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Attachment 2
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Sacramento River winter Chinook cohort reconstruction: analysis of ocean fishery impacts

DRAFT REPORT

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1 Abstract

Endangered Sacramento River winter Chinook (SRWC) are harvested incidentally in ocean salmon fisheries that target more abundant stocks. To evaluate the effect of these fisheries, cohort reconstructions were performed for ten broods (1998–2007) of hatchery-origin SRWC using coded-wire-tag data. Results indicate that the majority of ocean fishery impacts were attributed to recreational fisheries south of Point Arena, California. For complete broods 1998–2005, the number of potential SRWC spawners was reduced by an estimated 11 to 28 percent owing to ocean salmon fisheries. The spawner reduction rate for incomplete broods 2006 and 2007 will likely be zero, or nearly zero, due to the closure of most ocean salmon fisheries for 2008 and 2009 in California and Oregon. SRWC were predominantly caught as age-3, consistent with estimates of high ($>$ 85 percent) age-3 maturation rates that resulted in low ocean abundance of age-4 and older fish. Spawner reduction rates and ocean fishery age-3 impact rates were largely concordant and no temporal trend in these rates was observed over the range of years considered here, with the exception of recent years with widespread fisheries closures. In contrast to the relative consistency in ocean fishery effects on the SRWC population, the composite (hatchery and natural-origin) SRWC stock has experienced recent increases, and subsequent declines, in spawner escapement. These recent trends in spawner escapement cannot readily be explained by the exploitation history estimated during the same time frame.

2 Introduction

Chinook salmon fisheries in the ocean are conducted on a mixture of stocks, and fishing regulations are developed by the Pacific Fishery Management Council (PFMC) to primarily harvest abundant and/or productive target stocks. However, several non-target stocks, which may be listed as threatened or endangered by the Endangered Species Act (ESA), are caught incidentally in ocean fisheries. Sacramento River winter Chinook (SRWC) is one such stock. Measures intended to reduce or maintain the level of ocean fishery impacts on SRWC have been specified in the form of a National Marine Fisheries Service (NMFS) ESA consultation standard since the early 1990s. The primary focus of this Technical Memorandum is to evaluate the impact ocean fisheries have had on the SRWC stock.

Cohort reconstruction is a method commonly used in salmon stock assessment for estimation of exploitation rates. The basic principle of cohort reconstruction is the sequential estimation of a cohort's abundance from the end of the cohorts life span, when abundance is zero, to a specified earlier age (commonly age-2). A full cohort reconstruction can be completed only once the cohort's life span has ended. Age-specific escapement and harvest data are required and, in general, the natural mortality rates are assumed. Incomplete cohorts (i.e., cohorts whose life span has not yet ended) can also be partially reconstructed, but age-specific maturation rates must be assumed for the portion of the cohort yet to be observed. The reconstruction of a cohort's abundance enables the estimation of maturation, ocean harvest, contact, and impact rates, all of which allow for inference about the degree to which ocean fisheries impact a stock.

Cohort analysis methods can be applied to SRWC owing to the availability of age structured ocean harvest, river harvest, and escapement data derived from coded wire tag (CWT) recoveries. The cohort reconstructions described herein apply only to the hatchery-origin portion of the SRWC stock. No attempt was made to perform cohort reconstructions for the natural-origin portion of the stock, hence, the total abundance of SRWC is larger than the estimated abundances reported here. For other cohort reconstructions, such as those performed for Klamath River fall Chinook (Mohr 2006; Goldwasser et al. 2001), the natural area (non-hatchery) origin component of the cohort is reconstructed to obtain estimates of abundance for the composite natural and hatchery-origin stock. To rebuild the abundance of the natural stock, the assumption is made that the hatchery-origin portion of the stock shares the same harvest, impact, and contact rates as the natural-origin portion of the stock. Our goal with this analysis is limited to estimation of fishery impact and maturation rates, and not to obtain estimates of composite stock abundance. Hence, only the hatchery-origin portion of the stock is reconstructed.

