048	47,316	65,364
2009	5,433	12,277	17,710	10,492	12,671	23,163	15,925	24,948	40,873
2010	8,666	25,688	34,354	24,484	65,438	89,922	33,150	91,126	124,276
2011	19,312	20,466	39,778	22,176	57,388	79,564	41,488	77,854	119,342
2012	77,318	67,190	144,508	41,878	99,043	140,921	119,196	166,233	285,429
2013	67,758	90,119	157,877	33,453	215,516	248,969	101,211	305,635	406,846
2014	17,937	80,407	98,344	25,872	88,260	114,132	43,809	168,667	212,476
2015	13,861	40,696	54,557	25,103	33,808	58,911	38,964	74,504	113,468
2016	8,306	10,563	18,869	25,096	45,734	70,830	33,402	56,297	89,699
2017	1,316	1,526	2,842	25,162	16,325	41,487	26,478	17,851	44,329
2018	8,207	18,317	26,524	25,570	53,372	78,942	33,777	71,689	105,466
2019	13,065	53,706	66,771	29,073	67,923	96,996	42,138	121,629	163,767
2020	12,478	36,447	48,925	25,444	63,722	89,166	37,922	100,169	138,091
2021[d/]	14,555	52,320	66,875	16,700	20,908	37,608	31,255	73,228	104,483
Goal[e/]									122,000

a/ Above the Feather River; 1971-1985 estimates include Tehama-Colusa Spaw ning Channel.

b/ Fish spaw ning in natural areas are the result of hatchery and natural production; estimates generally based on carcass surveys.

c/ Estimation methodology for 2002 w as changed due to an extremely high Battle Creek escapement.

d/ Preliminary.

e/ Sacramento River fall Chinook S_{MSY}.

Comment: their forecast was about 10% too high (actual 120,000 including jacks). If harvest reached 50% of forecast it would have been 67,000 or nearly 55%. However,

restrictive regulations kept the harvest rate below expectations. A total of 104,483 hatchery and natural area adult spawners were estimated to have returned to the Sacramento River Basin in 2021. Fall Chinook returns to Sacramento River hatcheries in 2021 totaled 31,255 adults and 7,773 jacks, and escapement to natural areas was 73,228 adults and 9,230 jacks. So technically the population average was above the escapement level and was not considered overfished.

- *Recreational angling for salmon in the Sacramento River and its tributaries was expected to result in a catch of 21,800 adult SRFC. Actual harvest of SRFC in 2021 totaled 10,788 adults and 3,143 jacks.*

- *Forecast for 2022: The adopted management measures have a projected escapement of 198,694. Sacramento Index exploitation rate of 49.9%.*

TABLE B-1. Sacramento River fall Chinook salmon escapement in numbers of fish.[a/b/]

Year or Average	Upper Sacramento Natural Areas[c/d/e/]		Lower Sacramento Natural Areas[c/]: Feather River		Yuba River		American River[f/]		Natural Area Totals[c/]		Sacramento Hatcheries: Coleman		Feather River		Nimbus		Hatchery Totals		Sacramento Totals	
	Adults	Jacks	Adults	Jacks	Adults	Jacks	Adults	Jacks	Adults	Jacks	Adults	Jacks	Adults	Jacks	Adults	Jacks	Adults[g/]	Jacks	Adults	Jacks
1981-1985	57,913	22,432	36,252	5,243	12,825	5,146	32,803	5,142	139,793	37,963	11,557	3,734	6,845	884	10,072	2,257	29,832	7,689	169,625	45,651
1986-1990	87,396	17,244	38,709	6,426	9,261	2,444	25,663	3,917	161,029	30,031	11,507	2,288	5,837	1,947	5,685	1,349	23,028	5,584	184,057	35,616
1991-1995	60,151	11,496	32,578	4,355	8,309	2,131	29,804	4,367	130,842	22,350	11,948	2,295	10,537	2,762	6,414	1,447	28,899	6,505	159,741	28,855
1996-2000	153,777	8,383	54,225 [h/]	6,806	20,233	4,600	62,613	10,061	290,848	29,851	29,965	3,001	13,342	1,497	7,795	1,407	51,102	5,905	341,949	35,756
2001-2005	197,215 [i/]	7,600	88,250	7,064	18,461	2,861	107,941	14,198	411,867	31,723	72,122	6,018	18,300	2,507	12,221	4,799	102,643	13,324	514,510	45,047
2006-2010	40,050	2,884	29,544	1,451	5,913	512	10,483	1,035	85,990	5,883	18,528	2,193	9,411	1,522	5,454	648	33,393	4,363	119,383	10,245
2011	20,466	15,096	35,656	11,633	6,917	2,204	14,815	10,422	77,854	39,355	19,312	23,068	15,925	16,691	6,251	6,429	41,488	46,188	119,342	85,543
2012	67,190	7,125	57,507	6,142	6,009	1,722	35,527	3,296	166,233	18,285	77,318	8,198	33,628	8,533	8,250	1,007	119,196	17,738	285,429	36,023
2013	90,119	6,253	145,650	5,559	13,830	1,050	56,036	2,192	305,635	15,054	67,758	2,103	25,152	2,470	8,301	775	101,211	5,348	406,846	20,402
2014	80,407	7,193	55,480	5,241	9,885	1,819	22,895	3,580	168,667	17,833	17,937	903	18,824	4,596	7,048	1,295	43,809	6,794	212,476	24,627
2015	40,696	3,342	18,069	2,497	3,844	2,789	11,895	3,844	74,504	12,472	13,861	1,863	17,700	3,116	7,403	2,419	38,964	7,398	113,468	19,870
2016	10,563	803	34,054	4,727	2,143	1,422	9,537	4,936	56,297	11,888	8,306	225	17,594	2,962	7,502	1,922	33,402	5,109	89,699	16,997
2017	1,526	4,015	8,120	2,414	1,207	441	6,998	2,665	17,851	9,535	1,316	5,080	16,598	8,448	8,564 [j/]	2,015 [j/]	26,478	15,543	44,329	25,078
2018	18,317	11,998	39,210	6,616	2,140	933	12,022	9,070	71,689	28,617	8,207	5,991	21,084	7,272	4,486	1,726	33,777	14,989	105,466	43,606
2019	53,706	5,203	43,352	8,611	2,677	671	21,894	5,136	121,629	19,621	13,065	1,204	19,731	7,372	9,342	1,954	42,138	10,530	163,767	30,151
2020	36,447	3,747	40,499	2,470	3,801	393	19,422	3,034	100,169	9,644	12,478	1,259	20,340	1,853	5,104	1,160	37,922	4,272	138,091	13,916
2021[k/]	52,320	4,597	9,203	485	3,918	703	7,787	3,445	73,228	9,230	14,555	1,884	9,372	2,146	7,328	3,743	31,255	7,773	104,483	17,003
GOALS	-	-	-	-	-	-	-	-	-	-	12,000[l/]	-	6,000[l/]	-	4,000[l/]	-	22,000[l/]	-	122,000[m/]	-

a/ In 2004, CDFW reviewed and updated 1971-2003 escapement estimates to reflect final project reports.
b/ Chinook spawning during the fall; may include spring run fish in some survey areas.
c/ Most natural area estimates based on carcass surveys with a jack length cut-off.
d/ Upper Sacramento mainstem estimates generally based on carcass surveys with a jack length cut-off, however, jack estimates from Red Bluff Diversion Dam (RBDD) reports have occasionally been used. Early (pre-2001) mainstem Sacramento River adult and jack estimates based on RBDD passage.
e/ Upper Sacramento River escapement includes Sacramento River mainstem; Battle, Clear, Mill, Deer, Butte, Cottonwood, and Cow creeks; and other small tributaries when surveys were conducted. Specific escapement estimates by tributary can be found at www.calfish.org.
f/ American River adult and jack ecapement estimates include fish taken at Nimbus Weir, 1979-current. In previous versions of this table, fish taken at Nimbus Weir were included in the Nimbus Fish Hatchery counts.
g/ Total adults in Sacramento hatcheries include Tehama-Colusa Fish Facility escapements, 1971-1985.
h/ Survey methodology was variable for 1998-99; may not be comparable to other surveys.
i/ Change in 2002 estimation methodology due to extremely high Battle Creek escapement.
j/ Nimbus Fish Hatchery opened three weeks early to collect anticipated stray Chinook originating from Coleman National Fish Hatchery. During this time, 2,886 fish were collected.
k/ Preliminary.
l/ Current hatchery-specific goals, not PFMC goals.
m/ Sacramento River fall Chinook S_{MSY}.

