NOAA Technical Memorandum NMFS

JUNE 2013

THE SACRAMENTO INDEX *(SI)*

Michael R. O'Farrell[1]
Michael S. Mohr[1]
Melodie L. Palmer-Zwahlen[2]
Allen M. Grover[3,1]

[1]National Marine Fisheries Service
Southwest Fisheries Science Center
Fishery Ecology Division
110 Shaffer Road
Santa Cruz, CA 95060

[2]California Departmentof Fish and Wildlife
Marine Region
Ocean Salmon Project
5355 Skylane Boulevard, Suite B
Santa Rosa, CA 95403

[3]Institute of Marine Sciences
University of California, Santa Cruz
1156 High Street
Santa Cruz, CA 95064

NOAA-TM-NMFS-SWFSC-512

U. S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

The National Oceanic and Atmospheric Administration (NOAA), organized in 1970, has evolved into an agency that establishes national policies and manages and conserves our oceanic, coastal, and atmospheric resources. An organizational element within NOAA, the Office of Fisheries, is responsible for fisheries policy and the direction of the National Marine Fisheries Service (NMFS).

In addition to its formal publications, the NMFS uses the NOAA Technical Memorandum series to issue informal scientific and technical publications when complete formal review and editorial processing are not appropriate or feasible. Documents within this series, however, reflect sound professional work and may be referenced in the formal scientific and technical literature.

NOAA Technical Memorandum NMFS
This TM series is used for documentation and timely communication of preliminary results, interim reports, or special purpose information. The TMs have not received complete formal review, editorial control, or detailed editing.

JUNE 2013

THE SACRAMENTO INDEX *(SI)*

Michael R. O'Farrell[1]
Michael S. Mohr[1]
Melodie L. Palmer-Zwahlen[2]
Allen M. Grover[3,1]

[1]National Marine Fisheries Service
Southwest Fisheries Science Center
Fishery Ecology Division
110 Shaffer Road
Santa Cruz, CA 95060

[2]California Departmentof Fish and Wildlife
Marine Region
Ocean Salmon Project
5355 Skylane Boulevard, Suite B
Santa Rosa, CA 95403

[3]Institute of Marine Sciences
University of California, Santa Cruz
1156 High Street
Santa Cruz, CA 95064

NOAA-TM-NMFS-SWFSC-512

U.S. DEPARTMENT OF COMMERCE
Cameron F. Kerry, Acting Secretary
National Oceanic and Atmospheric Administration
Dr. Kathryn D. Sullivan, Acting Administrator
National Marine Fisheries Service
Russell Smith, Acting Assistant Administrator for Fisheries

1 Abstract

In response to an abrupt decline in Sacramento River fall Chinook (SRFC) salmon abundance, and the need to provide improved scientific advice to fishery managers, the Sacramento Index (*SI*) was developed in 2008. The *SI* is a combined-age index of adult SRFC ocean abundance comprised of three components: ocean harvest, river harvest, and spawner escapement. This paper provides comprehensive documentation of the methods used to estimate the components of the *SI* and the method used to forecast the *SI* for fishery planning purposes. Properties of the time series of *SI* estimates are also discussed. The *SI* has been an integral part of PFMC ocean salmon fishery management since its development, and will likely be used as the basis for SRFC assessment into the foreseeable future.

2 Introduction

Sacramento River fall Chinook (SRFC) salmon (*Oncorhynchus tshawytscha*) have historically been the largest contributor to ocean salmon harvest off California and Oregon. However, the high abundances of SRFC that had for decades supported robust ocean and river fisheries experienced a recent, precipitous decline. In 2007 the escapement of natural and hatchery adults (estimated $\geq$ age-3) fell below the conservation objective goal range of 122,000–180,000 spawners. In addition, the 2007 jack (estimated age-2) escapement was the lowest on record by a wide margin, indicating a very weak year class expected to recruit to ocean fisheries in 2008. In response to these indicators of low SRFC abundance, the Sacramento Index (*SI*) and Sacramento Harvest Model (*SHM*; Mohr and O'Farrell In prep.) were developed to provide improved scientific advice to the Pacific Fishery Management Council (PFMC) during the annual salmon fishery planning process.

The *SI* is an age-aggregated index of adult SRFC abundance. An annual forecast of the *SI* is an input to the *SHM*, which is used to forecast harvest, exploitation rates, escapement and other quantities useful for managing the SRFC stock. The *SI* and *SHM* have been an integral part of the PFMC salmon fishery planning process since 2008, and will likely continue to be used in this capacity for the foreseeable future.

This paper (1) describes methods used prior to the *SI* for assessment of SRFC, (2) defines the *SI*, (3) describes the data and methods used to estimate the components of the *SI*, (4) examines the characteristics of the *SI* over time, and (5) describes the *SI* forecasting method. The estimates presented herein represent the best estimates of the *SI* and its components as of December 2012. However, estimated values, even for years in the past, are subject to change due to the addition of new data and/or re-evaluation of existing data. The definitive estimates of the *SI* and its constituent parts used for assessment and management of SRFC are published annually in Table II-1 of the PFMC Preseason I report (e.g., PFMC 2012a). All notation used in this paper is described in Table 1. Table 2 defines pertinent ocean fishery management areas.

Table 1. Notation used in this paper.

Symbol	*Description*
	Acronyms
CWT	Coded-wire tag
CVI	Central Valley Index
GSI	Genetic Stock Identification
KRFC	Klamath River fall Chinook
SHM	Sacramento Harvest Model
SI	Sacramento Index
SRFC	Sacramento River fall Chinook
	Variables and Parameters
β_{SI}	Slope parameter for the Sacramento Index forecast model
C	Contacts
E	Spawner escapement
h	Harvest rate
h_{CVI}	CVI ocean harvest rate index
H	Harvest
J	Jacks
j	Proportion of jacks
I	Impacts
l	Total length
l^*	Minimum size limit in total length
λ	Ratio of adult SRFC harvest per sample expanded SRFC CWT recovery
π	Proportion of Central Valley Chinook escapement expected to be SRFC
ϕ	Proportion of Central Valley Chinook ocean harvest or contacts expected to be SRFC
p	Stock proportion
R	River return
s	Release mortality rate
Z	Sample expanded coded-wire tag recoveries
	Subscripts
a	Management area
k	Stream section
m	Month
o	Ocean
r	River
t	Biological year
x	Fishery
y	Calendar year
	Stock Components
K	Hatchery- and natural-origin KRFC
N	All hatchery-origin Chinook except Central Valley hatchery-origin Chinook and K
S	Sacramento River fall Chinook
T	Total Chinook
V	Central Valley hatchery-origin Chinook other than adult SRFC

3 Pre-*SI* Assessment Methods

Prior to 2008 SRFC escapement projections were derived from forecasts of the Central Valley Index (*CVI*), which served as an index of abundance for the combined stocks of Central Valley Chinook, including SRFC, Sacramento River winter Chinook, Sacramento River late-fall Chinook, Central Valley spring Chinook, and San Joaquin River fall Chinook. The *CVI* was an annual index defined as the calendar year sum of Central Valley Chinook adult escapement (E_{CV}) and the ocean harvest of Chinook (all stocks, including non-Central Valley) between Point Arena, California, and the U.S./Mexico border ($H_{o,T,\mathsf{AM}}$)

$$CVI = E_{CV} + H_{o,T,\mathsf{AM}}. \tag{1}$$

Linear regression of the *CVI* in year *y* against Central Valley Chinook jack spawning escapement in year *y-1*, with *y* = 1990–forward, was used to forecast the current year *CVI* based on the previous year's jack escapement (e.g., see PFMC 2007, Figure II-1). SRFC adult escapement (E) was then forecast using the projected *CVI*, the anticipated *CVI* ocean harvest rate index ($h_{CVI} = H_{o,T,\mathsf{AM}}/CVI$), and the anticipated proportion (π) of E_{CV} that would be SRFC as

$$E = CVI \times (1 - h_{CVI}) \times \pi, \tag{2}$$

allowing for a pre-season evaluation of E relative to the SRFC escapement goal. In the last use of this model for forecasting purposes (year 2007), the previous year's h_{CVI} estimate, and the mean of the previous five years of π estimates, were used for these quantities in Equation (2). Prior to 2008, stocks other than SRFC constrained ocean fisheries and a model more sophisticated than Equation (2) was unnecessary for annual salmon fishery planning. However, there were several shortcomings to using the *CVI* for fishery assessment, including (1) the *CVI* was not SRFC-specific, (2) the *CVI* was calculated on a calendar year basis rather than on a biological year (between annual spawning events) basis, (3) ocean harvest north of Point Arena was not accounted for, and (4) river harvest was not accounted for.

4 *SI* Specification

The shortcomings of the *CVI* coupled with the critical status of SRFC in 2008 hastened the development of the *SI*. The *SI* is defined as

$$SI = H_{o,S} + H_r + E, \quad (3)$$

where $H_{o,S}$ is the Sept. 1 through Aug. 31 (biological year) ocean harvest of SRFC south of Cape Falcon, H_r is river harvest of adult SRFC, and E is SRFC adult escapement to both natural areas and hatcheries. Methods developed in 2008 enabled estimation of SRFC ocean harvest for all months, areas, and fisheries south of Cape Falcon which represented a significant improvement in the extent, resolution, and specificity of SRFC ocean harvest information compared to that previously available. Analysis of the existing SRFC river harvest estimates derived from California Department of Fish and Wildlife (CDFW) angler surveys, coupled with the methods described in this paper, enabled the development of an uninterrupted river harvest time series. Estimates of adult SRFC escapement to natural areas and hatcheries are made annually and published in the PFMC Review of Ocean Salmon Fisheries report (e.g., PFMC 2012c). The advances made in the estimation of ocean and river harvest, in addition to the availability of a time series of annual escapement, allowed for the development of the *SI* as specified by Equation 3.

5 *SI* Components

5.1 Ocean Harvest

The ocean harvest of SRFC is a major component of the *SI*, and for the purposes of the *SI*, is defined as the Sept. 1 through Aug. 31 SRFC ocean harvest south of Cape Falcon, OR. SRFC are harvested north of Cape Falcon, but this harvest was determined to be a small proportion of the overall SRFC ocean harvest (Appendix A). As a result, SRFC harvest north of Cape Falcon is not included in the estimation of $H_{o,S}$.