SRWC was first listed under the Endangered Species Act (ESA) as threatened in 1989, and, since 1994, has been listed as endangered. The SRWC Evolutionary Significant Unit (ESU) has a high extinction risk, primarily owing to the lack of spatial structure in river spawning areas. Most SRWC historical spawning habitat lies behind impassable Keswick and Shasta Dams and current spawning is nearly all limited to a short stretch of the mainstem Sacramento River below Keswick Dam, an area not historically utilized by SRWC for spawning. Previous analysis of ocean harvest and impacts on SRWC has been confined to periods when marking and tagging of SRWC has occurred. In brood years 1969 and 1970, naturally produced SRWC were marked with a fin clip and estimates of marked SRWC harvest were made by CDFG (1989). The fin clips used to distinguish SRWC were also used for other stocks at this time, which likely confounded estimates of marked SRWC harvest in areas north of Point Arena, California. Nevertheless, these data and estimates indicated that marked SRWC were harvested primarily by the recreational fishery south of Point Arena. In addition, harvest of SRWC was highest in the months of February, March, July, and August. Marking and coded wire tagging of SRWC at Coleman National Fish Hatchery (CNFH) occurred in the early to mid 1990s, and harvest estimates for the tagged portion of the stock exist from broods 1991–1995 (Grover et al. 2004). For these broods, the spatiotemporal pattern of harvest was similar to that reported for the marked broods of 1969 and 1970 with the exception of a notable reduction in February and March harvest. These relative reductions in February and March harvest are clearly due to changes in fishing regulations in 1990 which closed or greatly reduced February and March fisheries south of Point Arena to protect SRWC. Prior to these changes in 1990, the recreational fishery in areas south of Point Arena began in mid-February. In 1998, marking and coded wire tagging of nearly 100% of SRWC hatchery production began at

Livingston Stone National Fish Hatchery (LSNFH), a conservation hatchery that produces SRWC at the upstream terminus of anadromy on the Sacramento River. The marking and CWT program at LSNFH enabled the reconstructions of the 1998–2000 SRWC broods (Grover et al. 2004). An analysis of harvest on these broods again found that the recreational fishery in areas south of Point Arena contributed most heavily to the total harvest. February harvest was nonexistent and March harvest was extremely low owing to restrictions on opening and closing dates for salmon seasons and minimum size limits specified by the ESA consultation standard. In addition, maturation rates for age-3 SRWC were estimated to be very high ($> 90\%$) and age-3 ocean impact rates ranged between 20% and 23%. Since the Grover et al. (2004) report, data from five new complete broods (2001–2005) and two incomplete broods (2006–2007) have become available.

The purpose of this memo is to estimate the degree that ocean salmon fisheries impact the endangered SRWC stock. We describe and present the cohort reconstructions for the hatchery component of this stock, and the subsequent estimation of maturation and ocean fishery impact rates that the reconstructions enable. Section 3 describes in detail the data and methods used for the cohort reconstructions and the estimators for maturation, harvest, contact, and impact rates. Results, including estimates of ocean impact rates and other key metrics are presented in Section 4. Discussion of the results, and comparisons of these results to those found in past assessments are presented in Section 5. We finish with a set of conclusions arising from our analysis. Additional details that pertain to the cohort reconstructions are presented in a set of Appendices at the end of this report.

3 Data and Methods

3.1 Data

Age-specific estimates of natural area escapement, hatchery escapement, river harvest, and ocean harvest of the hatchery-origin SRWC stock component are base requirements for cohort reconstruction. Estimates of these quantities can be derived from expanded CWT recoveries. CWTs recovered from river and ocean sampling programs are expanded for marking/tagging rates of less than 100% as well as non-exhaustive sampling of escapement and fisheries.