TABLE B-2. San Joaquin River fall Chinook salmon escapement in numbers of fish.[a/]

Year or	San Joaquin Natural Areas[b/]												San Joaquin Hatcheries						San Joaquin	
	Mokelumne River		Stanislaus River		Tuolumne River		Merced River		Other Tributaries[c/d/]		Totals		Mokelumne River		Merced River		Totals		Totals	
Average	Adults	Jacks	Adults	Jacks	Adults	Jacks	Adults	Jacks	Adults	Jacks	Adults	Jacks	Adults	Jacks	Adults	Jacks	Adults	Jacks	Adults	Jacks
1981-1985	7,346	394	4,649	633	12,902	5,143	9,749	4,551	284	0	34,930	10,721	759	734	797	449	1,556	1,183	36,486	11,904
1986-1990	1,294	162	4,174	824	2,951	2,910	2,414	480	20	0	10,853	4,377	278	286	299	140	577	426	11,430	4,803
1991-1995	865	281	472	123	264	139	1,026	360	0	0	2,626	904	1,077	554	239	233	1,316	788	3,943	1,691
1996-2000	2,334	791	3,536	802	7,144	2,160	3,838	873	0	0	16,853	4,626	3,413	1,052	769	525	4,182	1,576	21,035	6,203
2001-2005	3,264	572	4,905	822	3,668	658	4,674	828	148	26	16,659	2,905	5,177	2,392	716	387	5,894	2,780	22,553	5,685
2006-2010	812	183	937	181	293	86	583	101	285	3	2,910	554	1,639	811	93	47	1,731	858	4,641	1,412
2011	705	1,962	433	630	231	647	640	975	518	0	2,527	4,214	2,409	13,513	99	338	2,508	13,851	5,035	18,065
2012	3,836	1,635	3,550	456	485	298	1,947	310	1,034	149	10,852	2,848	4,430	2,190	628	372	5,058	2,562	15,910	5,410
2013	5,806	1,265	2,562	283	1,798	128	2,673	153	0	0	12,839	1,829	3,698	1,483	918	180	4,616	1,663	17,455	3,492
2014	1,973	1,324	1,837	1,227	150	56	611	249	401	0	4,972	2,856	4,417	4,403	229	582	4,646	4,985	9,618	7,841
2015	3,075	1,506	4,050	2,086	42	71	860	387	180	0	8,207	4,050	5,170	3,128	556	642	5,726	3,770	13,933	7,820
2016	1,279	705	5,231	3,961	661	696	1,232	2,099	986	262	9,389	7,723	3,314	3,573	1,995	970	5,309	4,543	14,698	12,266
2017	4,626	1,018	2,225	1,274	690	428	2,349	832	575	95	10,465	3,647	4,651	9,668	602	1,099	5,253	10,767	15,718	14,414
2018	6,456	3,599	2,018	359	734	343	349	529	630	158	10,187	4,988	4,937	2,483	264	639	5,201	3,122	15,388	8,110
2019	3,325	1,042	1,221	283	828	103	1,952	259	435	0	7,761	1,687	5,806	2,697	628	339	6,434	3,036	14,195	4,723
2020	179	422	461	80	240	31	394	32	0	0	1,274	565	2,141	1,302	141	44	2,282	1,346	3,556	1,911
2021[e/]	258	568	1,970	2,374	133	53	290	197	833	0	3,484	3,192	2,116	2,101	57	210	2,173	2,311	5,657	5,503
GOALS[f/]	-	-	-	-	-	-	-	-	-	-	-	-	3,000[g/]	-	1,000	-	4,000	-	-	-

a/ In 2004, CDFW review ed and updated 1971-2003 escapement estimates to reflect final project reports.

b/ Most natural area estimates based on carcass surveys w ith a jack length cut-off.

c/ Other San Joaquin tributary escapement includes Cosumnes and Calaveras Rivers w hen surveys w ere conducted. In some years no survey w as conducted due to logistical or environmental limitations.

d/ Calculating jack proportions w as not possible in some years due to sampling and/or environmental limitations. In those years jacks are included in the adult escapement values.

e/ Preliminary.

f/ Current hatchery-specific goals, not PFMC goals.

g/ Due to modernization of the hatchery facility and improved efficiencies, the Mokelumne Hatchery escapement goal w as reduced from 5,000 to 3,000 adults in 2010.

Appendix C -Review of Key Literature

1. Satterthwaite (2022). Literature Review for Sacramento River Fall Chinook Conservation Objective and Associated Smsy Reference Point -- Prepared for Pacific Fishery Management Council's Salmon Methodolo... Technical Report · October 2022 DOI: 10.13140/RG.2.2.27280.48645

- *The hatchery contributions were based on "mitigation requirements or hatchery capacities, whichever is higher" and were set equal to 9,000 for the Upper-River hatchery (i.e., Coleman National Fish Hatchery), 5,000 for Feather River Hatchery, and 6,000 for Nimbus Hatchery on the American River. According to PFMC 2022b Table B-1, current fall-run Chinook goals are 12,000 adults for Coleman National Fish Hatchery, 6,000 adults for Feather River Hatchery, and 4,000 adults for Nimbus Hatchery (totaling 22,000 hatchery adults, compared to a total of 20,000 for the goals stated in PFMC [1984]).*

Comment: These goals are set based on the need for eggs in each hatchery. Goals for each hatchery are difficult to evaluate because not all smolts are marked/tagged and what is taken into the hatchery is only a portion of the production, and furthermore many marked fish are strays from other hatcheries.

- *PFMC (1984, p. 3-19) further states that natural-area escapement of 99,000 to the Upper-River is unlikely to be achieved until "problems caused by the Red Bluff Diversion Dam are rectified and so establishes an "interim" (p. 3-19) alternative contribution of 50,000 for natural areas and the hatchery in the Upper-River combined, based on Upper-River fall Chinook runs "fall[ing] from 81,700 to 51,500 adult[s]" from 1979-1983[4] (PFMC 1984, p. 3-19) and an expectation that returns would stabilize at about 50,000. In fact, returns to the Upper-River were much higher than this for the late 1980s and the late 1990s through the early 2000s (Figure 1). The specific problems with RBDD and how they would be rectified are not clearly stated on p. 3-19 of PFMC (1984), although p. 3-18 refers to passage problems. Construction of RBDD was completed in 1964 (https://www.usbr.gov/projects/index.php?id=244). RBDD was decommissioned and its gates were permanently locked in the open position in 2013 (and had been fully open since May 2011), although the structure has not been removed and its removal is not planned (Duda 2013). Efforts to improve passage occurred prior to this as well (USBR 2008). Since 1964, natural-area escapements above RBDD exceeded 100,000 in 1965-1966, 1968-1969, 1988, 1995-1997, and 1999-2003 (Azat 2021), and in some additional years escapement to Coleman National Fish Hatchery far exceeded 9,000 and brought total Upper-River escapement above 100,000.*

Comment: The drop in natural-area escapement to record lows in 2009 and then again in 2016 and 2017 also occurred in the tributaries is the main concern being addressed in the recovery programs. Hatchery contributions to adult production and returns from that production also suffered and contributed to the overall declines and record lows. The

drastic declines were unanticipated by the PFMC leading to the fishery closures in 2008 and 2009. The goals are meant to guide fishery regulations. Such goals and forecasts are meaningless unless such sharp population declines can be anticipated. The way the fisheries are managed at present has led to fishery closures and overfishing (Figure C-1). It is therefore reasonable to assume that the patterns in Figure A, are in part due to fishery effects (i.e., overfishing).

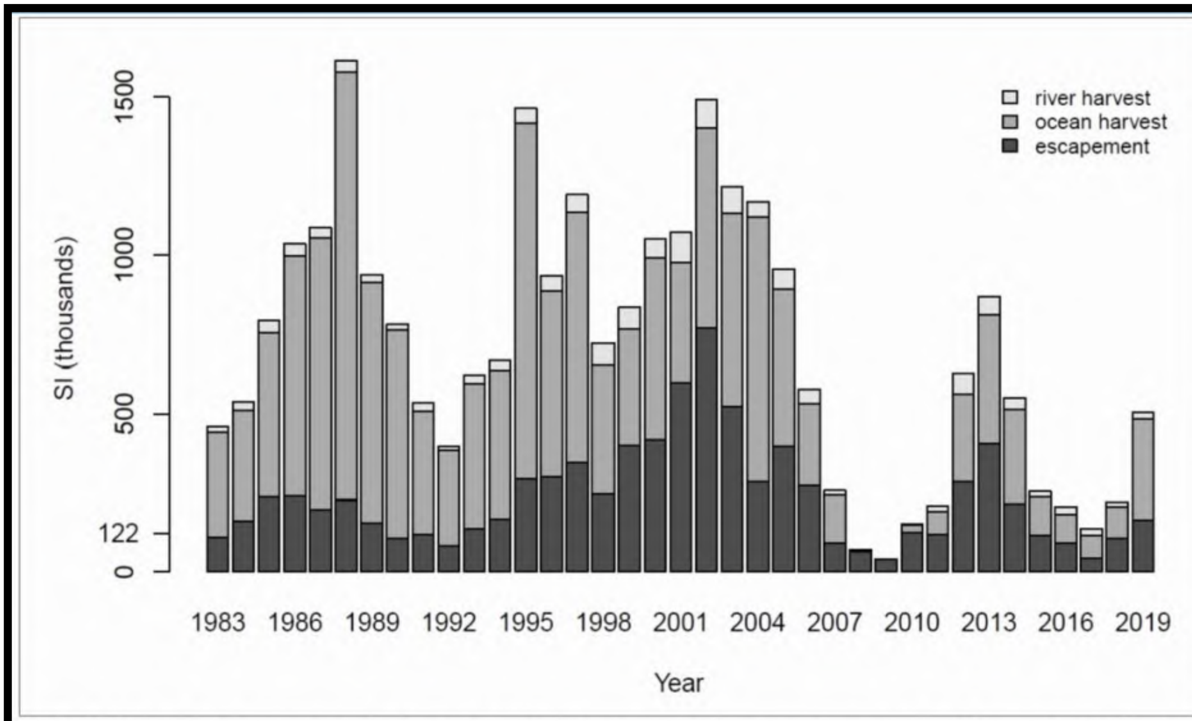


FIGURE II-1. The Sacramento Index (SI) and relative levels of its components. The Sacramento River fall Chinook S_{MSY} of 122,000 adult spawners is noted on the vertical axis.

Figure C-1.

- *The FMP (p. 14) defines S_{MSY} as "The abundance of adult spawners that is expected, on average, to produce MSY." Maximum Sustainable Yield (MSY) is defined on page 13 as "the largest long-term average catch or yield that can be taken from a stock or stock complex under prevailing ecological and environmental conditions and fishery technological characteristics, and distribution of catch among fleets". PFMC (1984) does not attempt to quantify expected yield.*

Comment: Maximum sustained yield is an unreasonable way to manage the Sacramento Fall Run because of extreme effects of drought and hatchery practices (trucking) on recruitment. The latter factor alone can have a substantial effect as exemplified by one release group in 2014 from the Feather River Hatchery to Half Moon Bay on the coast south of San Francisco contributing nearly 50% of the returns to the Feather River Hatchery two years later in 2016 (Figure C-2). The release group was only 368,000 smolts

out of the over 8 million released by the Feather Hatchery in 2014. In contrast, the San Pablo Bay net pen releases yielded about the same number of returns from 6.92 million released smolts. The escapement patterns for 2014 exemplify both the drought problem and the trucking problem in developing forecasts of harvestable adults in the ocean.