The *SI* is intended to be an index of SRFC *adult* ocean abundance. While measures are taken to ensure that only adults are included in the H_r and E estimates, directly restricting $H_{o,S}$ to include only age 3–5 SRFC is not possible given the limitations of available ocean harvest age composition data. In general, age-2 Chinook are smaller than commercial fishery minimum size limits, and smaller than recreational fishery minimum size limits for much of the fishing season. For these reasons, the contribution of age-2 fish to the ocean harvest is small. We thus consider the *SI* to be an index of SRFC adult ocean abundance, yet acknowledge that a relatively small number of age-2 fish may be harvested in ocean fisheries and therefore contribute to the *SI*.

Estimation of $H_{o,S}$ from the mixed-stock ocean harvest presents challenges due to data limitations. In particular, the current lack of a time series of age-specific escapement data and consistent marking and tagging of SRFC at Central Valley hatcheries has precluded using cohort reconstruction methods to estimate SRFC ocean harvest (as is done, for example, with Klamath River fall Chinook, KRFC). The data currently available for estimation of $H_{o,S}$ are coded-wire tags (CWTs) recovered in ocean fisheries. We used these CWT recoveries from ocean fisheries south of Cape Falcon, and the historical dominance of SRFC in the ocean harvest south of Point Arena, to estimate $H_{o,S}$ for all time-area-fisheries south of Cape Falcon. The remainder of Section 5.1 describes the details of this estimation methodology.

5.1.1 Data

Total Chinook (mixed-stock) harvest is estimated annually by management area $a \in \{\mathsf{NO, CO, KO, KC, FB, SF, MO}\}$ (Table 2), month m, and fishery $x \in \{\mathsf{Commercial, Recreational}\}$ from well-developed sampling programs conducted by CDFW and the Oregon Department of Fish and Wildlife. Summaries of this harvest can be found in PFMC (2012c, Appendix A). To obtain an estimate of $H_{o,S}$ from this mixed-stock harvest, two additional sources of information were required.

The first additional source of information required to derive $H_{o,S}$ was the estimated ocean harvest of KRFC in all months, areas, and fisheries south of Cape Falcon. These estimates are sourced from KRFC cohort reconstruction results available for brood years 1979–forward. The databases and methods used for KRFC cohort reconstructions are described in detail by Goldwasser et al. (2001) and Mohr (2006).

The second additional source of information required to derive $H_{o,S}$ was the CWT recovery

Table 2. Description of management areas south of Cape Falcon, Oregon. KMZ denotes the Klamath Management Zone which extends from Humbug Mountain, Oregon to Horse Mountain, California. "Falcon-to-Arena" is the region extending from Cape Falcon, Oregon to Point Arena, California, consisting of the {NO, CO, KO, KC, FB} areas. "Arena-to-Mexico" is the region extending from Point Arena, California, to the U.S./Mexico border, consisting of the {SF, MO} areas.

Area	*Abbreviation*	*Northern border*	*Major ports*
Northern Oregon	NO	Cape Falcon, OR	Newport, Tillamook
Central Oregon	CO	Florence South Jetty, OR	Coos Bay
Oregon KMZ	KO	Humbug Mountain, OR	Brookings
California KMZ	KC	OR/CA border	Eureka, Crescent City
Fort Bragg	FB	Horse Mountain, CA	Fort Bragg
Falcon-to-Arena	FA		
San Francisco	SF	Point Arena, CA	San Francisco
Monterey	MO	Pigeon Point, CA	Monterey
Arena-to-Mexico	AM		

data from all Chinook stocks other than KRFC in all time-area-fisheries south of Cape Falcon (obtained from the Regional Mark Processing Center, http://www.rmpc.org). CWTs recovered in both commercial and recreational fisheries were expanded for the non-exhaustive sampling of ocean harvest to produce stock-specific estimates of the total number of CWT fish harvested in all time-area-fisheries. These sample-expanded estimates were then further expanded to account for the hatchery mark-rate (tagged versus untagged) in order to estimate hatchery-specific ocean harvest by time-area-fishery. An exception to this procedure was used in the case of age 3–5 SRFC, where it was not feasible to expand for the hatchery mark-rate because of the low and variable tagging rates historically employed at SRFC-producing hatcheries. Age 3–5 SRFC CWTs[1] were therefore only expanded for sampling.

5.1.2 Methods

Estimation of $H_{o,S}$ is performed by means of a two-part process that exploits the fact that SRFC dominate ocean Chinook harvest in the AM region. For each biological year t (m = Sept. 1, *t-1*

[1]In an attempt to constrain the estimate of SRFC ocean harvest to age 3–5 fish, we limited the CWT recoveries used for estimation to age 3–5 fish. Hereafter, reference to "SRFC CWT" implies SRFC CWTs from age 3–5 fish.

through Aug. 31, t), for the areas south of Point Arena, $a \in \{\mathsf{SF}, \mathsf{MO}\}$, and in both the commercial and recreational fisheries, the month, area, and fishery-specific ocean harvest of SRFC ($H_{o,S,a,m,x}$) was estimated by subtracting the estimated harvest of all other stock groups that could be accounted for from the total Chinook harvest ($H_{o,T,a,m,x}$) :

$$H_{o,S,a,m,x} = H_{o,T,a,m,x} - \sum_{g=K,V,N} H_{o,g,a,m,x} , \qquad \text{for} \quad a \in \{\mathsf{SF}, \mathsf{MO}\}. \tag{4}$$

$H_{o,K,a,m,x}$ is the estimated harvest of KRFC, hatchery- and natural-origin, derived from the KRFC cohort reconstruction. $H_{o,V,a,m,x}$ is the estimated harvest of all Central Valley hatchery-origin Chinook other than SRFC (including Sacramento River late-fall Chinook, Sacramento River winter Chinook, Central Valley spring Chinook, and San Joaquin River fall Chinook), as well as hatchery-origin age-2 SRFC CWT (expanded for both sampling and the hatchery mark rate, when possible). $H_{o,N,a,m,x}$ is the estimated harvest of all non-Central Valley hatchery-origin Chinook stocks (excluding KRFC).

The summation term in Equation (4) represents the best estimate of all known Chinook harvest in the SF and MO areas, other than age 3–5 SRFC. This term omits the harvest of stocks without a CWT hatchery component (e.g., California coastal Chinook), natural-origin fish from stocks with hatchery components (except for KRFC), and age-2 SRFC natural-origin fish. These omissions likely constitute a small proportion of the total harvest in these southern areas (Winans et al. 2001).

To derive estimates of $H_{o,S,a,m,x}$ for the time-area-fisheries between Cape Falcon and Point Arena (FA), we applied the ratio of SRFC harvest per SRFC CWT observed south of Point Arena (AM) to the number of SRFC CWTs recovered in the areas between Cape Falcon and Point Arena on a biological year basis as follows. Yearly SRFC ocean harvest in the AM region was determined by summing $H_{o,S,a,m,x}$ over the SF and MO areas, over all months (Sept. 1 through Aug. 31), and over both fisheries:

$$H_{o,S,\mathsf{AM}} = \sum_{a=\mathsf{SF},\mathsf{MO}} \sum_{m,x} H_{o,S,a,m,x} . \tag{5}$$

The number of SRFC sample-expanded CWTs recovered over this same subset of the harvest, $Z_{o,S,\mathsf{AM}}$, led to the ratio

$$\lambda = \frac{H_{o,S,\mathsf{AM}}}{Z_{o,S,\mathsf{AM}}}, \tag{6}$$

which represents the expected number of SRFC (hatchery- and natural-origin) harvested per SRFC CWT in the harvest, independent of month and fishery. For months, areas, and fisheries between Cape Falcon and Point Arena, λ was then multiplied by the number of SRFC sample-expanded CWT recoveries, $Z_{o,S,a,m,x}$, to estimate the respective SRFC ocean harvest:

$$H_{o,S,a,m,x} = Z_{o,S,a,m,x} \times \lambda, \qquad \text{for} \quad a \in \{\mathsf{NO}, \mathsf{CO}, \mathsf{KO}, \mathsf{KC}, \mathsf{FB}\}. \tag{7}$$

With this two-part (north and south of Point Arena) method, the SRFC ocean harvest for each month, area, and fishery south of Cape Falcon was estimated, which allowed for estimation of the overall SRFC ocean harvest south of Cape Falcon,

$$H_{o,S} = \sum_{a,m,x} H_{o,S,a,m,x} \;. \tag{8}$$

The procedures described above parse each time-area-fishery Chinook total (T) harvest into four components: S, K, V, and N. For the areas south of Point Arena, the sum of these four components, by construction, equaled the total harvest. However, for the areas north of Point Arena, the estimated harvest of S, K, V, and N would be unlikely to sum exactly to the total harvest owing to unaccounted for natural production of the V and N components, unreported hatchery releases, and potential reporting errors. As a result, the estimated component harvests were adjusted so that they did sum to the total harvest, using the methods described in Appendix B.

Estimates of $H_{o,S}$ do not account for mortality resulting from the release of sublegal size fish or dropoffs (fish that die due to contact with fishing gear, but are not brought to the boat). However, mortality associated with non-retention fishing activities such as genetic stock identification (GSI) sampling programs and coho-only fisheries are included in the SI when they occur. Because these fisheries or sampling programs are non-retention for Chinook salmon, no CWTs are available for the estimation of SRFC impacts.

For a GSI non-retention sampling program, the number of SRFC contacted by month, area, and mode of sampling (e.g., commercial or recreational) is estimated from the number of Chinook contacted and the results of the genetic analysis. Assuming that the stock proportions determined from the genetic analysis are representative of the stock composition of the total number of Chinook contacted, non-retention GSI impacts are computed as

$$I^{GSI}_{o,S,a,m,x} \; = \; C_{o,T,a,m,x}[l \geq l^*] \times p_{o,CV,a,m,x} \times \phi_{o,a,m,x} \times s_{o,a,m,x} \; , \tag{9}$$

where $C_{o,T,a,m,x}[l \geq l^*]$ is the number of total Chinook sampled in the GSI study, with length (l) greater than or equal to the customary minimum size limit (l^*) for that month, area, and fishery stratum. Estimates of stock proportions p are derived from the genetic analysis. GSI methods are not able to distinguish SRFC from Sacramento River late fall Chinook, Feather River Hatchery spring Chinook, and San Joaquin River fall Chinook; each of these stocks are included in a Central Valley fall reporting group. Sacramento River winter Chinook and natural populations of Central Valley spring Chinook are identifiable by GSI and thus separate into their own reporting groups. The stock proportion $p_{o,CV,a,m,x}$ is the sum of all Central Valley GSI reporting groups, and is an estimate of the proportion of all Central Valley-origin Chinook sampled in the stratum. $\phi_{o,a,m,x}$ is the proportion of adult SRFC expected from a sample of Central Valley Chinook contacted in an ocean fishery stratum, estimated using historical ratios of S to $S+V$. Finally, $s_{o,a,m,x}$ is the release mortality rate (Mohr and O'Farrell In prep.). Total non-retention GSI sampling impacts of SRFC,

$$I^{GSI}_{o,S} \; = \; \sum_{a,m,x} I^{GSI}_{o,S,a,m,x}, \tag{10}$$

are included into the ocean harvest component of the *SI* when such programs occur.