Nearly 100% of SRWC hatchery production is marked with a clipped adipose fin and tagged with a CWT. To account for the remaining unmarked/untagged portion of hatchery production, a *production expansion factor* $(1/\phi)$ is applied to each CWT recovered. The quantity ϕ is the proportion of hatchery releases for a particular tag code that received an adipose fin clip and a CWT. This proportion is estimated for each tag code in each brood year by the staff of LSNFH and is reported to the Regional Mark Processing Center (RMPC; http://www.rmpc.org).

All hatchery-origin SRWC caught in fisheries and returning to the river to spawn are not sampled in ocean and river monitoring programs, and all CWTs are not recovered and decoded. To account for the non-exhaustive sampling of harvest and escapement, a *sample expansion factor* $(1/\lambda)$ has been developed and is applied to each CWT recovered. The sampling fraction, λ, represents the fraction of the total escapement or harvest that was effectively sampled for CWTs in a particular stratum. Descriptions of escapement, river harvest, and ocean harvest sampling programs, and the methods used to estimate sample expansion factors, are described in the Escapement, River harvest, and Ocean harvest sections that follow.

Definitions for the notation used in this report are found in Table 1. A list of every CWT used in this analysis, as well as production and sample expansion factors associated with each CWT recovery, is available from the first author upon request.

3.1.1 Escapement

Spawner escapement of hatchery-origin SRWC occurs both to a trap operated by LSNFH at the base of Keswick Dam (the upstream anadromous boundary to the Sacramento River), as well as to natural spawning areas in the mainstem Sacramento River. SRWC returning to the Keswick trap serve as broodstock at LSNFH and are directly enumerated. Heads of SRWC with a clipped adipose fin used as hatchery broodstock are retained for CWT extraction and decoding. Estimation of natural area escapement of the SRWC hatchery-origin stock relies on CWT recoveries as well as sample expansion factors that account for the nonexhaustive sampling of natural spawning areas.

Carcass surveys and mark-recapture estimation methods have been used in the Sacramento

Table 1. Notation used in this analysis.

Symbol	Definition
a	Subscript denoting age, $a \in \{2,3,4,5\}$
C	Ocean fishery contacts
c	Contact rate
com	Term denoting the commercial fishery
D	Number of deaths due to "drop off" mortality
d	Drop off mortality rate
E	Escapement of hatchery-origin SRWC (to natural areas and the hatchery)
f	Fishing effort
H	Harvest
h	Harvest rate
hat	Term denoting hatchery spawner
I	Ocean fishery impacts
i	Impact rate
l	Total length, in inches
l^*	Minimum size limit for ocean fisheries; total length in inches
$1/\lambda$	Sample expansion factor
M	Number of mature, hatchery-origin SRWC returning to the river mouth
M^0	Simulated level of M absent the effects of ocean fisheries
m	Maturation rate
N	Ocean abundance of hatchery-origin SRWC
nat	Term denoting natural spawning areas
o	Subscript denoting ocean
p	Proportion of ocean harvest expected to be $\geq$ the minimum legal size
$1/\phi$	Production expansion factor
R	Number of decoded CWT recoveries
r	Subscript denoting river
rec	Term denoting the recreational fishery
rel	Subscript denoting releases from the hatchery
S	Number of deaths due to release mortality
s	Release mortality rate
t	Subscript denoting month
V	Number of deaths due to natural mortality
v	Monthly natural mortality rate
x	Subscript denoting fishery, $x \in$ {commercial, recreational}
y	Subscript denoting year
z	Subscript denoting area, $z \in$ {NO,CO,KO,KC,FB,SF,MO}

River to estimate natural area escapement of Chinook continuously since 1996. SRWC targeted carcass surveys are conducted jointly by the California Department of Fish and Game (CDFG) and the United States Fish and Wildlife Service (USFWS) from May–August in the mainstem Sacramento River upstream from Red Bluff Diversion Dam (RBDD). While Killam and Kreb (2008) and USFWS (2008) describe the SRWC carcass survey in detail, a general description of the survey and the application of CWT production and sample expansion factors follows.