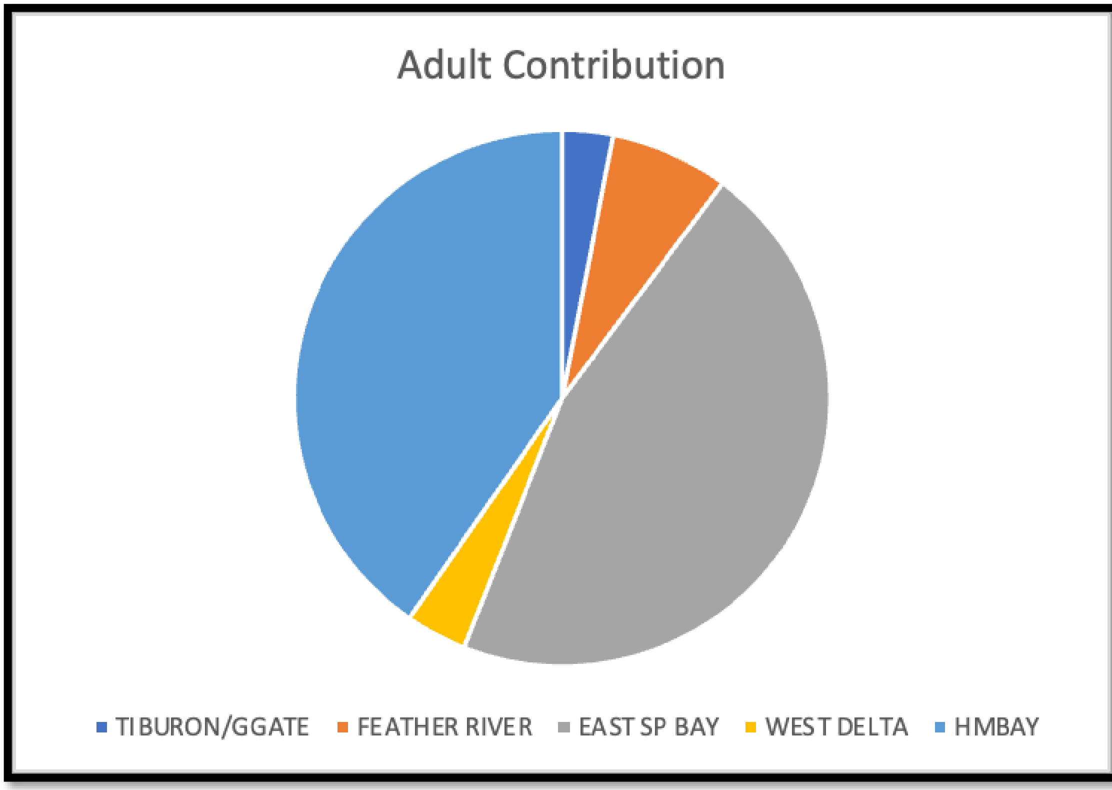


Figure C-2

- *The FMP (p. 21) states that the SRFC conservation objective "is intended to provide adequate escapement of natural and hatchery production", but "adequate" is not defined. PFMC (1984) rejected the idea of formally establishing area-specific subgoals. However, if the individual hatchery and natural area contributions identified are considered to represent adequate[7] levels of spawners in the respective areas, total escapement equal to their sum is exceedingly unlikely to lead to adequate escapement to all areas, since some level of variation is expected in the proportion of escapement returning to each area, and there is no reason to expect the proportions escaping to different areas to exactly equal their proportional contributions to the total objective. Footnote 7: Presumably, "adequate" hatchery performance entails meeting the mitigation requirement. However, "adequate" escapement might be less than the optimal spawning escapement in a given natural area, with the idea that successful management would sometimes miss the optimum above and sometimes below. However, the contributions reported in PFMC (1984) are far below the levels estimated to maximize production or yield, as described in the review of other literature later in this report. Nevertheless, it might make sense to assess the probability of all subareas being* *above some percentage of their optimal contribution, similar to setting MSST equal to 75% of SMSY.*

Comment: The PFMC estimates the fishable stock of adult Sacramento River Fall Run salmon using a forecast model that is updated from year to year to better predict the true fishable stock. However, the whole FMP process for setting regulations including the forecasted fishable stock is not adequate to protect the populations from overfishing. The predicted escapement from the model used has usually been below the actual escapement estimate (Figure C-3). Though reasonably accurate in the past decade, the model significantly overestimated escapement from 2015-2017 leading to overfishing (see Figure C-1).

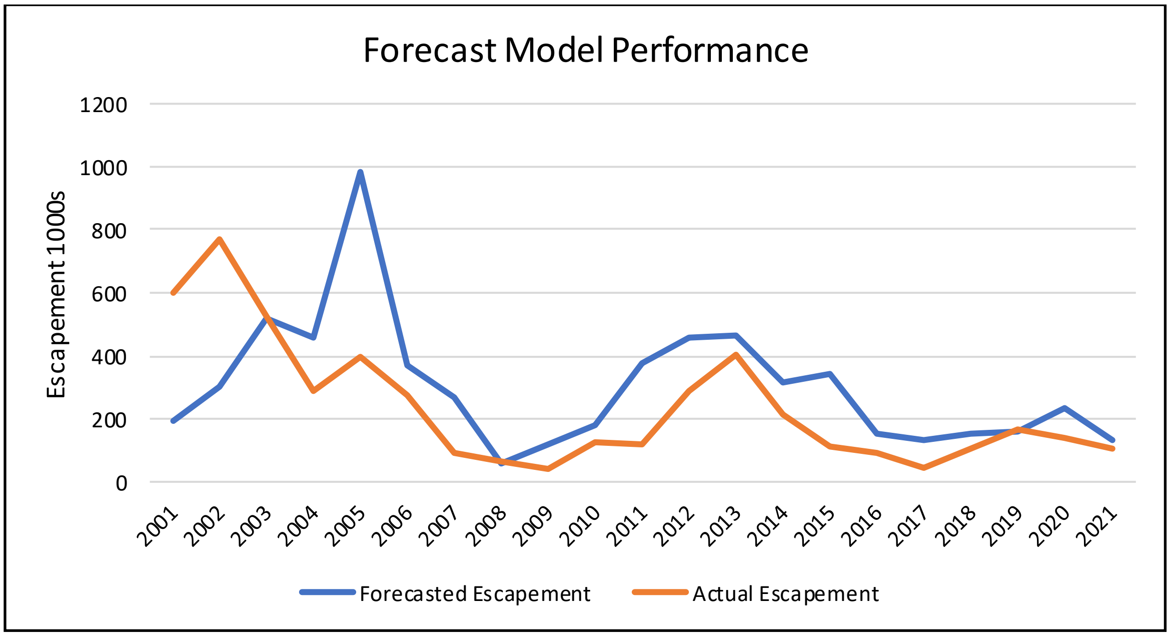


Figure C-3..

- *PFMC (1984, p. 3-19) further states that "<u>the distinction between hatchery and natural fish has become lost in these parts of the river</u>" (apparently intending to exclude the Yuba from "these parts", though this is not entirely clear). Williamson and May (2005) documented extensive hybridization and homogenization among Central Valley fall Chinook at the seven microsatellite loci they examined, which they attributed to <u>extensive hatchery straying and introgression with fish spawning in natural areas</u>. However, Meek et al. (2020) performed a broader genomic study and found greater population structure than previously documented, including evidence for differentiation and adaptation. <u>A comprehensive review of comparisons between hatchery- and natural-origin fish in genetic and phenotypic aspects is beyond the scope of this paper</u>, but the articles cited in the previous sentence may provide good entry points to the literature, along with CA HSRG (2012). Additionally, PFMC (1984) argued that hatcheries on the Feather and American Rivers close their ladders once capacity is reached and* *additional fish that would have returned to the hatchery remain in the river and are counted as natural spawners. However, in reality spawners collected at individual hatcheries have often been far above capacity (see Table 1) and following the practice described in PFMC (1984) could have unintended consequences like inadvertent selection on return timing or even age at return.* (Emphasis added)

Comment: What Satterthwaite is noting in this paragraph are real concerns that wreak havoc on fishery harvest modelling and management. Hatchery and wild origin fish can both be found in the hatchery or in the in-river population elements. There is no effort to segregate stocks in natural spawning areas and minimal effort in hatcheries. The Sacramento River Fall Run DPS/ESU with its many rivers and three hatcheries are at the minimum one large homogeneous (mixed genetic) population. Furthermore, hatcheries would benefit from lower pHOS. Non-sanctuary mixed stock spawning should also benefit with the infusion of "purer" strain adult spawners that take on characteristics better adapted to that river.

- *ASETF (1979) discusses Sacramento River Chinook abundances and goals on pp. 5-7. It states that "Estimates of the number of salmon spawning in the Sacramento River drainage are not based on solid data. The average annual escapement might have been 300,000 to 500,000 chinook [sic] salmon, and an escapement of 400,000 adults is used in this report."*

Comment: Such estimation statistical error is carried over into the forecasting and spawner/recruit analyses making the management process less precise and reliable for the purposes employed. However, this is the problem with all measured data and should not stop the data's use in managing the fisheries. However, it may require more conservative approaches and outcomes that acknowledge a lack of precision or even a negative bias (Figure C-3). In this case, a more conservation strategy is necessary to ensure against over-fishing and better accounting of drought and water management effects.