For coho-only fisheries, where data exist for the number of Chinook contacted $C_{o,T,a,m,x}$ and released, SRFC impacts are computed as

$$I^{coho}_{o,S,a,m,x} = C_{o,T,a,m,x} \times p_{o,S,a,m,x} \times s_{o,a,m,x}. \tag{11}$$

Here, $p_{o,S,a,m,x}$ is the proportion of the total Chinook contacts expected to be SRFC, estimated from historical CWT data. Because length data for released Chinook are not available from coho-only fisheries, no attempt is made to adjust the estimated contacts on the basis of typical minimum size limits, as is done for GSI non-retention studies (Equation 10). Total coho-only fishery SRFC impacts,

$$I^{coho}_{o,S} \; = \; \sum_{a,m,x} I^{coho}_{o,S,a,m,x}, \tag{12}$$

are included in the ocean harvest component of the *SI* when such fisheries occur.

Table 3. For the area south of Point Arena, estimated SRFC ocean harvest ($H_{o,S,\text{AM}}$), number of SRFC age 3–5 sample-expanded coded-wire tags recovered ($Z_{o,S,\text{AM}}$), and their ratio (λ, equation (6)), for the Sept. 1, *t-1* through Aug. 31, *t* period.

Year (t)	$H_{o,S,\text{AM}}$	$Z_{o,S,\text{AM}}$	λ
1983	260623	7937	32.84
1984	274228	5318	51.57
1985	311042	3314	93.87
1986	539967	8363	64.56
1987	530784	7192	73.80
1988	868328	15752	55.12
1989	480444	8181	58.72
1990	454661	8742	52.01
1991	314016	4771	65.82
1992	195550	1156	169.18
1993	376379	2907	129.46
1994	416463	2913	142.96
1995	999702	10256	97.48
1996	460301	13090	35.16
1997	652585	19007	34.33
1998	331318	17060	19.42
1999	342172	13259	25.81
2000	512085	4896	104.59
2001	223497	7565	29.54
2002	414657	10506	39.47
2003	261362	13156	19.87
2004	485351	16271	29.83
2005	344519	4212	81.80
2006	151129	1508	100.24
2007	109800	528	207.92
2008	3384	13	252.54
2009	0	0	NA
2010	12232	1949	6.28
2011	36107	5081	7.11

5.1.3 Results

For the region south of Point Arena, Table 3 displays the estimated SRFC ocean harvest, the number of age 3–5 SRFC sample-expanded CWTs recovered, and their ratio for each biological year. Salmon fisheries were largely closed in 2008 and 2009 for the region south of Point Arena. Harvest and λ estimates in Table 3 for 2008 were entirely the result of fall 2007 salmon fisheries.

No salmon fisheries were conducted south of Point Arena from December 2007 through August 2009.

Factors likely contributing to the observed annual variation in λ include variable SRFC natural-origin production, and variable tagging rates at SRFC-producing hatcheries. For example, while production levels at Coleman National Fish Hatchery have remained steady, the number of fish coded-wire tagged decreased sharply beginning with brood year 2002. It is likely that this reduction in tagging rate beginning with the 2002 brood year at least partially accounts for the high λ values observed in 2005–2008. However, since the 2006 brood year, SRFC produced in Sacramento Basin hatcheries have been marked and tagged at a target rate of 25 percent (Buttars 2012), which represents a substantial increase in the marking and tagging rate relative to prior years.

Figure 1 displays total Chinook and SRFC ocean harvest estimates for the seven management areas south of Cape Falcon, 1983–2011. The proportion of total Chinook harvest attributed to SRFC is substantial for all areas, and exceedingly high in southern areas.

Non-retention GSI sampling or coho-only fisheries have been rare occurrences and when they do occur, the estimates of SRFC impacts have been very low. Non-retention fishing activities occurred in years 2008–2010 and fewer than 400 SRFC impacts were estimated over that three-year period.

5.2 River Harvest

Estimates of adult SRFC river harvest are derived from angler surveys and hindcasted values for years when angler surveys were not completed. The hindcasted river harvest estimates for the survey “gap” years together with the harvest estimates for the survey years, provide a complete time series of H_r from 1970 forward.

5.2.1 Data

Summary estimates of harvest and fishing effort, derived from the Sacramento River Basin angler surveys conducted by the CDFW, were obtained from Dr. Robert G. Titus (CDFW, personal communication). SRFC river harvest and angler effort estimates exist for 1991–1994, 1998–2000,

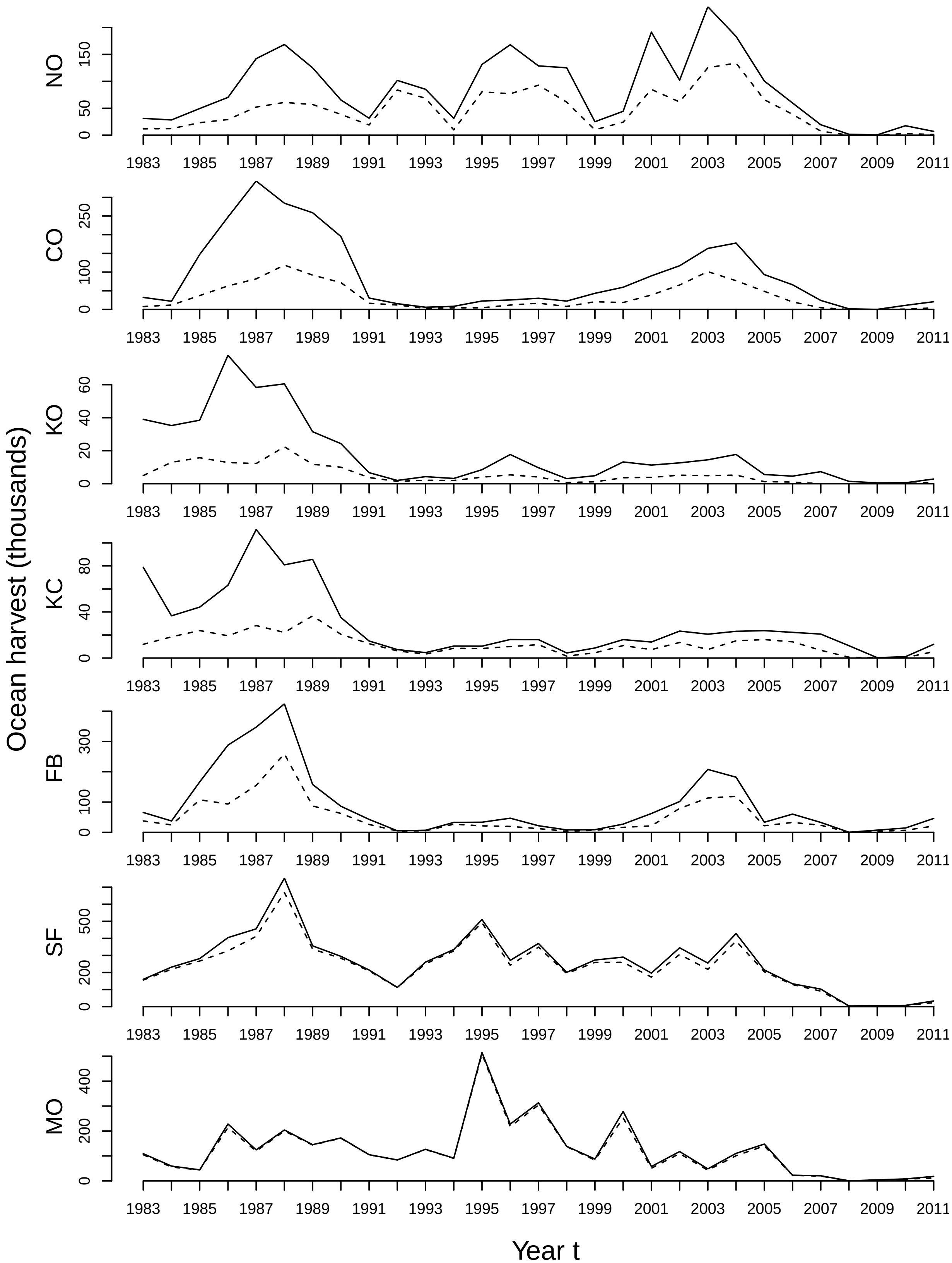

Figure 1. Estimated total Chinook (solid lines) and Sacramento River fall Chinook (dashed lines) ocean harvest south of Cape Falcon, Oregon, for the Sept. 1, *t-1* through Aug. 31, *t* period. Note that the y-axis scale differs for each management area.

2002, and 2007–2011[2]. The proportion of jacks in samples of creel-surveyed fish in conjunction with the river harvest estimates allowed for estimation of adult river harvest. Creel surveys were performed on eight sections of the Sacramento River, three sections of the American River, and three sections of the Feather River (Titus et al. 2010). Some additional surveys were conducted on the Yuba River, but survey effort there was much lower and estimated harvest (when surveys were conducted) was very low relative to the other surveyed rivers. For this reason, harvest and effort estimates from the Yuba River surveys were not included in the assessment. The estimated number of caught-and-released Chinook are available for the survey years, but were not used in the assessment.

In some angler survey years data were lacking for a particular month-stream-section, hence no estimates of harvest or effort were available. The methods employed to interpolate for these missing estimates are described in Appendix C. The effect of this interpolation was minor; the percent difference in the resulting river harvest estimate using the interpolated and non-interpolated datasets was less than four percent for all years.

5.2.2 Methods

For the surveyed years, Sacramento River Basin total annual harvest of SRFC adults, H_r, was estimated by first summing the estimated overall Chinook harvest (including jacks) over the constituent months m, streams s, and within-stream sections k, then multiplying this sum by the complement of the jack proportion (j):

$$H_r = (1 - j) \sum_{m,s,k} H_{r,m,s,k}. \tag{13}$$

All Chinook caught between the months of June and December were assumed to be SRFC, with an exception for a portion of the Sacramento River. For sections 4–8 of the Sacramento River (all sections upstream from Knights Landing; Titus et al. 2010), December SRFC harvest was assumed to be zero, and November SRFC harvest was assumed to be one-half of the estimated

[2]Limited survey data exist for 2001 but these data were not used in the assessment since survey coverage in time and space was greatly reduced relative to the other years.