Carcass surveys are conducted by field crews which examine carcasses of Chinook salmon found both on the bank and the bottom of the river. Carcasses encountered during the survey are considered to be "fresh" if they exhibit characteristics of recent death (e.g., at least one clear eye), or "decayed" if death was obviously not recent. A clipped adipose fin on any fresh or decayed carcass indicates hatchery-origin and the heads of all adipose clipped fish (and those with an unknown disposition of the adipose fin) are removed for CWT recovery and decoding. Fresh carcasses receive a visible, uniquely numbered, external tag and are returned to the river. If an externally tagged carcass is later recovered on a subsequent survey, it is noted and chopped in half to preclude counting at a later date. Decayed carcasses are noted then chopped in half and returned to the river. Data from the carcass surveys are used to estimate total escapement of SRWC to natural areas by applying Jolly-Seber mark-recapture estimation methods.

The number of hatchery-origin SRWC utilizing natural spawning areas is not directly estimated using Jolly-Seber methods. Instead, the escapement estimate for the hatchery-origin portion of the stock is derived from the total number of CWTs recovered and decoded, tag code specific production expansion factors, and spawning year specific carcass survey sample expansion factor. The method used to derive this sample expansion factor, developed by the authors of this report, is described in Appendix B. The derived sample expansion factors for spawning years 2001–2010, along with the data from which they were derived, is provided in Appendix C.

The spawner escapement of age a hatchery-origin SRWC in year y is estimated by the sum

$$E_{ay} = E_{ay}^{hat} + E_{ay}^{nat}. \tag{1}$$

The first term on the right-hand side of equation (1) is the hatchery-origin SRWC escapement to LSNFH, via the Keswick trap. The estimate of the hatchery-origin escapement to LSNFH, per CWT recovered and decoded, is equal to the production expansion factor $1/\phi$ associated with that decoded CWT. E_{ay}^{hat} is estimated by summing the expanded CWTs by year and age. The second term on the right-hand side of equation (1) is the hatchery-origin SRWC escapement to natural spawning areas. The estimate of hatchery-origin escapement to natural areas, per CWT recovered and decoded from the carcass survey, is equal to $(1/\lambda)(1/\phi)$. Both sample and production expansion factors are specific to each decoded CWT. E_{ay}^{nat} is estimated by summing the expanded CWTs by year and age.

3.1.2 River harvest

Recreational Chinook salmon fisheries have occurred annually in the Sacramento River, typically beginning in June or July and ending in December. Due to the timing of the river fishery, and the run timing of SRWC, few SRWC are expected to be harvested in the Sacramento River. The peak migration period of SRWC into the Sacramento River occurs in March (Fisher 1994) when the river fishery is closed to salmon retention.

CDFG conducted angler surveys on the Sacramento River from 2000–2002, resulting in eight winter Chinook CWT recoveries[1]. The sampling program was eliminated in 2003–2005, and most of 2006. In November of 2006, river fishery sampling began again in the upper Sacramento River and continues to the present time. Since the resumption of the sampling program, one winter run CWT was recovered in 2008, and two winter run CWTs were recovered in 2009.

The primary sampling method used for the river fishery has been a roving creel survey conducted by boat. The survey results in estimates of the number of angler hours by time and area. Historical time and area specific estimates of catch-per-angler-hour are then applied to estimate the total catch by time and area. These catch-per-angler-hour estimates were derived from his-

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[1] Seven of the eight fish were caught between 28 Dec 2000 and 14 Jan 2001, just prior to the 15 Jan 2001 closure of the fishery. The California Fish and Game Commission responded to this finding by advancing the fishery closure date in all years subsequent to 2001 from Jan 15 to Jan 1 in order to minimize fishery impacts on SRWC.

torical exit surveys of anglers conducted along the Sacramento River. During the survey angler interviews, samplers collect heads from adipose fin clipped fish for CWT recovery and decoding.