- *SRFCRT (1994) had the goal of "determin[ing] why the escapement goal for [SRFC] was not met in 1990-1992, and to recommend actions to assure future productivity of the stock", where "the escapement goal" refers to the conservation objective established by PFMC (1984).*

Comment: The PFMC has not learned from their failures to protect the Sacramento fall run population. The forecasting tools missed some stock collapses, resulting in the fishery closure for two years. It is imperative that such forecasting failures be analyzed to improve future forecasting. If this would have been accomplished in 2004 and 2005, the stock collapse and closure in 2008 and 2009 might have been avoided. Other system management actions could have been implemented to minimize the stock collapse.

- *Hallock (1978, p. 3) states that "Defining spawning levels to serve as management goals is a difficult and largely subjective process" and goes on to recommend "an 'average' escapement goal, which is a desirable level around which escapement will fluctuate".*

Comment: This seems reasonable given the error and bias depicted in Figures C-1 and C-3. At a minimum, a more conservative target than a fixed 122,000 escapement should have been considered in 2004 and 2005 as escapement approached the target.

- *Hallock (1977 his Table 4, 1978 his Table 1) suggested SRFC escapement goals of 150,000 for the Upper Sacramento (which he defines as the mainstem and tributaries above the confluence with the Feather River), 40,000 for the Feather River, 25,000 for the Yuba River[13], and 30,000 for the American River, totaling 245,000 spawners.*

Comment: Once the 1976-77 and 1987-92 drought response in the population were observed and documented, a more conservative approach to the population management (fishery, hatchery, and habitat conditions) should have been adopted. While changes were made in hatchery (e.g., Bay-Delta smolt releases) and habitat (e.g., removal of RBDD and other operational changes such as CVPIA actions), no effective changes were made in PFMC management strategy (i.e., the 122,000 goal stands today).

- *As with PFMC (1984), setting a total goal equal to the sum of goals for individual areas makes it unlikely that all goals will be met simultaneously, although Hallock (1977, 1978) seems to accept this possibility since he states that fluctuations around the goals are expected. As these values are not linked to projections of yield or production, and not explicitly linked to capacity, it is not clear that they would satisfy any of the definitions or goals in the FMP for use as conservation objectives or S_{MSY}, although they might be regarded as implicit estimates of capacity.*

Comment: The goals should be separate for each of these three regions because over the past two decades vastly different hatchery strategies and habitat conditions among the rivers occurred. For example, while the Feather and American hatcheries have helped their populations through the drought collapses, the upper Sacramento River hatchery (Coleman) has not.

- *The FMP (p. 21) states that Reisenbichler (1986) found that 118,000 natural-area spawners would maximize production, but it is not clear how this number was extracted from Reisenbichler (1986); nor how it could have been given that Reisenbichler (1986) did not consider the entire Sacramento Basin and used different time periods for the parts he did consider.*

Comment: One might choose 118,000 for maximum production for the earlier decades for which Reisenbichler was reviewing, however a close look at Figure C-1 would not support such a number for sustained yield escapement in the past three decades.

- *Combining the separate stock-recruit relationships estimated by Reisenbichler (1986) into an implied total SRFC escapement goal is challenging, if not impossible, because they cover different time periods, differ in whether they include jacks, and omit part of the system. In addition, Resienbichler (1986) excluded putative "outlier" years (p. 42), depends on questionable inferences about ocean harvest (p. 46) along with limited information on age structure (p. 49), and noted simulations showing that estimates of stock-recruit parameters are "imprecise (have large standard deviations) and often highly biased" (p. 82). Nevertheless, because Reisenbichler (1986) reported the parameters of his fitted Ricker stock-recruit relationships, values for S_{MSY} for subsets of the basin for particular time periods can be calculated using the approach described in Scheuerell (2016), as reported in Table 2. However, the values resulting from the reported parameter estimates seem implausibly small, and are inconsistent with the values displayed in the figures in Reisenbichler (1986).*

Comment: the 118,000 is too small an escapement level to generate a maximum yield level. A population that small during a drought (Figure C-1) would tend to crash rather than sustain yield. An operating level in the range of 300-400 thousand would seem more capable of sustaining the target maximum level of harvest. A somewhat lower level could be sustained if the harvest were focused on the hatchery component of the stock (300,000 harvest of 400,000 hatchery stock yielding 100,000 hatchery escapement on average to be added to 100,000 average natural (wild) escapement under near zero harvest.

- *PFMC (2019) was adopted by the Council and includes a Ricker stock-recruit relationship fitted to fry-equivalent juvenile production as a function of natural-area female spawners in the Upper Sacramento (above RBDD) for brood years 2002-2015 (pp. 24-25). This analysis indicated that maximum production would occur for an escapement of approximately 80,000 females to natural areas above RBDD, or approximately 160,000 spawners assuming a 50:50 sex ratio.*

Comment: This recommendation seems reasonable if the 100,000 hatchery escapement from Coleman is added to the 40-60 escapement indicated for natural escapement. This would be only for the upper river component and would not include the Feather, American, or smaller tributaries below Red Bluff.

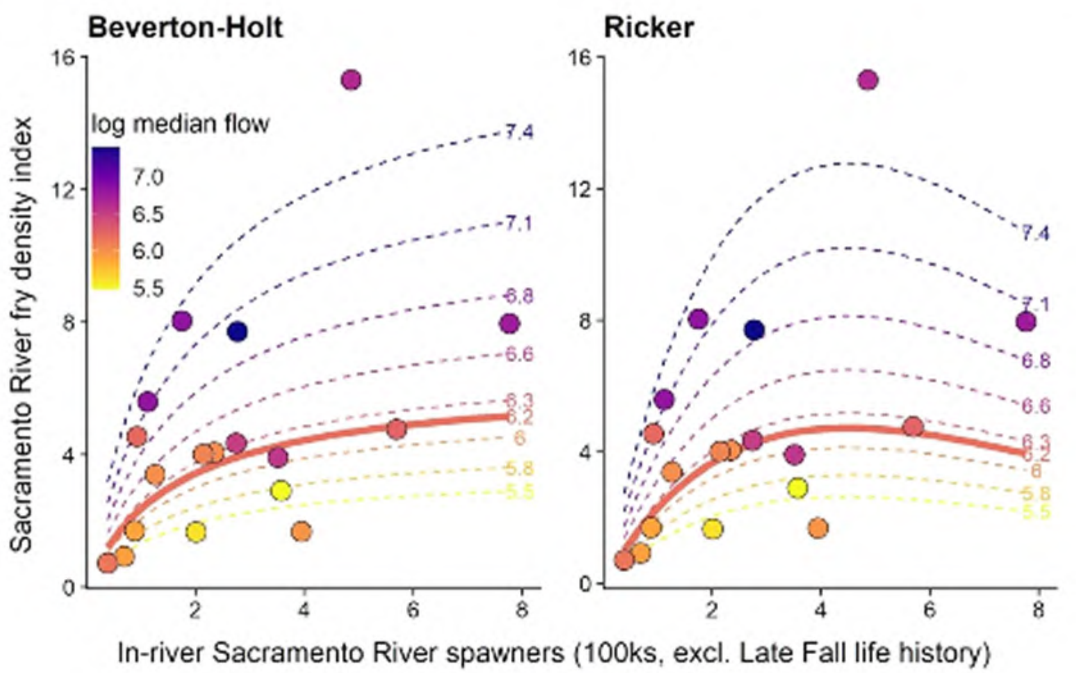
- *While PFMC (1984) stated that it would be difficult to meet an Upper-River goal without over-escapement to the Lower-River, there is considerable variability in the proportion of total escapement (including escapement to hatcheries) which occurs to natural areas of the Upper River (Table 1), ranging from 3% to 64% with median 38% for the years reported in Table 1. In addition, the proportion of total escapement returning to the Upper-River would be expected to be higher on average if production there was higher, as would be expected in response to higher Upper-River escapements.*

Comment: there is not much straying to the upper river, but there are high straying rates to the lower river tributaries from the upper river, especially from Coleman hatchery. In recent years there has been transfers of hatchery eggs or adults back to Coleman from the Feather and American hatcheries. Adjustments to the number of hatchery spawners or the number of smolts released can be made for each river if necessary to account for straying.

- *Munsch et al. (2020) modeled a Chinook fry production index for the Sacramento River basin as a function of flow and natural-area spawners, using data from outmigration years 1999-2016. Due to the size and timing cutoffs in the fry production index, Munsch et al. (2020) argued that the analysis largely excludes hatchery-origin fish and the late-fall life history, but includes fall, spring, and winter run timings. Thus Munsch et al. (2020) considered the natural-area escapement of these three run timings combined, although fall-run predominates by a very large margin. Munsch et al. (2020) found that fry production was maximized at a natural-area escapement of around 400,000[19] spawners.... While Munsch et al. (2020) found strong effects of flow, they also found that even at the lowest flow levels included in the study, fry production tended to increase with increases in natural-area spawner abundance well above 200,000 (Figure 5).*

Comment: see Satterthwaite's Figure 5 below. It seems unnecessary to include winter-run fry in this analysis because it broadens the season of flow to four to six months. Munsch did exclude late-fall run fry from spring months, why not winter run fry from the fall months. In any case, to assume maximum production is greatest at 400,000 escapement for all the flow ranges may be unreasonable and unnecessary when 200-300,000 may be equally reasonable under this range of variability. Furthermore, fry density estimates (an estimate subject to considerable variation and bias) are not independent of flow, thus complicating the relationship and the interpretation and use of it.

Figure 5. Annual fry density index compared with spawner abundances and flow (median flow between December and May measured at USGS flow gages 11447650 on the Sacramento River and 11303500 on the San Joaquin [two gages summed]) overlaid with predictions from the model describing the relationship among these variables. These models are parameterized by a Beverton–Holt and Ricker stock–recruitment relationships and a linear effect of log-transformed flow. The thick, solid line indicates the median value of median log-transformed flow across all years. Predictions from these top two models were shown because AIC values indicated they fit the data similarly well. Other flow metrics yielded broadly similar results, see Munsch et al. (2020) for details. Reproduced from Munsch et al. (2020) in compliance with the Creative Commons Attribution 4.0 International License (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author(s) and source are credited.