November Chinook harvest from the angler survey. This modification for the upper sections of the Sacramento River were made to account for the presence of Sacramento River late-fall Chinook in the river harvest (Killam and Kreb 2008).

To hindcast river harvest for years where no angler survey estimates were available, and river fisheries were relatively unconstrained[3], a method was developed based on the estimated average river harvest rate. A description of this method follows.

Adding H_r to the SRFC adult escapement estimate E yields the estimated SRFC adult river run abundance

$$R = H_r + E, \tag{14}$$

and the estimated SRFC adult river harvest rate

$$h_r = H_r / R. \tag{15}$$

Harvest in the largely unconstrained river fisheries was modeled as being proportional to the river run abundance with an additive error term. The proportionality constant in this model is the mean harvest rate, h_r:

$$H_r = h_r R + \varepsilon. \tag{16}$$

The mean harvest rate was then estimated from the survey data using the ratio estimator

$$\hat{h}_r = \overline{H}_r / \overline{R}, \tag{17}$$

where $\overline{H}_r$ and $\overline{R}$ denote the arithmetic mean of H_r and R over the survey years with unconstrained river fisheries, respectively. The ratio estimator is the optimal estimator of the mean harvest rate under model (16) assuming the variance of ε increases in proportion to R (Thompson 2002).

The fitted river harvest rate model was used to hindcast the SRFC adult river harvest for years in which angler surveys were not conducted, based on the relationship

$$\widehat{H}_r = \widehat{R} \times \hat{h}_r = (\widehat{H}_r + E) \times \hat{h}_r, \tag{18}$$

[3] River harvest was highly constrained from 2008 to 2010; estimates from these years were not used for the hindcasting procedure.

noting that E is available for years 1970–forward. Solving (18) for $\widehat{H}_r$ results in

$$\widehat{H}_r = \frac{E \times \hat{h}_r}{1 - \hat{h}_r}. \tag{19}$$

During the early development of the *SI* river harvest component, other harvest rate models were considered, including those that specified the river harvest rate as a nonlinear function of the river run abundance. However, the differences between the more complex model formulations and the mean harvest rate model presented here were negligible. In particular, the hindcasted river harvest values derived using alternative methods were similar to those values estimated using the mean harvest rate model for years 1990-forward when angler surveys were not conducted (the ”gap” years). For this reason, and the simplicity of assuming a one-parameter harvest rate model, alternative models were not considered further.

Finally, in an attempt to reasonably bracket the river harvest hindcast estimates described above, the minimum and maximum annual harvest rates estimated over the survey years with unrestricted river fisheries were substituted in place of $\hat{h}_r$ in Equation (19) to compute a minimum and maximum hindcast river harvest, respectively.

5.2.3 Results

Figure 2 demonstrates the model fitted to the harvest rate estimates derived from the angler survey for years with unconstrained river fisheries. The line in Figure 2 represents the fitted mean harvest rate model, Equation 17, with $\hat{h}_r = 0.140$.

Survey-derived H_r, R, and h_r, as well as model-derived harvest hindcasts, $\hat{H}_r$, are presented in Table 4. Hindcasted harvest estimates prior to 1991 assume that pre-1991 fisheries resembled post-1991 fisheries in terms of effort capacity, effort response to abundance, etc. Mean hindcasted harvests, as well as minimum and maximum hindcast harvest brackets are plotted in Figure 3. Comparison of the model-derived harvest hindcasts to the survey-derived harvest estimates provides some indication of the adequacy of the river harvest hindcast method for representing the non-survey years.

Table 4. Sacramento River fall Chinook adult river return summary statistics and estimates, 1970–2011: escapement (E), river run abundance (R), fishery harvest ($H_r, \hat{H}_{r,*}$), and harvest rate (h_r). Escapement estimates are sourced from PFMC (2012b, Tables B-1 and B-2) and PFMC (2012a, Table II-1), river harvest estimates were developed as described in this report, with $\hat{H}_{r,min}$, $\hat{H}_{r,max}$, and $\hat{H}_{r,mean}$ derived from equation (19) and sourced from PFMC (2012a, Table II-1). River fisheries were heavily restricted in 2008–2010, therefore $\hat{H}_{r,*}$ was not hindcasted for those years.

		Angler survey			*Model-estimated harvest*		
Year	E	H_r	R	h_r	$\hat{H}_{r,min}$	$\hat{H}_{r,mean}$	$\hat{H}_{r,max}$
1970	156665	—	—	—	18159	25566	44474
1971	154882	—	—	—	17952	25275	43968
1972	92157	—	—	—	10682	15039	26162
1973	220060	—	—	—	25507	35912	62471
1974	202017	—	—	—	23416	32967	57349
1975	155621	—	—	—	18038	25396	44178
1976	167866	—	—	—	19457	27394	47654
1977	164010	—	—	—	19011	26765	46560
1978	126949	—	—	—	14715	20717	36039
1979	172398	—	—	—	19983	28134	48941
1980	142109	—	—	—	16472	23191	40342
1981	174958	—	—	—	20280	28552	49668
1982	164640	—	—	—	19084	26868	46738
1983	110248	—	—	—	12779	17991	31297
1984	158972	—	—	—	18427	25943	45129
1985	239306	—	—	—	27738	39053	67935
1986	240103	—	—	—	27831	39183	68161
1987	195064	—	—	—	22610	31833	55375
1988	227468	—	—	—	26366	37121	64574
1989	152563	—	—	—	17684	24897	43310
1990	105090	—	—	—	12181	17150	29833
1991	118869	26009	144878	0.180	13778	19398	33745
1992	81545	13324	94869	0.140	9452	13307	23149
1993	137390	27701	165091	0.168	15925	22421	39003
1994	165586	28855	194441	0.148	19193	27022	47007
1995	295314	—	—	—	34230	48193	83835
1996	301632	—	—	—	34962	49224	85628
1997	344840	—	—	—	39971	56275	97894
1998	245907	69809	315717	0.221	28503	40130	69809
1999	399830	68854	468684	0.147	46345	65249	113505
2000	417537	59471	477008	0.125	48397	68138	118531
2001	596775	—	—	—	69173	97388	169414
2002	769868	89236	859104	0.104	89236	125635	218552
2003	523016	—	—	—	60623	85351	148475
2004	286885	—	—	—	33253	46817	81442
2005	396005	—	—	—	45901	64624	112419
2006	275030	—	—	—	31879	44882	78076
2007	91374	14316	105690	0.135	10591	14911	25939
2008	65364	137	65501	0.002	NA	NA	NA
2009	40873	0	40873	0.000	NA	NA	NA
2010	124270	2469	126739	0.019	NA	NA	NA
2011	114741	17362	132103	0.131	13300	18725	32573

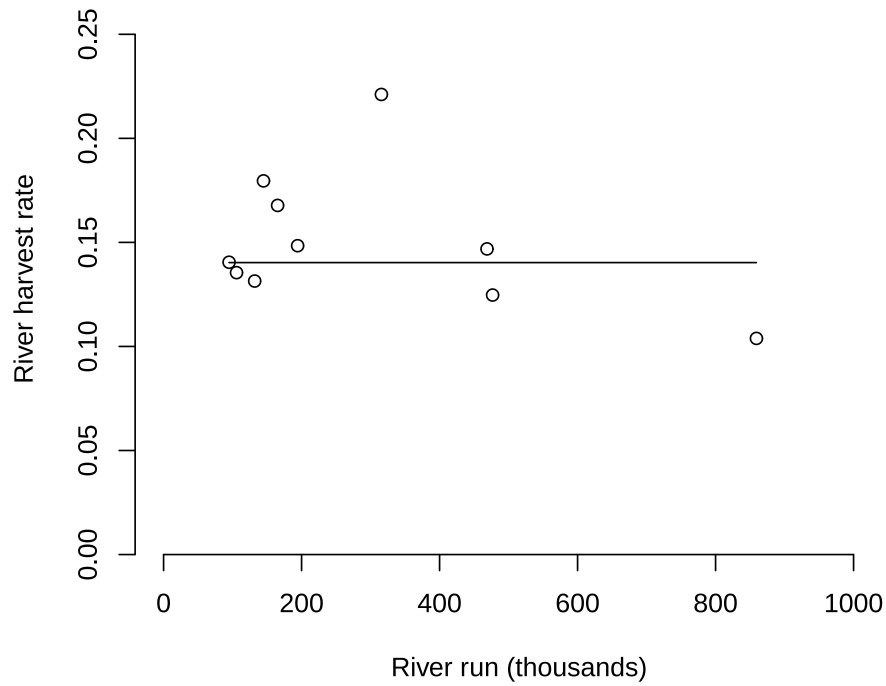

Figure 2. Sacramento River fall Chinook adult river harvest rate estimated for years with unconstrained river fisheries plotted as a function of the adult river run abundance. The line represents the fitted mean harvest rate model, equation (17).

5.3 Escapement

SRFC escapement estimates are compiled annually from hatcheries and natural-area spawning surveys in the Sacramento River Basin. Tables B-1 and B-2 in PFMC (2012c) report natural-area and hatchery escapement, respectively, for Central Valley fall Chinook. The combined natural-area and hatchery escapement, both jacks and adults, for SRFC can be computed from these tables by summing the Sacramento River total adult (or jack) escapement (located in Table B-1) and the total adult (or jack) escapement from Sacramento hatcheries (located in Table B-2). In this paper, Table 4 displays the combined natural-area and hatchery adult escapement of SRFC used for the construction of the *SI*.