The sampling fraction is computed as the ratio of the number of fish sampled to the total catch by time and area. The estimate of the hatchery-origin SRWC river harvest, per CWT recovered and decoded from the angler survey, is equal to $(1/\lambda)(1/\phi)$. Both production and sample expansion factors are specific to each decoded CWT. H_{ray} is then estimated by summing the expanded CWTs by year and age.

3.1.3 Ocean harvest

Commercial and recreational ocean salmon fishery harvest is sampled by CDFG and Oregon Department of Fish and Wildlife (ODFW) in their respective states using similar methods. Both state agencies maintain a CWT extraction and decoding laboratory, and report data associated with CWTs to RMPC. Each state agency also reports catch and fishing effort by month, management area, and fishery each year in the PFMC "Review of Ocean Fisheries" document series (e.g., PFMC 2011). The seven ocean management areas used to spatially stratify ocean harvest estimates of hatchery-origin SRWC for this analysis are described in Table 2. Previous cohort reconstructions considered an eighth area, South of Sur, that resulted from splitting the MO management area into separate northern and southern areas. Fishing effort and landings south of Point Sur, California are generally quite low relative to more northern areas, and typically fisheries management measures are equivalent over the entire region from Pigeon Point to the U.S./Mexico border. Splitting MO into two areas has no effect on reconstructed SRWC abundance, impact rate, or spawner reduction rate estimates. For these reasons, the South of Sur management area was not included in this analysis.

Commercial fishery sampling primarily occurs during fish sales transactions. Salmon are counted, weights are recorded, and heads or snouts are collected from all adipose fin clipped Chinook salmon for CWT extraction and decoding. At this time, fishermen are interviewed to determine the number of days fished and area of catch. The sampling fraction is computed as the ratio of salmon sampled to the total landing estimate, which is based on landing receipts.

Table 2. Ocean management areas used in this analysis. Areas are contiguous, listed from north to south. The southern border of the MO area is the U.S./Mexico border. KMZ denotes Klamath Management Zone.

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
San Francisco	SF	Point Arena, CA	San Francisco
Monterey	MO	Pigeon Point, CA	Monterey

Recreational fishery sampling is performed differently depending if the fishing activity occurs on commercial passenger fishing vessels (CPFV) or privately operated fishing vessels (POFV). For the CPFV recreational fishery, sampling to determine catch and effort is similar to that of the commercial fishery, and landing receipts reported to the respective state agencies are used to make total landings estimates. Heads or snouts are taken from all adipose fin clipped salmon examined by dockside samplers, and the sampling fraction is computed in the same manner as described for commercial fisheries. For the POFV recreational fishery, the sampling is structured differently because landings receipts are not required for private boaters. POFV sampling programs are typically a stratified random creel survey of all available points of landing within a port area. Sampling effort is also stratified by day-type: weekend/holiday versus weekday. Samplers attempt to interview all returning anglers, record the number of Chinook landed per angler, and collect heads or snouts from adipose fin clipped Chinook salmon for CWT extraction and decoding. Estimates of total catch and fishing effort are made based on the sampled catch and the ratio of days and sites sampled to the total number of possible days and sites in the stratum. The catch and effort estimates are then aggregated to an estimate of catch and effort by port and month.

Both CDFG and ODFW attempt to sample at least 20% of the landed catch in the recreational and commercial fishery, for each month and management area. Sample expansion factors reported by CDFG and ODFW to RMPC were derived from sampling fractions and include corrections for heads not collected and for CWTs that were lost or not readable, as was done for the carcass surveys. Estimated hatchery-origin SRWC harvest, per decoded CWT recovery, is equal to $(1/\lambda)(1/\phi)$. Both sample and production expansion factors are specific to each decoded CWT. H_{oatzxy}, the ocean harvest of hatchery-origin SRWC by age, month (t), area (z), fishery (x) and year is then estimated by summing the respective expanded CWTs.