Comment: It seems reasonable to model winter-season wild fry production (likely fall run) and flow (to represent the probability of fry survival to the ocean) with natural area (in-river) fall run escapement. If fry production or ocean stock or escapement were maximized at 400,000 spawners, then that would be a reasonable target stock size.

- *Hallock (1977, 1978) proposed a Sacramento Late Fall Chinook escapement goal of 25,000, although it is unclear whether this includes jacks and/or hatchery returns.*

Comment: Based natural area and hatchery escapement estimates for late-fall-run salmon, escapement of 25,000 may not be achievable at least under present conditions. While an escapement goal of 10,000 seems reasonable.

- *The current S_{MSY} reference point of 122,000 includes fish returning to both hatcheries and natural areas. In recent years (2012-2021), a median 69% of total adult SRFC spawners returned to natural areas (PFMC 2022b Table B-1), suggesting this reference point is roughly equivalent to a goal of 84,000 natural-area spawning adults in practice. For 1970-2021, a median 82% of SRFC adults spawned in natural areas (PFMC 2022b Table B-1), such that the S_{MSY} reference point would roughly correspond to 100,000 natural-area adult SRFC spawners.*

Comment: The 100,000 natural spawners coupled with 100,000 hatchery spawners would seem a reasonable target escapement. Both these numbers are well below present levels of escapement for the upper river above the mouth of Feather. Such targets would not be appropriate for the entire Sacramento River Fall Run population as pictured in Figure C-1 that included the Feather and American Rivers and their hatcheries, which should have their own targets based on such an analysis as above.

Appendix D - Sacramento River Salmon Production – Brood Year 2017

2018 Sacramento Fall Run Salmon Survival

Brood-year 2017 fall-run salmon in the Sacramento River did not fare well due to poor hatchery and natural in-river production because of poor spring river and Delta flows and high water temperatures. Hatchery salmon releases were of two common practices at state and federal salmon hatcheries in the Central Valley - releasing about half their 30 million hatchery salmon smolts at or near their production hatchery and trucking the remainder to the Bay. Choosing one practice over the other is a controversial subject that has received a lot of attention over the past two decades. Rather than get into the weeds of the controversy and explain the various arguments, I will just lay out what occurred with some hatchery release groups in 2018. The results clearly indicate a gross waste of smolts produced, which coupled with poor natural survival of river-reared smolts led to the poor salmon returns in 2020. If it were not for selected hatchery smolt releases to the Bay and coast, the 2020 escapement would have fallen below 100,000 (see Figure 9).

American River Hatchery Releases

Two American River release groups released in May 2018 and their return as adults in 2020 provide a good example of wasted resource. Release group #061465 was 669,000 fall run smolts (3-4 inches long) that were transported 20 miles downstream from the American River (Nimbus) Hatchery and released into the mouth of the American River under the Jibboom Street Bridge. Release group #061467 was 650,000 fall run smolts transported approximately 100 miles downstream to net pens at the Wickland Oil Terminal for release into eastern San Pablo Bay about 20 miles from the Golden Gate Bridge and the Pacific Ocean. The estimated %survival based on tag recoveries was 0.04% for group #061465 and 2.20% for group #061467. The returns by locations are shown in Figures D-1 and D-2. These results are more common than not for the American and Feather River hatcheries under drier year conditions.

Coleman Hatchery Releases

While the American River Hatchery tag group #061467 was achieving a 2.2% return, Coleman releases at the hatchery (Figure D-3) achieved an average of less than 0.5% (range of 0.01 to 0.67). The late April releases achieved a return of only 8 out of 380,000 released (0.01%). A 2-% return would have achieved 7600 returns. One only need look at the conditions in the lower Sacramento River in May 2018 (Figure D-4) to understand the problem with the May Coleman releases – water temperatures reached a highly stressful level of 70°F most days in May 2018. In contrast, the Bay release site had near optimum water temperatures (Figure D-5). A Bay release would have bypassed over 200 miles of adverse river conditions for over 6 million Coleman hatchery smolts.

Feather River Hatchery Releases

The Feather River Hatchery releases tell a very similar story with much higher survival for Bay/Coast releases than river releases (Figure D-6).

Release Timing vs Flow Pulses

Releases prior to flow pulses have dramatically higher survival than releases after flow pulses in drier year types (Figure D-7).

Delta Salvage

South Delta export pumping plants salvaged juvenile fall run salmon into early June (Figure D-8). Given the general lack of code-wire tag returns in May and June we can assume most of these juvenile salmon were wild-natural born spring and fall run Chinook.

Survival of Brood-Year 2017 Salmon (Escapement in 2020)

Many of the natural born salmon juvenile salmon also remained in the upper river (Figure D-9) into early June. Few of these late spring salmon migrants made it to the Bay in 2018 (see Figure 10). The overall population recruitment of brood year 2017 is shown in Figure D-11 as the number 18 representing the 2018 conditions described above. The number 18 is green because 2018 was a normal water year. The green circle around the 18 represents the fish (about 150,000) that returned to spawn in water year 2020 also a normal water year. The number 10 (from the record low spawners 2009, but also green/green) came back in 2012 at near 300,000 spawners. Thus compared to broodyear 2009, broodyear production 2017 from a similar level of spawners produced only about a half the escapement (recruits).

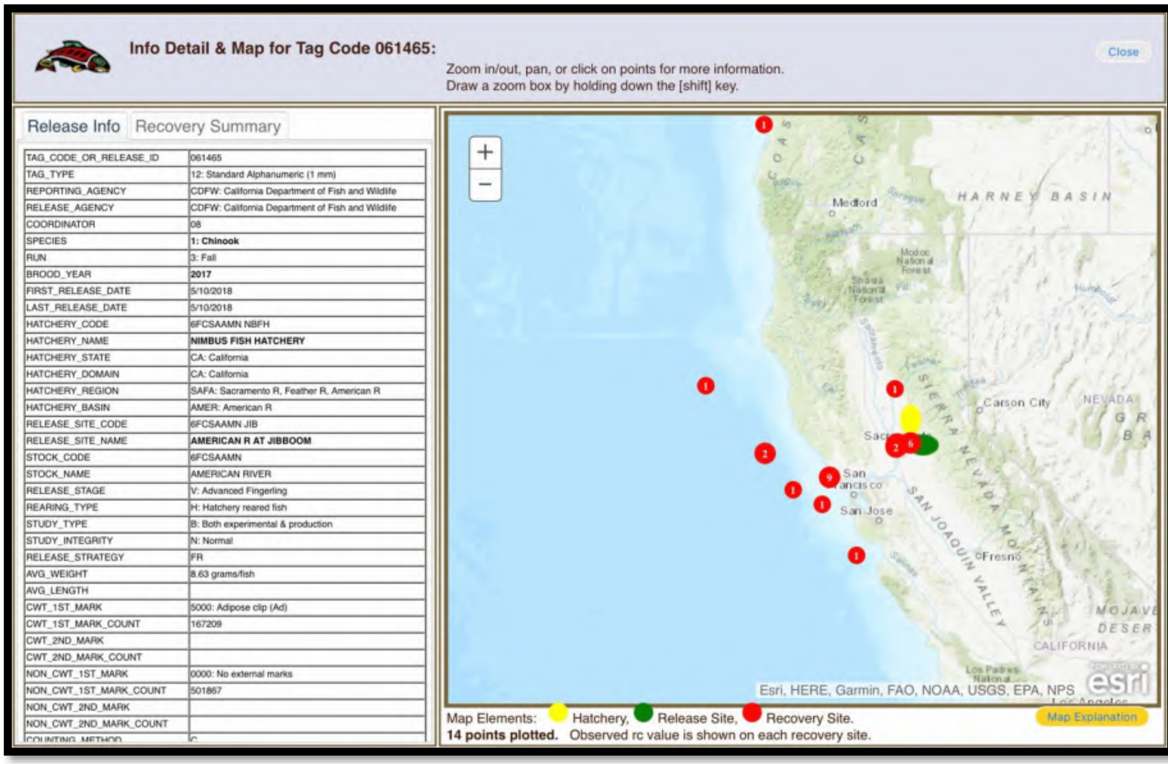


Figure D-1. Returns for tag group #061465.

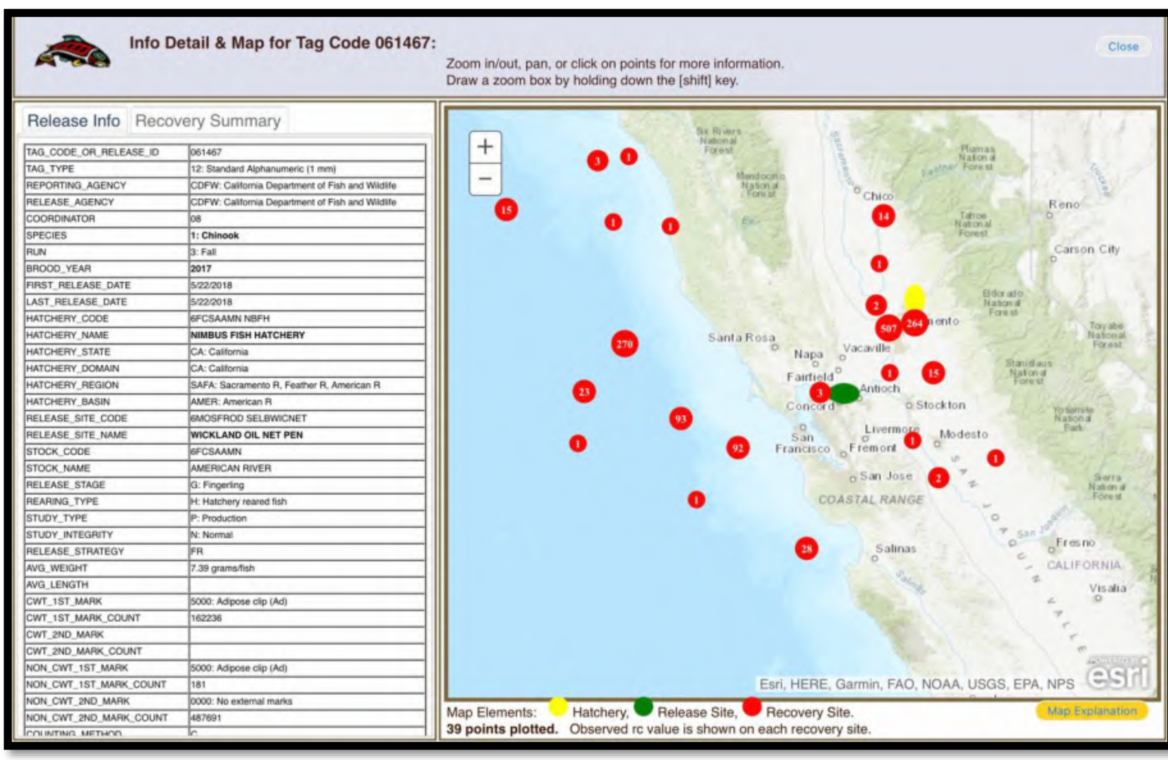


Figure D-2. Returns from tag group #061467.