Sacramento River Basin hatcheries producing fall Chinook, which include Coleman National Fish Hatchery (Battle Creek), Feather River Hatchery (Feather River) and Nimbus Hatchery (American River), enumerate jacks and adults separately as they enter the hatchery based on a fork length (FL) "cut-off" value (jack: FL $<$ cut-off; adult: FL $\geq$ cut-off). For most years since 1990, Coleman National Fish Hatchery has used a jack cut-off length of 65 cm while Feather River and Nimbus

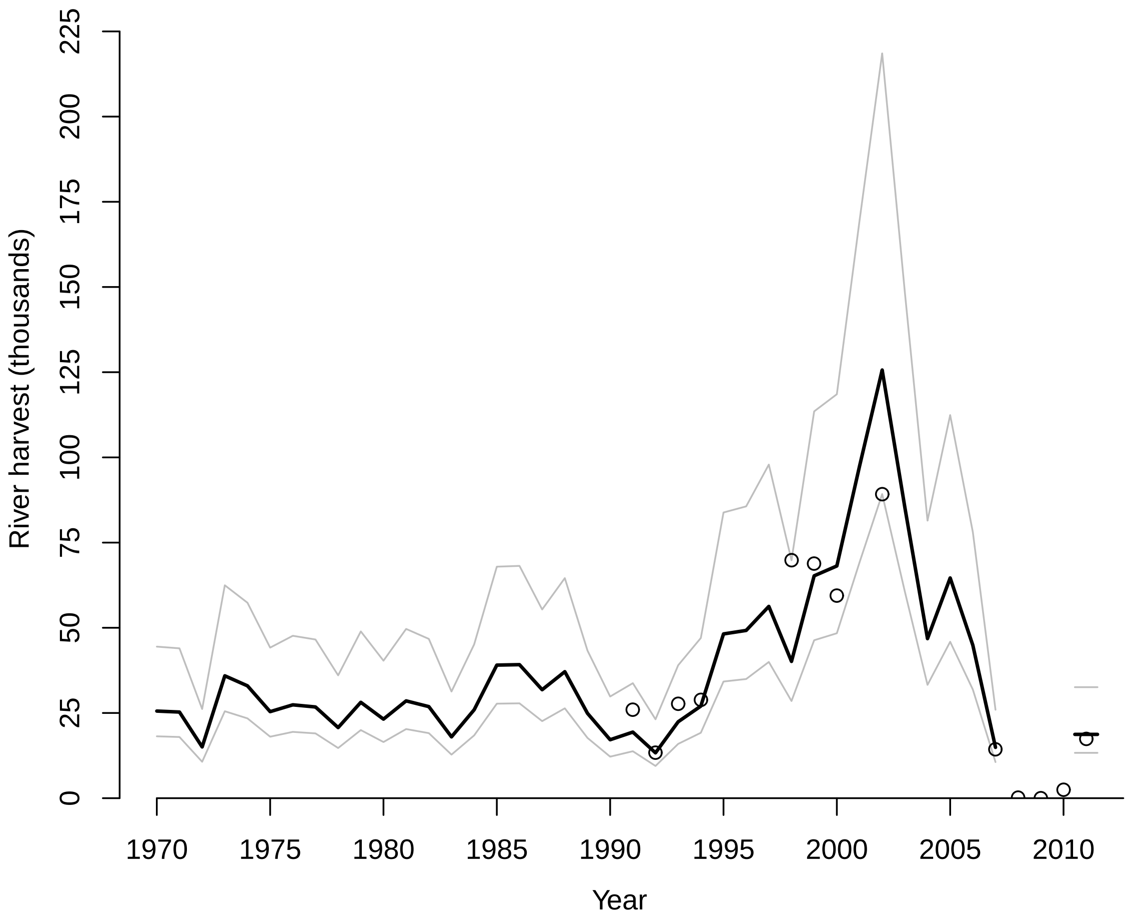

Figure 3. Estimated and hindcast river harvest of Sacramento River fall Chinook adults, 1970–2011. Circles are survey-derived estimates. The black line is the hindcasted harvest using the fitted mean harvest rate model. Grey lines depict the minimum and maximum hindcasted harvest, using the minimum and maximum harvest rates estimated for years when the river fishery was unconstrained. Hindcast river harvest estimates were not made for 2008–2010 because the river fishery was heavily constrained in those years.

Hatcheries have used a 61 cm jack cut-off length. However, in recent years the jack cut-off length at these hatcheries has varied. Since 2010 the jack cut-off length at Coleman National Fish Hatchery has been allowed to vary on an annual basis based on analysis of CWT recovery data collected as fish return to the hatchery. At Nimbus hatchery, the jack cut-off was increased to 68.5 cm beginning in 2010. At Feather River Hatchery, the jack cut-off was 61 cm from 1990–2005, and 65 cm thereafter.

Natural-area escapement estimates have been made using various methods, including carcass surveys, aerial redd counts, ladder counts, weir counts and video monitoring (Table 5; also see

Table 5. Sacramento River fall Chinook natural-area escapement survey methods employed from 1990–2011. Other small tributaries not listed in this table may contribute to SRFC natural-area escapement estimates in some years. Cut-off: fork length (FL) value used to distinguish a jack (FL $<$ cut-off) from an adult (FL $\geq$ cut-off). R: Red Bluff Diversion Dam passage, May 15–Sept. 15 (upstream tributary escapements subtracted from passage to estimate mainstem escapement); S: carcass survey; V: video monitoring; C: carcass count; M: male; F: female; CDFW: California Department of Fish and Wildlife; USFWS: United States Fish and Wildlife Service; DWR: Department of Water Resources. See text for additional details.

			Jack Proportion		
System	*Years*	*Escapement Survey*	*Survey*	*Cut-off (cm)*	*Agency*
Mainstem Sacramento River	1990–2000	R	R	61	CDFW/USFWS
	2001–2005	S	S	61	CDFW
	2006–2011	S	S	M: 67–75.5 F: 59–67.5	CDFW
Clear Creek	1990–2010	S	S	61	CDFW
	2011	S	S	M: 75.5 F: 67.5	CDFW
Battle Creek	1990–2005	S	S	61	CDFW/USFWS
	2006–2011	V	C	61	CDFW/USFWS
Deer Creek	1993–1994	S	S	61	CDFW
	1997–1998	S	S	61	CDFW
	2004–2011	S	S	61	CDFW
Mill Creek	1992–1994	S	S	61	CDFW
	1997–1998	S	S	61	CDFW
	2002–2011	S	S	61	CDFW
Butte Creek	1995–1998	S	S	61	CDFW
	2001–2005	S	S	61	CDFW
	2006–2008	S	S	65	CDFW
	2009–2011	S	S	61	CDFW
Yuba River	1990–2002	S	S	61	CDFW
	2003–2007	S	S	64.5	CDFW
	2008–2011	V/S	S	65	CDFW
Feather River	1990–1999	S	S	61	CDFW
	2000–2005	S	S	68	DWR
	2006–2011	S	S	65	DWR
American River	1990–2009	S	S	67–70	CDFW
	2010–2011	S	S	68	CDFW

CDFG (2007) for more information on the individual sampling programs). For 1990–2011, all natural-area surveys in the American, Yuba, and Feather Rivers were carcass surveys employing mark-recapture estimation methods, with one exception. Beginning in 2011, the Yuba River escapement survey switched from a carcass survey for all sections of the river to a carcass survey below Daguerre Point Dam and video monitoring above the dam. The upper mainstem Sacramento River natural-area escapement estimates are a combination of individual survey-derived estimates performed on the Sacramento River mainstem, Battle Creek, Clear Creek, and other minor tributaries (see Table B-1 in PFMC 2012c). Sampling in the minor tributaries (e.g., Deer, Mill, and Butte Creeks) has been sporadic over time. However, since 2004, surveys have been conducted without interruption on Deer, Mill, and Butte Creeks, and sampling is expected to continue on these and other small tributaries into the future (Bergman et al. 2012). Escapement to these minor tributaries generally represents a small fraction of the overall SRFC escapement.

Jack and adult proportions are determined by a survey-specific fork length cut-off value. For natural-area escapement surveys, this cut-off value has varied from 61.0–75.5 cm (Table 5). In some instances, the cut-off value has been arrived at empirically based on analysis of that year's length frequency distribution and/or analysis of CWT recoveries. Jack cut-off values have been adjusted both during and after the escapement survey after analysis of such data. More often, the cut-off value has been treated as a fixed constant across a series of years. In recent years, surveys for the mainstem Sacramento River and Clear Creek have employed a sex-specific cut-off length.

6 *SI* Properties: 1983–2011

Figure 4 displays the *SI* time series, and its constituent parts, for years 1983–2011. Annual updates of this figure, and the table of estimates underpinning it, are published in the PFMC Preseason I report (e.g., see PFMC 2012a, Figure II-1 and Table II-1).

Both the *SI* and the relative contribution of its components have varied over this time period. The lowest levels of the *SI*, by a substantial margin, occurred between 2007 and 2011, but the *SI* was also relatively low in 1983–1984 and in the early 1990s. The high *SI* levels that occurred during the 2000–2005 period are comparable to the levels of the late 1980s, although the relative contribution of the *SI* components in these two periods differs. For the period between 1983 and 1997, the proportion of the *SI* taken as ocean harvest averaged 0.72 (range: 0.62–0.84), whereas between 1998 and 2007 the average proportion was 0.51 (range: 0.35–0.71). Fisheries from 2008–2010 were either completely closed or highly constrained, and therefore nearly all of the *SI* was a result of the escapement component.

Figure 5 illustrates the reduction in the SRFC exploitation rate, defined as the fraction of the *SI* comprised of harvest (both ocean and river, though dominated by ocean harvest). This ‘harvest fraction’ is an approximation of a total exploitation rate which is estimable by cohort reconstruction. However, for consistency between this paper and other reports (e.g., PFMC 2012a; PFMC 2012), the SRFC harvest fraction will be referred to as the exploitation rate. Consistently high exploitation rates were estimated from the early-1980s until the mid-1990s. After the mid-1990s, a decreasing trend in the exploitation rate was evident. The very low exploitation rates in 2008–2010 resulted from closed or heavily constrained fisheries; a more typical level of fishing opportunity resumed in 2011.

The contrast between the time series of SRFC abundance (as indexed by the *SI*) and the time series of SRFC escapement is also notable. The anomalously high escapement levels in years 1999–2003 were due, at least in part, to the reduced exploitation rate over this period. High levels of the *SI* in the mid- to late-1980s did not translate into comparable high levels of escapement due to the relatively high fraction of fish removed by fisheries during this period.

A comparison between the *SI* and *CVI* for years through 2007 (the last year the *CVI* was estimated) is displayed in Figure 6. The two indices of abundance are highly correlated ($R^2 = 0.93$). This result is not surprising given the dominance of SRFC relative to other Central Valley Chinook stocks in both escapement and ocean harvest in the AM region over this period. The 1:1 line plotted in Figure 6 illustrates that the *SI* exceeded the *CVI* in all years, with the exception of 2000, due primarily to the inclusion of FA-region ocean harvest and river harvest in the *SI*.