3.2 Methods

3.2.1 Cohort reconstruction

The reconstruction of a cohort with no extant individuals (i.e., a "complete" cohort) proceeds sequentially from the end of that cohort's life span. Given the estimated quantities E_a, H_{ra}, and H_{oatzx} (hereafter ignoring the year y subscripts), we defined the age-specific number of mature, hatchery-origin SRWC leaving the ocean for the Sacramento River

$$M_a = E_a + H_{ra} \tag{2}$$

and the following metrics pertaining to ocean fisheries:

$$C_{oatzx} = H_{oatzx}/p_{oatzx} \tag{3}$$

$$S_{oatzx} = (C_{oatzx} - H_{oatzx}) \times s_{oatzx} \tag{4}$$

$$D_{oatzx} = C_{oatzx} \times d \tag{5}$$

$$I_{oatzx} = H_{oatzx} + S_{oatzx} + D_{oatzx}. \tag{6}$$

M_a is defined as escapement from ocean fisheries, and in the absence of river fishery harvest, is equal to spawner escapement. Natural mortality is assumed to be zero in the river. The quantity p_{oatzx} was estimated based on a length-at-age model for SRWC and the month, area, and fishery specific size limit (Appendix A). The release mortality rate conventions employed are $s = 0.26$ for the commercial fishery and $s = 0.14$ for the recreational fishery, based on a review of hook and release mortality studies by the PFMC Salmon Technical Team (STT 2000). In addition, for recreational fisheries in SF and MO, the estimate of s has dependence on the proportion of anglers "mooching", a style of fishing that results in greater release mortality rate than trolling (Grover et al. 2002). The dropoff mortality rate d was assumed to be 0.05, the value recommended by STT (2000).

Ocean impacts were aggregated over management areas and fisheries to produce an estimate of the total ocean-wide fishery impacts incurred by age and month,

$$I_{oat} = \sum_{zx} I_{oatzx}. \tag{7}$$

Given these quantities, individual cohorts were reconstructed in the following manner:

$$N_{oat} = \begin{cases} 0 & a \geq 6 \\ I_{oat} + V_{oat} + M_a + N_{o(a+1)(t+1)} & a \in \{2,3,4,5\};\ t = Feb \\ I_{oat} + V_{oat} + N_{oa(t+1)} & a \in \{2,3,4,5\};\ t \neq Feb \end{cases} \tag{8}$$

where

$$V_{oat} = \begin{cases} (M_a + N_{o(a+1)(t+1)}) \times [v_a/(1-v_a)] & a \in \{2,3,4,5\};\ t = Feb \\ N_{oa(t+1)} \times [v_a/(1-v_a)] & a \in \{2,3,4,5\};\ t \neq Feb. \end{cases} \tag{9}$$

The cohort reconstruction approximates river entry timing, and exit from ocean fisheries, by specifying that mature fish enter the river on the last day of February. The monthly, age-specific natural mortality rate (v_a) for age-2 is assumed to be 0.0561, which corresponds to a 50% annual rate. The monthly natural mortality rate for ages 3, 4, and 5 is assumed to be 0.0184, corresponding to a 20% annual rate. The use of assumed values for v_a is necessary for estimation of exploitation rates through cohort analysis, and the values used here are consistent with those used for other Pacific salmon (e.g., Goldwasser et al. 2001).

For the most recent cohorts with life spans not yet completed, we used an approximation to perform a partial cohort reconstruction. For the 2006 brood, the age-5 river harvest and escapement have not yet been estimated. Since the data do not extend into the age-5 portion of this cohort, the reconstruction of ocean abundance begins at the month of ocean exit (February) prior to age-4 escapement. Cohort abundance of age-4 individuals on Feb 1 was approximated as

$$N_{o(4)(Feb)} = I_{o(4)(Feb)} + V_{o(4)(Feb)} + \frac{M_4}{avg\{m_4\}}, \tag{10}$$

where $avg\{m_4\}$ is the mean age-4 maturation rate estimated from all complete cohorts and

$$V_{o(4)(Feb)} = \frac{M_4}{avg\{m_4\}} \times \frac{v_4}{1-v_4}. \tag{11}$$

The ocean abundance of the 2006 cohort was then rebuilt from February 1, age-4, using equation sets (8) and (9).