07:40:44 12/12/2022 Regional Mark Information System PAGE 1
REPORT: SA1 SPECIES SURVIVAL ANALYSIS
SPECIES: Chin

Tagcode	BrYr	Date Rel	Release Location....	Hatchery Location...	#CWT....	LossRt	#Non-CWT.	Total Rel	#Obs.	#Est....	% Surv
053999	2017	20180420	COLEMAN NFH	COLEMAN NFH	15497	0	47739	63236	1	1.01	0.01
056235	2017	20180406	COLEMAN NFH	COLEMAN NFH	106255	0	319021	425276	198	711.08	0.67
056236	2017	20180406	COLEMAN NFH	COLEMAN NFH	113145	0	339786	452931	199	754.75	0.67
056237	2017	20180406	COLEMAN NFH	COLEMAN NFH	115967	0	349469	465436	102	439.90	0.38
056238	2017	20180406	COLEMAN NFH	COLEMAN NFH	114566	0	345167	459733	110	455.24	0.40
056239	2017	20180406	COLEMAN NFH	COLEMAN NFH	98678	0	297400	396078	135	521.84	0.53
056240	2017	20180406	COLEMAN NFH	COLEMAN NFH	102013	0	307491	409504	67	248.88	0.24
056241	2017	20180420	COLEMAN NFH	COLEMAN NFH	78830	0	237972	316802	2	7.87	0.01
056242	2017	20180406	COLEMAN NFH	COLEMAN NFH	87790	0	264771	352561	64	265.20	0.30
056243	2017	20180406	COLEMAN NFH	COLEMAN NFH	94803	0	285771	380574	57	229.75	0.24
056244	2017	20180413	COLEMAN NFH	COLEMAN NFH	79660	0	240279	319939	28	91.21	0.11
056245	2017	20180413	COLEMAN NFH	COLEMAN NFH	77645	0	234297	311942	5	14.53	0.02
056246	2017	20180406	COLEMAN NFH	COLEMAN NFH	71606	0	216283	287889	85	385.85	0.54
056247	2017	20180406	COLEMAN NFH	COLEMAN NFH	81222	0	244999	326221	126	484.23	0.60
056248	2017	20180413	COLEMAN NFH	COLEMAN NFH	72941	0	220257	293198	5	23.59	0.03
056249	2017	20180413	COLEMAN NFH	COLEMAN NFH	58894	0	178038	236932	7	23.58	0.04

Figure D-3. Coleman Hatchery April 2018 release returns.

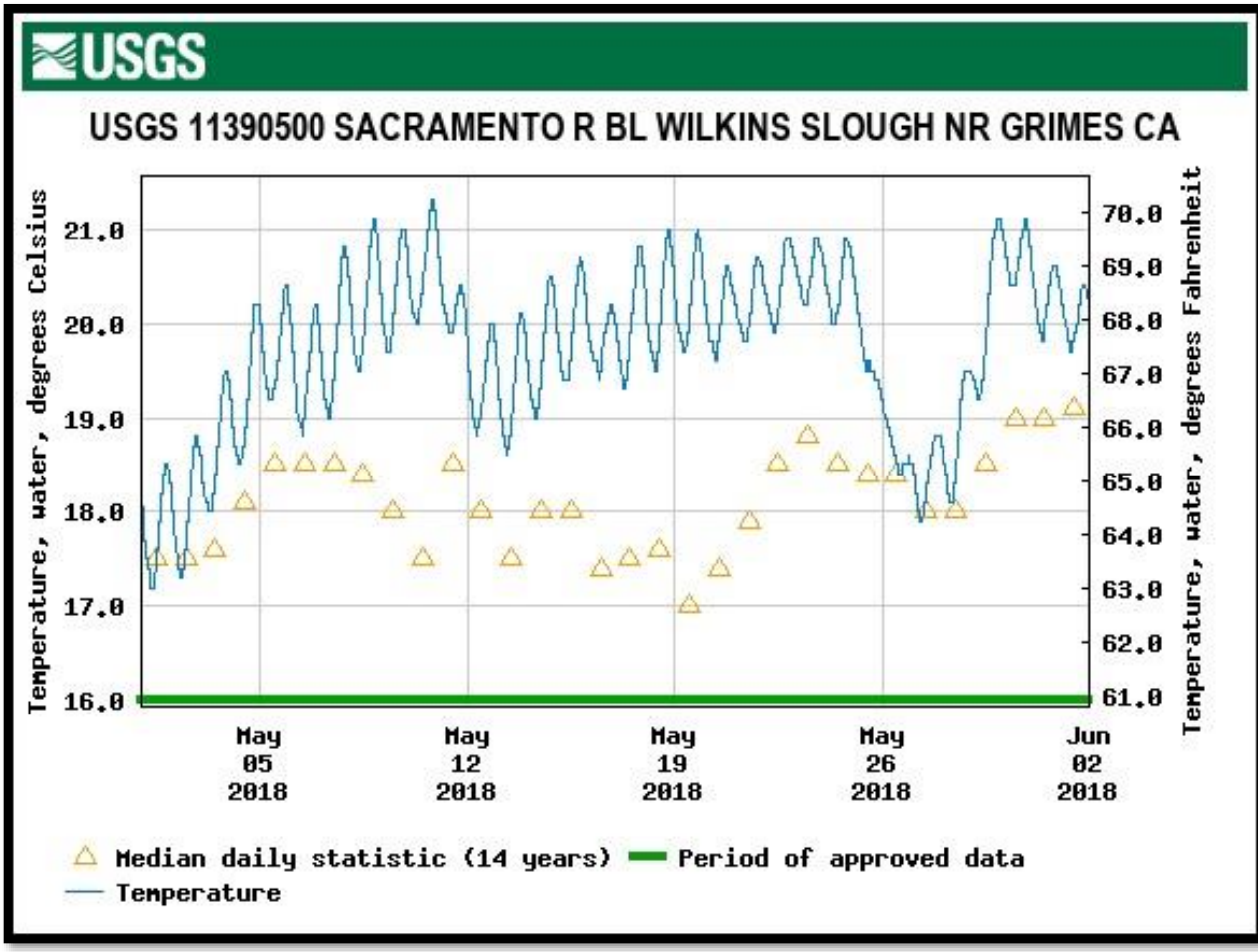


Figure D-4. Lower Sacramento River water temperatures at Wilkins Slough in May 2018.

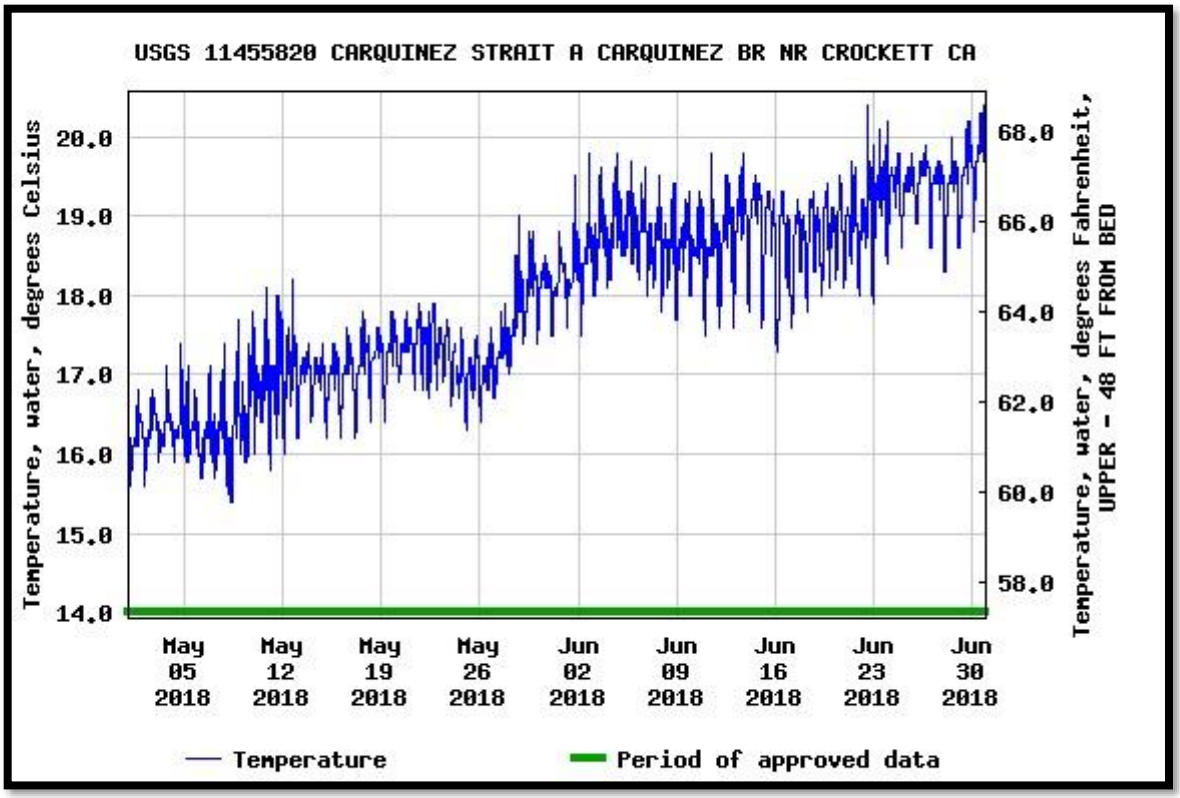


Figure D-5. Water temperatures near hatchery smolt Bay release site in May 2018.