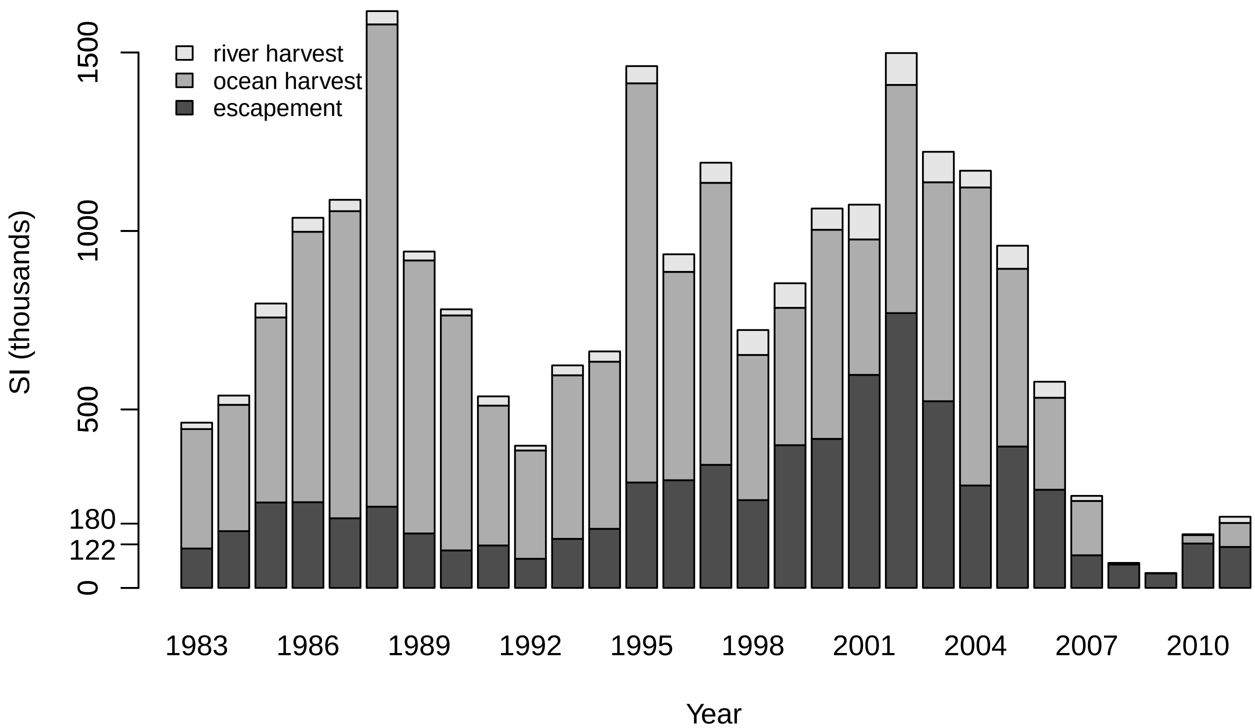

Figure 4. The Sacramento Index (*SI*) and its components, 1983–2011.

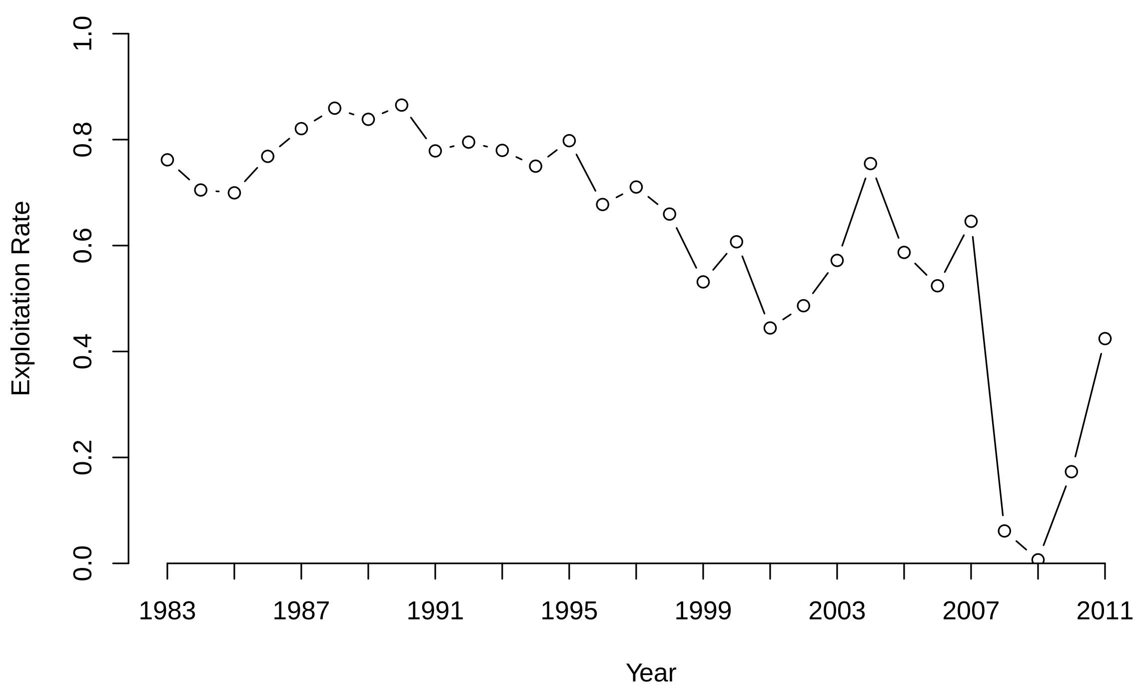

Figure 5. Estimated Sacramento River fall Chinook exploitation rate.

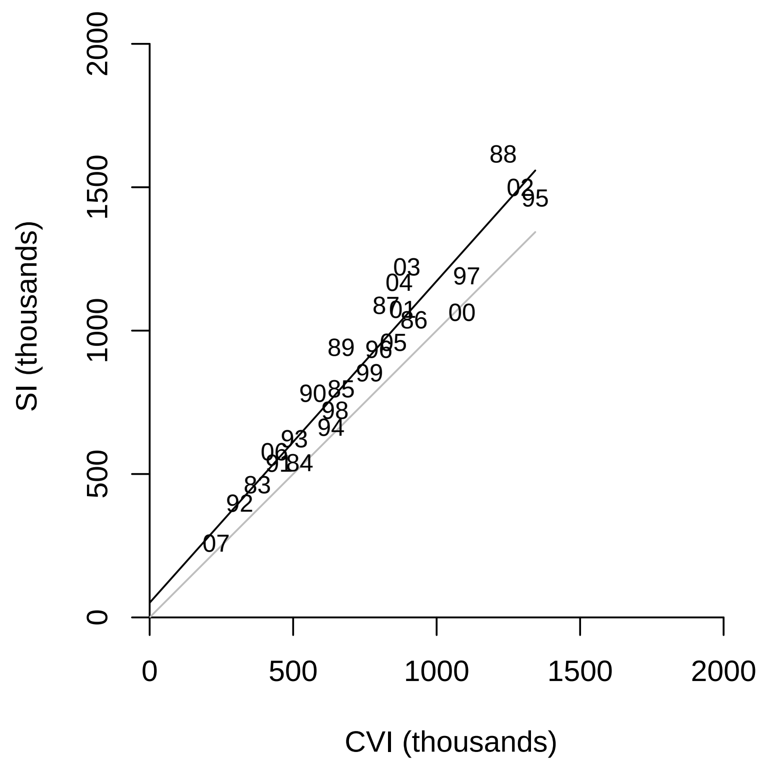

Figure 6. The Sacramento Index (*SI*) and the Central Valley Index (*CVI*) from 1983–2007 plotted on equal scales. The black line is the least-squares regression line for the *SI* and *CVI* ($R^2 = 0.93$). The grey line is the 1:1 line (*SI* = *CVI*).

7 *SI* Forecast

The *SHM*-based forecasts of SRFC harvest and escapement made during the PFMC preseason fishery planning process are based in part on a forecast of the *SI*. The *SI* forecast in turn has been based on the previous year's jack (*J*) spawning escapement using a statistical model relating *J* in year *t-1* to the *SI* in year *t*.

A variety of statistical models were examined between years 2008 and 2012 for use in forecasting the *SI* (e.g., see PFMC 2008b). However, in each of those years a zero-intercept linear model with additive errors was used

$$SI = \beta_{SI} J + \varepsilon, \tag{20}$$

and the ratio estimator

$$\hat{\beta}_{SI} = \bar{SI}/\bar{J} \tag{21}$$

was judged to be the optimal estimator of β_{SI}.

Since the initial *SI* forecast model was employed in 2008 the method has not been altered, though modifications to the subset of the jack escapement and *SI* data used for forecasting has changed over these years. The data used for *SI* forecasts, as well as the *SI* forecasts themselves, are documented annually in the PFMC Preseason Report I (PFMC 2008a, 2009, 2010, 2011, 2012a). The data and model used for *SI* forecasting are carefully evaluated each year, and modifications are considered as warranted.

8 Conclusions

The *SI* was developed in response to a sharp decline in SRFC abundance and the need to provide better scientific advice to the PFMC. Novel methods were required for the development of the *SI*, particularly for the estimation of SRFC ocean harvest in all fisheries south of Cape Falcon and the development of an uninterrupted time series of SRFC river harvest.

Together, the *SI* and *SHM* significantly advanced the extent, resolution, and specificity of the SRFC assessment framework. The development of the *SI* and *SHM* enabled the direct evaluation of proposed ocean fishery management measures for all months, areas (south of Cape Falcon), and fisheries. In addition, the effect of river fisheries on SRFC escapement was able to be forecast and incorporated into the fishery planning process. Neither of these features were possible within the previous *CVI*-based assessment framework.

Since initial development in 2008, the *SI* has been an important component of PFMC salmon management, and we anticipate that the *SI* and *SHM* will continue to be used for SRFC assessment and fishery planning for the foreseeable future. However, the *SI* could be considered a “data poor” index of abundance owing to the lack of separate accounting for cohort-specific abundances. The inconsistent marking and tagging practices in Sacramento Basin hatcheries and lack of age-specific run size information did not allow for the development of age structured assessment approaches in 2008. However, we note that several improvements to hatchery marking and tagging practices, as well as escapement estimation methodology, are being implemented in the Sacramento Basin. Beginning with brood year 2006, SRFC released from each of the three Sacramento Basin hatcheries were marked with an adipose fin clip and tagged with a CWT at a target rate of 25 percent (constant fractional marking (CFM), Buttars 2012). Implementation of a Central Valley Chinook monitoring plan (Bergman et al. 2012) that considered the needs of SRFC assessment and management began in 2011. A scale-aging program has been developed by CDFW to estimate age-specific run size for Central Valley Chinook (Grover and Kormos 2008). Combined efforts focused on CWT recovery and age-specific run size estimation, combined with CFM at Basin hatcheries, will greatly increase the data richness for the SRFC stock. If these programs are carried forward into the future, the potential for age structured assessments will likely become possible. However, until the CWT recovery and age-specific run size data series are mature enough to perform age structured assessments, the *SI* will continue to be an important part of SRFC assessment and management.