For the 2007 brood, both age-4 and age-5 river harvest and escapement have not yet been estimated. For this brood, the reconstruction of ocean abundance begins on Feb 1 prior to age-3 escapement. This is accomplished by using equations (10) and (11), modifying the equations such that age-3 is substituted for age-4.

3.2.2 Estimation

Using the quantities defined in equations (2) through (7) and the reconstructed abundances, maturation, harvest, contact, and impact rates were estimated as follows. The maturation rate was estimated as the age-specific fraction of fish alive at the end of February that enter the river:

$$m_a = \frac{M_a}{N_{oa(Feb)} - I_{oa(Feb)} - V_{oa(Feb)}}. \tag{12}$$

Age, month, area, and fishery specific contact, harvest, and impact rates were estimated as:

$$c_{oatzx} = C_{oatzx}/N_{oat} \tag{13}$$

$$h_{oatzx} = H_{oatzx}/N_{oat} \tag{14}$$

$$i_{oatzx} = I_{oatzx}/N_{oat}. \tag{15}$$

Note that the denominator in these equations is the age-specific ocean-wide abundance at the beginning of month t. The annual age-specific impact rate, was estimated as

$$i_{oa} = \frac{\sum_{t=Mar}^{Feb} \sum_{zx} I_{oatzx}}{N_{oa(Mar\ 1)}}, \tag{16}$$

with the denominator in this case being the age-specific ocean-wide abundance at the beginning of the SRWC biological year (i.e., March 1).

The SRR, also referred to as the adult equivalent exploitation rate, is a measure of the effect of ocean fisheries on the adult spawning potential of a brood. It is the reduction in a brood's potential spawning escapement owing to ocean fisheries, relative to its escapement potential in the absence of ocean fishing:

$$SRR = \frac{M^0 - M}{M^0}. \tag{17}$$

M^0 is a brood's projected river return of adult SRWC (age 3–5), absent the effect of ocean fisheries, and M is a brood's observed adult river return. M^0 is derived by projecting the March 1, age-2 abundance forward through age-5 spawners, assuming that maturation rates are the cohort- and age-specific estimates determined by equation (12) and that all mortality is due to natural factors. This formulation isolates the impact of ocean fisheries on the spawning potential, and makes the assumption that no mortality is incurred after river entry. For incomplete cohorts, the SRR was expressed as a range of plausible estimates because maturation and ocean impact rates are unavailable for the final year, or two years, of the cohort's life span and therefore these values must be assumed. Maximum bounds of the SRR for incomplete cohorts were estimated by assuming that the unestimated, age-specific maturation rates were the maximum maturation rates (at age) observed from all complete broods. Impact rates were assumed be 1.0 after the last observed escapement (i.e., all fish died due to fisheries after the last observed escapement and the cohort therefore did not contribute to future escapement). Minimum bounds of the SRR were calculated by assuming that the unestimated maturation rates were equal to the minimum maturation rate at age observed for all complete broods. Impact rates after the last observed spawning escapement estimate were assumed to be zero. Hence, future returns were only limited by natural mortality.