060456	2017	20180616	FORT BAKER MINOR PT	FEATHER R HATCHERY	35309	106351	141660	194	748.18	2.12
060653	2017	20180501	MARE ISLAND NET PEN	FEATHER R HATCHERY	999026	3009404	4008430	3725	10861.48	1.09
060655	2017	20180531	MARE ISLAND NET PEN	FEATHER R HATCHERY	497572	1499636	1997208	2546	7554.02	1.52
061456	2017	20180502	SAC R ELKHORN BOAT R	FEATHER R HATCHERY	83845	252785	336630	4	12.15	0.01
061457	2017	20180502	SAC R ELKHORN BOAT R	FEATHER R HATCHERY	82425	251055	333480	5	16.14	0.02
061458	2017	20180502	SAC R ELKHORN BOAT R	FEATHER R HATCHERY	84219	253517	337736	9	27.79	0.03
061459	2017	20180519	FORT BAKER MINOR PT	FEATHER R HATCHERY	83704	252896	336600	555	1603.27	1.92
061460	2017	20180520	FORT BAKER MINOR PT	FEATHER R HATCHERY	78701	238248	316949	524	1518.10	1.93
061461	2017	20180520	FORT BAKER MINOR PT	FEATHER R HATCHERY	83283	248477	331760	431	1180.10	1.42
061462	2017	20180616	FORT BAKER MINOR PT	FEATHER R HATCHERY	83137	250063	333200	918	2650.08	3.19
061463	2017	20180617	FORT BAKER MINOR PT	FEATHER R HATCHERY	83053	251040	334093	1032	3250.97	3.91
061464	2017	20180617	FORT BAKER MINOR PT	FEATHER R HATCHERY	82686	254864	337550	1012	3195.66	3.86

Figure D-6. Feather River Hatchery April-May 2018 release returns.

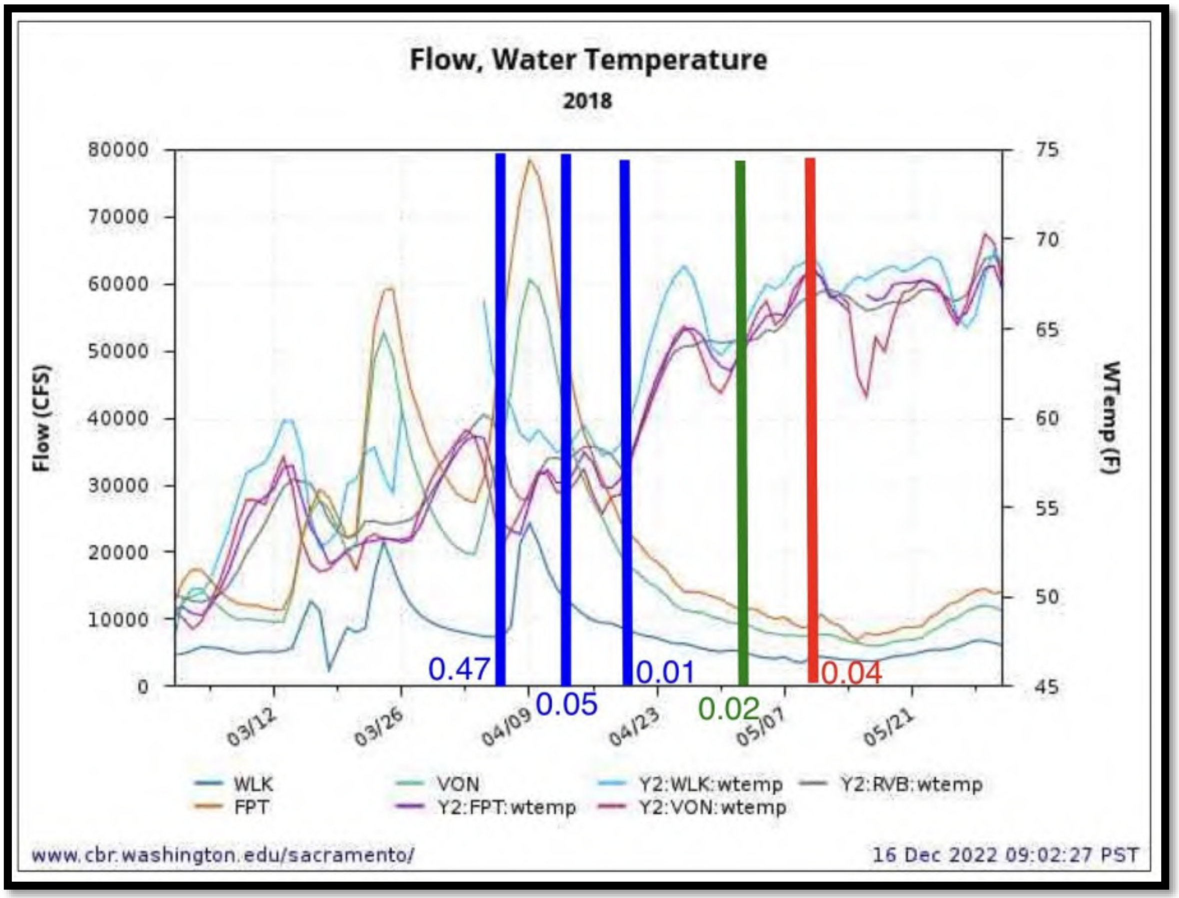


Figure D-7. Comparison of near-hatchery release survival of American (red), Feather (green), and Battle Creek (blue) for 2018 with lower Sacramento River flows and water temperatures. Lower Sacramento River at Wilkins Slough (WLK). Lower Sacramento River at mouth of the Feather River at Verona (VON). Lower Sacramento River below mouth of the American River at Freeport (FPT). Note Coleman release on 4/6 before the flow pulse had 10-50 times higher survival than releases from the three hatcheries after the flow pulse.

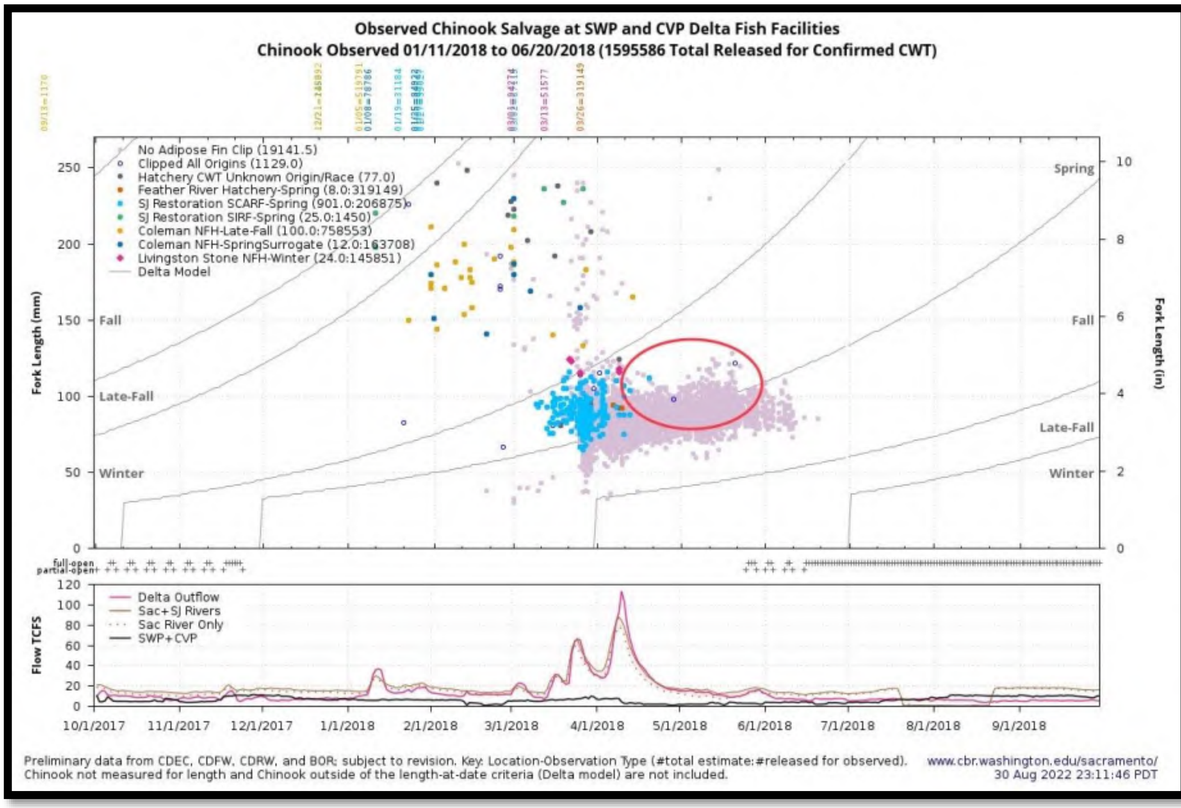


Figure D-8. Salmon salvage at south Delta pumping plants 1/1-6/20, 2018. Red circle shows period when some hatchery smolts were collected but most May-June salvaged salmon were un-clipped indicating a lack of hatchery released fish in the late spring time period.