9 Acknowledgements

We thank Rob Titus, CDFW Anadromous Resource Assessment Unit, for providing us access to the Sacramento River Basin angler survey data, and his willingness to discuss with us the particulars of the survey design, data, and estimates. Brett Kormos, CDFW Ocean Salmon Project, provided detailed SRFC escapement information. Will Satterthwaite and Arliss Winship provided a thoughtful review of this paper. We also wish thank all of those responsible for the ocean harvest, river harvest, and escapement monitoring programs that produced the data used herein.

References

Bergman, J. M., R. M. Nielson, and A. Low (2012). Central Valley Chinook salmon in-river escapement monitoring plan. California Department of Fish and Game Administrative Report Number: 2012-1.

Buttars, B. (2012). Central Valley salmon and steelhead marking/coded-wire tagging program. Pacific States Marine Fisheries Commission, 10950 Tyler Road, Red Bluff, California 96080.

California Department of Fish and Game (CDFG) (2007). Existing program summary: Central Valley salmon and steelhead monitoring programs. Edited by A. Low. California Deparment of Fish and Game, Sacramento, CA.

Goldwasser, L., M. S. Mohr, A. M. Grover, and M. L. Palmer-Zwahlen (2001). The supporting databases and biological analyses for the revision of the Klamath Ocean Harvest Model. Unpublished report. National Marine Fisheries Service, Santa Cruz, CA.

Grover, A. and B. Kormos (2008). The 2007 Central Valley Chinook age-specific run size estimates. Unpublished report, California Department of Fish and Game Scale Aging Program.

Killam, D. and B. Kreb (2008). Chinook salmon populations for the upper Sacramento River Basin in 2007. Sacramento River Salmon and Steelhead Assessment Project Technical Report No. 08-4, California Department of Fish and Game, Sacramento, CA.

Mohr, M. S. (2006). The cohort reconstruction model for Klamath River fall Chinook salmon. Unpublished report. National Marine Fisheries Service, Santa Cruz, CA.

Mohr, M. S. and M. R. O'Farrell (In prep.). The Sacramento Harvest Model. National Marine Fisheries Service, Santa Cruz, CA.

Pacific Fishery Management Council (PFMC) (2007). Preseason report I: Stock abundance analysis for 2007 ocean salmon fisheries. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

Pacific Fishery Management Council (PFMC) (2008a). Preseason report I: Stock abundance analysis for 2008 ocean salmon fisheries. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

Pacific Fishery Management Council (PFMC) (2008b). Preseason report II: Analysis of proposed regulatory options for 2008 ocean salmon fisheries. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

Pacific Fishery Management Council (PFMC) (2009). Preseason report I: Stock abundance analysis for 2009 ocean salmon fisheries. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

Pacific Fishery Management Council (PFMC) (2010). Preseason report I: Stock abundance analysis for 2010 ocean salmon fisheries. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

Pacific Fishery Management Council (PFMC) (2011). Preseason report I: Stock abundance analysis for 2011 ocean salmon fisheries. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

Pacific Fishery Management Council (PFMC) (2012). Pacific coast Salmon Fishery Management Plan for commercial and recreational salmon fisheries off the coasts of Washington, Oregon, and California as revised through Amendment 16. Pacific Fishery Management Council, Portland, OR. 90p.

Pacific Fishery Management Council (PFMC) (2012a). Preseason report I: Stock abundance analysis and environmental analysis part 1 for 2012 ocean salmon fishery regulations. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

Pacific Fishery Management Council (PFMC) (2012b). Review of 2011 ocean salmon fisheries: stock assessment and fishery evaluatio document for the Pacific Coast Salmon Fishery Management Plan. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

Pacific Fishery Management Council (PFMC) (2012c). Review of 2011 ocean salmon fisheries: stock assessment and fishery evaluation document for the Pacific Coast Salmon Fishery Management Plan. (Document prepared for the Council and its advisory entities). Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

Thompson, S. K. (2002). *Sampling, 2nd edition*. New York: Wiley.

Titus, R., M. Brown, J. Lyons, E. Collins, and L. Koerber (2010). Annual project performance report: Central Valley angler survey July 1, 2009 to June 30, 2010 [SFRA F-119-R]. California Department of Fish and Game.

Winans, G. A., D. Viele, A. Grover, M. Palmer-Zwahlen, D. Teel, and D. Van Doornik (2001). An update of genetic stock identification of Chinook salmon in the Pacific Northwest: test fisheries in California. *Reviews in Fisheries Science 9*, 213–237.

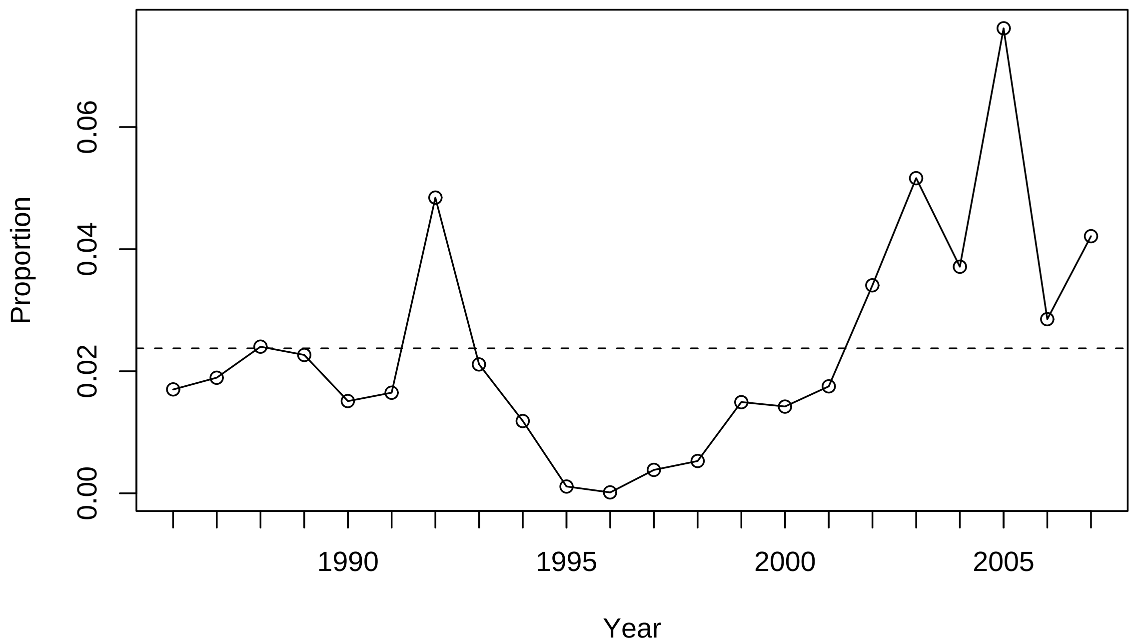

Figure A-1. Proportion of Sacramento River fall Chinook overall ocean harvest landed north of Cape Falcon, Oregon, 1986–2007. Dashed line depicts the mean proportion.

Appendix A Harvest North of Cape Falcon

The ocean harvest component of the *SI* includes SRFC harvest from Cape Falcon to the U.S./Mexico border, but not SRFC harvest north of Cape Falcon (NF). The proportion of the SRFC overall ocean harvest landed in the NF region was previously estimated and published in PFMC (2008b, Appendix B). In that document, the mean proportion of the SRFC overall ocean harvest landed in the NF region was estimated to be approximately one half of one percent over the 1986–2007 period. Subsequent to publication of PFMC (2008b), further analysis indicated that this estimate was likely too low.

For this paper, SRFC harvest in the NF region was estimated following the same methods that were used in the FA region. SRFC CWTs recovered in the NF region were expanded for sampling and multiplied by λ to estimate the SRFC harvest, as in Equation (7). The Sept. 1 through Aug. 31 SRFC harvest for the NF region was then divided by the Sept. 1 through Aug. 31 SRFC overall ocean harvest to obtain the proportion of SRFC overall ocean harvest landed in the NF region. Figure A-1 displays this proportion for the years 1986–2007. The proportion was less than or equal to five percent in all but one year (2005), and averaged 2.37 percent over this time period.

Appendix B Ocean Harvest Estimate Adjustment Methods

For the Cape Falcon to Point Arena region (FA), the month-area-fishery estimated harvest of the four components (S, K, V, N) are unlikely to sum exactly to the total harvest owing to a combination of factors such as sampling error, incomplete data for all stocks that contribute to the harvest in these areas, and variation in the distribution of untagged stocks that contribute to the λ expansion factors. For notational simplicity, we omit all harvest (H) subscripts in this Appendix other than those denoting the stock components (S, K, V, N) and total (T), noting that these methods are applied at the year-month-area-fishery level of stratification. For the FA region, over the period 1983–2011, there were a total of 1368 year-month-area-fishery strata. The sum of the component groups' harvest was less than the total harvest in 1059 of these strata, and greater than the total harvest in 298 of these strata. For those strata in which there was a difference between the group sum and total harvest, the magnitude of the difference (Δ) was

$$\Delta = |(H_S + H_K + H_V + H_N) - H_T|. \tag{B-1}$$

The methods used to adjust the component harvests depend on whether their sum was (1) less than or (2) greater than the total harvest, as described below.

B.1 Under-accounted: $H_S + H_K + H_V + H_N < H_T$

The rationale underlying the adjustments in this case was the following. The KRFC harvest estimates are based on expansion of recovered CWTs by well-determined sampling and mark rates, and well-quantified hatchery-to-natural production values, obtained through stock-level cohort analysis. Thus, H_K was not adjusted. H_V and H_N are likely minimum estimates since they do not account for the natural production of these stock groups and were thus adjusted. H_S estimates were not adjusted, and therefore the SI is unaffected. The magnitude of the difference, Δ, was prorated to H_V and H_N unless $H_V + H_N = 0$, in which case Δ was allocated to H_N if the area was off Oregon ($a \in \{\mathsf{NO}, \mathsf{CO}, \mathsf{KO}\}$) (harvest of N more likely there), or allocated to H_V if the area was off California ($a \in \{\mathsf{KC}, \mathsf{FB}\}$) (harvest of V more likely there). This set of adjustments is codified below, with $\widetilde{H}$ denoting the adjusted harvest:

$$\widetilde{H}_K = \quad H_K \tag{B-2}$$

$$\widetilde{H}_S = \quad H_S \tag{B-3}$$

$$\widetilde{H}_V = \begin{cases} H_V + \Delta[H_V/(H_V+H_N)] & : \quad H_V + H_N > 0 \\ \Delta & : \quad H_V + H_N = 0 \quad \text{and} \quad a \in \{\mathsf{KC}, \mathsf{FB}\} \\ 0 & : \quad H_V + H_N = 0 \quad \text{and} \quad a \in \{\mathsf{NO}, \mathsf{CO}, \mathsf{KO}\} \end{cases} \tag{B-4}$$

$$\widetilde{H}_N = \begin{cases} H_N + \Delta[H_N/(H_V+H_N)] & : \quad H_V + H_N > 0 \\ \Delta & : \quad H_V + H_N = 0 \quad \text{and} \quad a \in \{\mathsf{NO}, \mathsf{CO}, \mathsf{KO}\} \\ 0 & : \quad H_V + H_N = 0 \quad \text{and} \quad a \in \{\mathsf{KC}, \mathsf{FB}\}. \end{cases} \tag{B-5}$$

B.2 Over-accounted: $H_S + H_K + H_V + H_N > H_T$

The rationale underlying the adjustments in this case was the following. The KRFC harvest estimates are based on expansion of recovered CWTs by well-determined sampling and mark rates, and well-quantified hatchery-to-natural production values, obtained through stock-level cohort analysis. Thus, H_K was not adjusted. (In no instance did H_K exceed H_T.) H_V and H_N are likely minimum estimates since they do not account for the natural production of these stock groups, and thus H_S was reduced first to make up for the overage (down to zero if need be). If the H_S adjustment was insufficient to make up for the overage, and the area was off Oregon ($a \in \{\mathsf{NO}, \mathsf{CO}, \mathsf{KO}\}$), then H_V was reduced (down to zero if need be) followed by H_N, if necessary. (The latter ordering reflects the supposition that off Oregon, harvest of N is more likely than V.) If the H_S adjustment was insufficient to make up for the overage, and the area was off California ($a \in \{\mathsf{KC}, \mathsf{FB}\}$), then H_N was reduced (down to zero if need be) followed by H_V, if necessary. (The latter ordering reflects the supposition that off California, harvest of V is more likely than N.) This set of adjustments is codified below, with $\widetilde{H}$ denoting the adjusted harvest:

$$\widetilde{H}_K = \quad H_K \tag{B-6}$$

$$\widetilde{H}_S = \begin{cases} H_S - \Delta & : \quad \Delta \leq H_S \\ 0 & : \quad \text{otherwise} \end{cases} \tag{B-7}$$

$$\widetilde{H}_V = \begin{cases} H_V & : \quad \Delta \leq H_S \\ H_V - (\Delta - H_S) & : \quad H_S < \Delta \leq H_S + H_V \quad \text{and} \quad a \in \{\mathsf{NO}, \mathsf{CO}, \mathsf{KO}\} \\ H_V - (\Delta - H_S - H_N) & : \quad H_S + H_N < \Delta \leq H_S + H_V + H_N \quad \text{and} \quad a \in \{\mathsf{KC}, \mathsf{FB}\} \\ 0 & : \quad \text{otherwise} \end{cases} \tag{B-8}$$

$$\widetilde{H}_N = \begin{cases} H_N & : \quad \Delta \leq H_S \\ H_N - (\Delta - H_S) & : \quad H_S < \Delta \leq H_S + H_N \quad \text{and} \quad a \in \{\mathsf{KC}, \mathsf{FB}\} \\ H_N - (\Delta - H_S - H_V) & : \quad H_S + H_V < \Delta \leq H_S + H_N + H_V \quad \text{and} \quad a \in \{\mathsf{NO}, \mathsf{CO}, \mathsf{KO}\} \\ 0 & : \quad \text{otherwise} \end{cases} \tag{B-9}$$

The *SI* was reduced by this set of adjustments since $\widetilde{H}_S < H_S$. The unadjusted SRFC harvest ($H_{o,S}$), adjusted SRFC harvest ($\widetilde{H}_{o,S}$), and their ratio, are shown in Table B-1 for years 1983–2011. In general, the differences between the adjusted and unadjusted harvest estimates were small.

Table B-1. Sacramento River fall Chinook unadjusted ocean harvest ($H_{o,S}$), adjusted ocean harvest ($\tilde{H}_{o,S}$), and their ratio, for the Sept. 1, *t-1* through Aug. 31, *t* period.

Year (t)	$H_{o,S}$	$\tilde{H}_{o,S}$	$\tilde{H}_{o,S}/H_{o,S}$
1983	354943	334649	0.94
1984	358591	353907	0.99
1985	528541	518357	0.98
1986	760045	757633	1.00
1987	880515	860387	0.98
1988	1354994	1351289	1.00
1989	770568	764824	0.99
1990	682239	658309	0.96
1991	398858	391682	0.98
1992	358396	303479	0.85
1993	469505	458295	0.98
1994	480444	468073	0.97
1995	1121092	1118329	1.00
1996	584784	583793	1.00
1997	793351	790047	1.00
1998	406967	406747	1.00
1999	386569	384831	1.00
2000	597225	585828	0.98
2001	382134	379532	0.99
2002	647970	639368	0.99
2003	632709	613375	0.97
2004	901533	835025	0.93
2005	526506	498024	0.95
2006	272603	257674	0.95
2007	182178	152199	0.84
2008	4096	4096	1.00
2009	235	192	0.82
2010	23456	23273	0.99
2011	70788	69538	0.98

Appendix C River Harvest Data Interpolation Methods

In some years harvest estimates do not exist for a particular stratum (month-stream-section), either because the fishery was closed, or because the fishery was open but it lacked sample coverage. For strata in which the fishery was closed, harvest was assumed to be zero. For strata in which the fishery was open but data were lacking, harvest and angler effort were interpolated using data from the same stratum (month-stream-section) in other years that had a similar level of overall harvest, effort, and escapement.

Two "eras" were defined for the purpose of the interpolation. The "low harvest" era was characterized by relatively low harvest, effort, and escapement, and consisted of years 1991–1994 and 2007. The "high harvest" era was characterized by relatively high harvest, effort, and escapement, and consisted of years 1998–2000 and 2002.

Interpolation of missing estimates from a particular strata of the angler survey was performed by taking the mean of estimated harvest and effort in the same month-stream-section for the years in the era of the missing estimate. The use of this method may best be illustrated with an example. For September 1999, harvest and effort estimates were unavailable for the Feather River in river section 12.1. To interpolate for the missing harvest estimate, we first noted that 1999 was included in the high harvest era. The harvest estimate $\widehat{H}_r$ for this stratum was then computed in the following manner:

$$\widehat{H}_{r,\mathsf{Sept.},\mathsf{Feather},12.1,99} = \frac{1}{3} \times \sum_{t=98,00,02} H_{r,\mathsf{Sept.},\mathsf{Feather},12.1}(t), \tag{C-1}$$

where the years included in the summation are denoted by their last two digits. This method takes advantage of the relative similarity in harvests for the two distinct eras.

This interpolation method assumes that run timing and the spatio-temporal allocation of angler effort is consistent across years in the same stream and section. As such, the method is not able to account for year-effects, where harvest and effort levels may vary due to particular circumstances that occur in a given year (e.g., an abundance of good weather in a particular year results in increased harvest and/or effort).

The interpolation method described above was used for river harvest survey years through

2007. The percent difference between river harvest estimates before and after interpolation ranged between zero and four percent.

RECENT TECHNICAL MEMORANDUMS

SWFSC Technical Memorandums are accessible online at the SWFSC web site (http://swfsc.noaa.gov). Copies are also available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161 (http://www.ntis.gov). Recent issues of NOAA Technical Memorandums from the NMFS Southwest Fisheries Science Center are listed below:

NOAA-TM-NMFS-SWFSC-502 Upper Klamath and Trinity River Chinook salmon Biological Review Team report.
T.H. WILLIAMS, J.C. GARZA, N.J. HETRICK, S.T. LINDLEY, M.S. MOHR, J.M. MYERS, M.R. O'FARRELL, R.M. QUINONES, and D.J. TEEL
(December 2012)

503 Proceedings of the National Marine Fisheries Service Productivity Workshop, Santa Cruz, California, June 11-12, 2012.
A.T. MAMULA and J.B. WALDEN
(December 2012)

504 U.S. Pacific Marine Mammal Stock Assessments: 2012.
J.V. CARRETTA, K.A. FORNEY, E. OLESON, K. MARTIEN, M.M. MUTO, M.S. LOWRY, J. BARLOW, J. BAKER, B. HANSON, D. LYNCH, L. CARSWELL, R.L. BROWNELL JR., J. ROBBINS, D.K. MATTILA, K. RALLS, and M.C. HILL
(January 2013)

505 Spawning biomass of Pacific Sardine (*Sardinops sagax*) off U.S. in 2012.
LO, N.C.H., B.J. MACEWICZ, AND D.A. GRIFFITH
(March 2013)

506 Probability of taking a western North Pacific gray whale during the postponed Makah hunt.
J. E. MOORE, and D. W. WELLER
(March 2013)

507 Report of the National Marine Fisheries Service gray whale stock identification workshop.
D. W. WELLER, S. BETTRIDGE, R. L. BROWNELL JR., J. L. LAAKE, J. E. MOORE, P. E. ROSEL, B. L. TAYLOR, and P. R. WADE
(March 2013)

508 Inferring trackline detection probabilities from differences in apparent densities of beaked whales and dwarf & pygmy sperm whales in different survey conditions.
J. BARLOW
(April 2013)

509 Evaluation of an automated acoustic beaked whale detection algorithm using multiple validation and assessment methods.
E.K. JACOBSON, T. M. YACK, J. BARLOW
(March 2013)

510 Handbook for recognizing, evaluating, and documenting human interaction in stranded cetaceans and pinnipeds.
MOORE K. T. and S. G. BARCO
(March 2013)

511 A guide to constructing hydrophone arrays for passive acoustic data collection during NMFS shipboard cetacean surveys.
RANKIN, S., BARLOW, J. BARKLEY, Y. and VALTIERRA, R.
(May 2013)