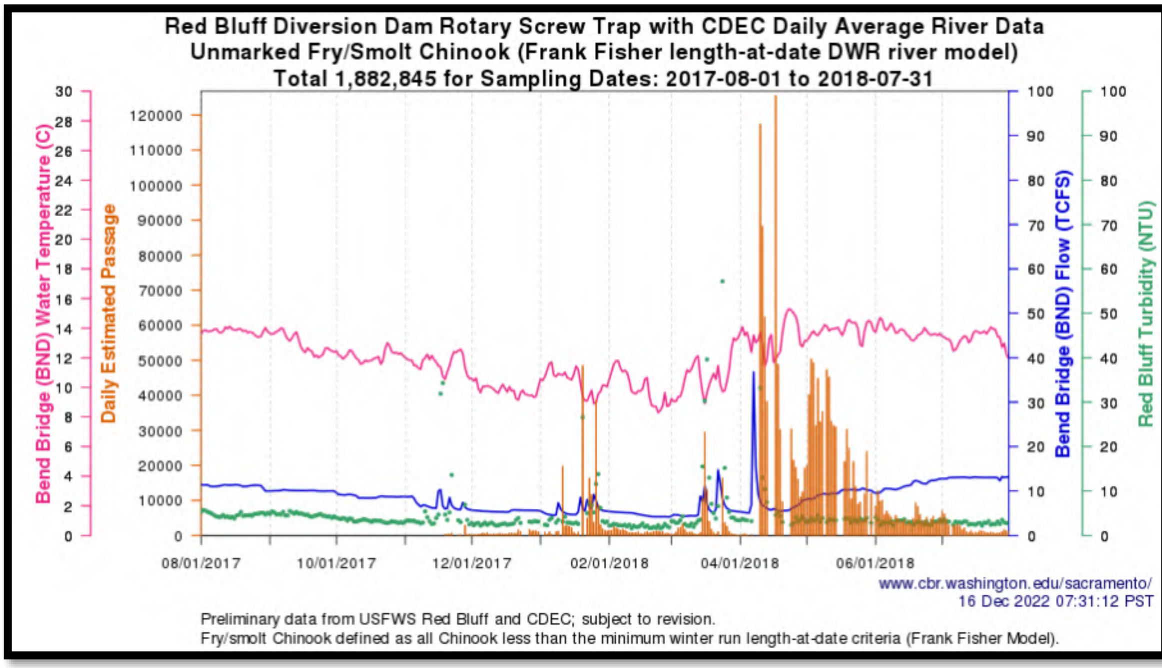


Figure D-9. Note the fry/smolt fall run are present in the upper river well into June.

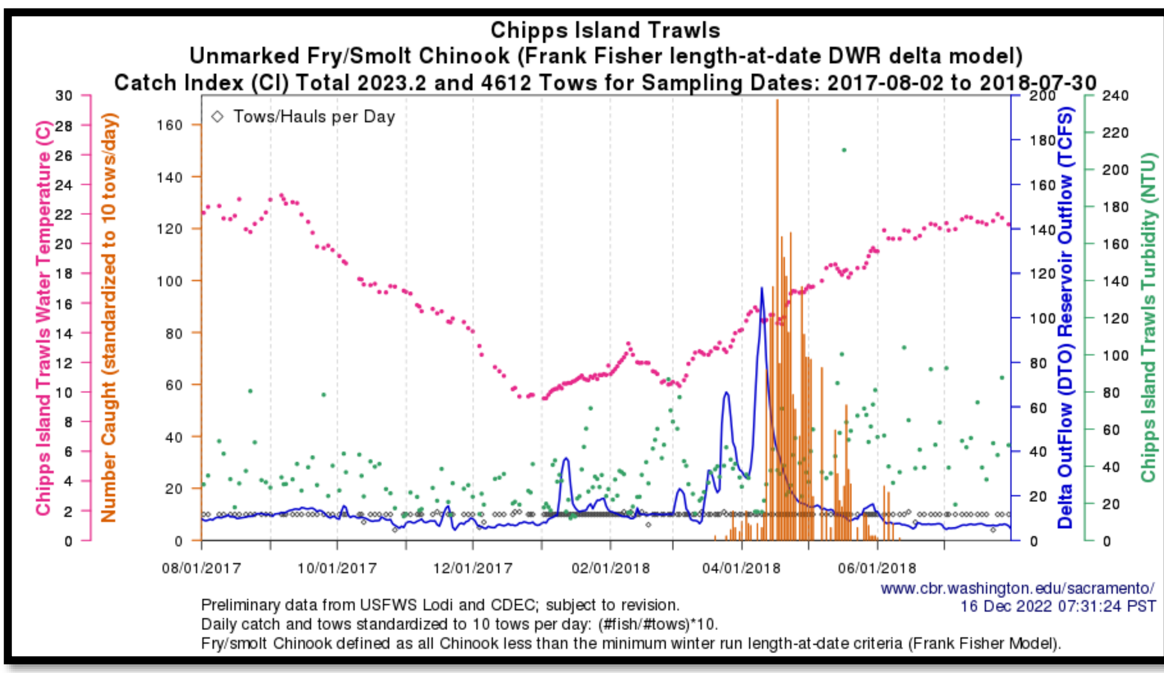


Figure D-10. Note the smolt fall run are fewer at Chipps Island at the entrance to the Bay after the end of May.

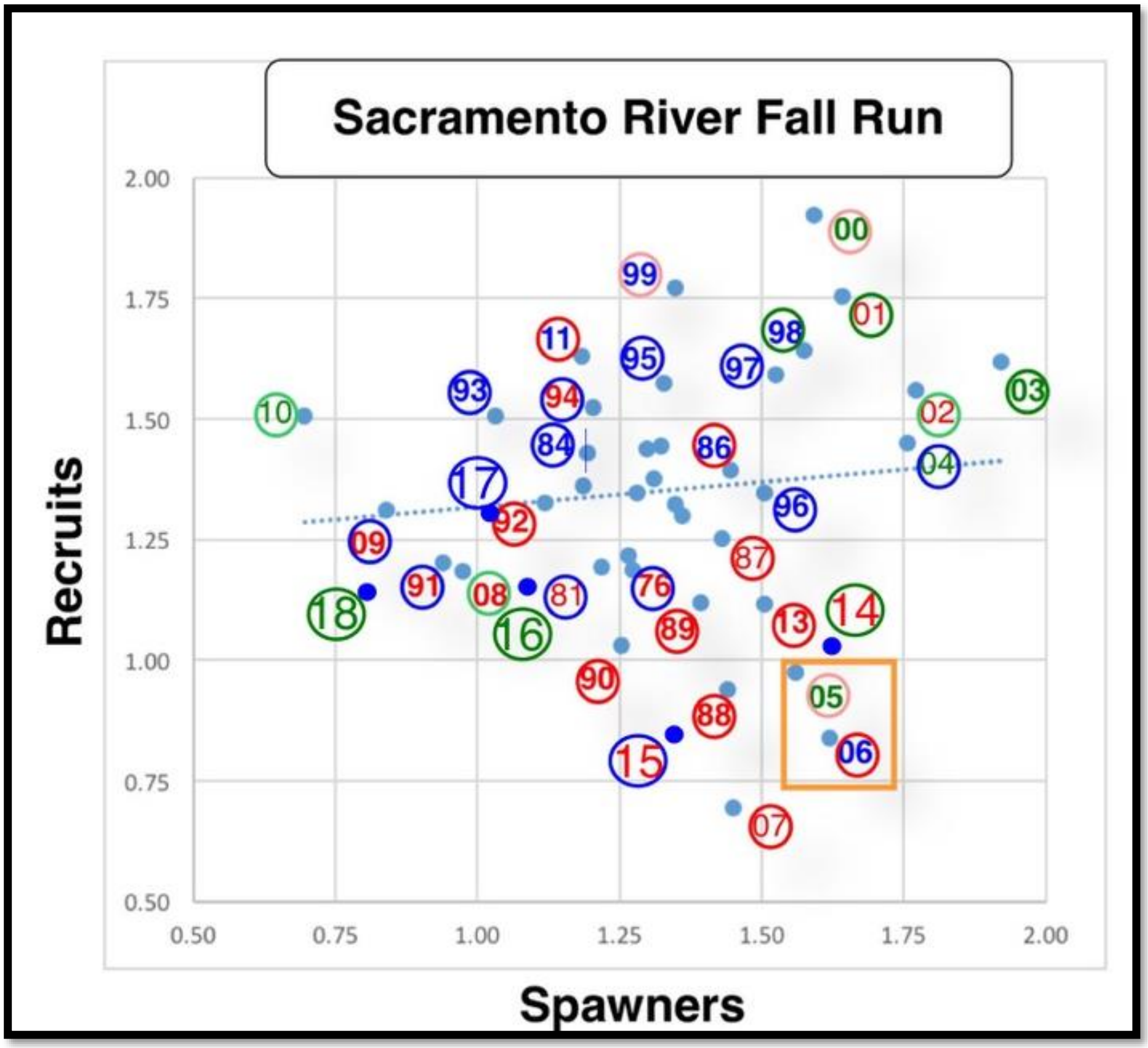


Figure D-11. Sacramento River spawners versus recruits three years later from escapement estimates (Log10X – 4 transformed). Note that some variability likely occurs from a low number of 2- and 4-year-old spawners in the escapement estimates. Numbers are sum of hatchery, mainstem, and tributary estimates from CDFW GrandTab database. Number shown is rearing year (winter-spring) following fall spawning year. For example: "88" represents rearing year for 1987 spawning or brood year. These fish returned to spawn (recruits) in 1990. The red "07" represents the record low run in fall 2009. Red years are critical or dry water years. Blue years are wet water years. Green years are normal water years. Red circles represent adult return years being drier water years. Blue circles represent return years being wet water years. Green circles represent return years being normal water years. Orange square denotes outlier years influenced by poor ocean conditions, floods, or hatchery management factors. Note that runs from wet years are up to ten times higher (1 log number) than the drought influenced years, particularly 87-90, 07-08, and 12-15.