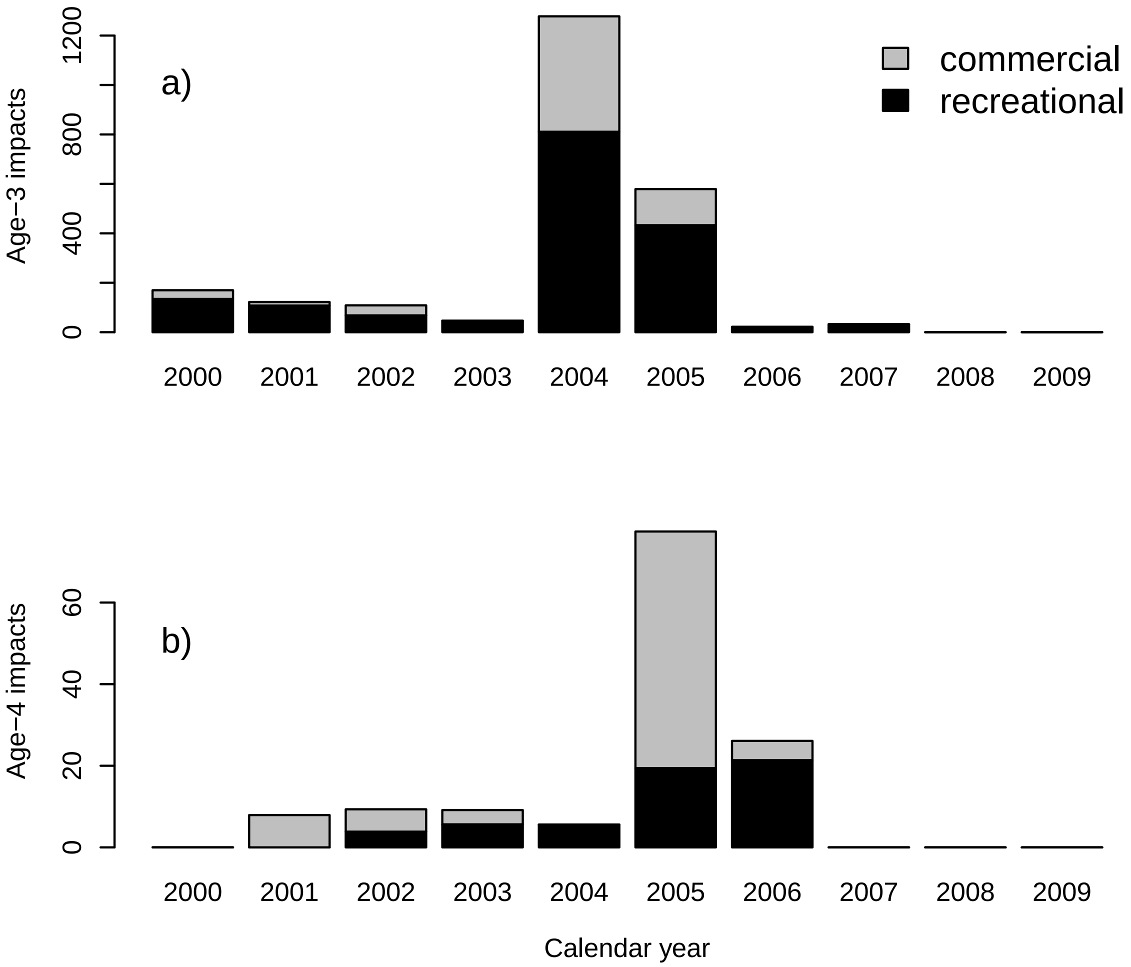

Figure 1. Ocean fishery impacts for hatchery-origin (a) age-3 and (b) age-4 Sacramento River winter Chinook estimated by calendar year. Total impacts by year are the sum of impacts over all ocean fishery management areas.

4 Results

The number of ocean fishery impacts on hatchery-origin SRWC has been quite variable between the years 2000 and 2009 (Figure 1). Age-3 impacts greatly outnumber age-4 impacts (note the scale difference between Figure 1a and 1b), and were primarily the result of recreational fisheries. Recreational fisheries have smaller minimum size limit regulations than commercial fisheries and therefore the relatively small age-3 SRWC are more vulnerable to retention in the recreational fishery. In general, a larger proportion of the age-4 impacts are attributed to the commercial fishery, likely reflecting the increased vulnerability of older and larger fish to retention in that fishery. The

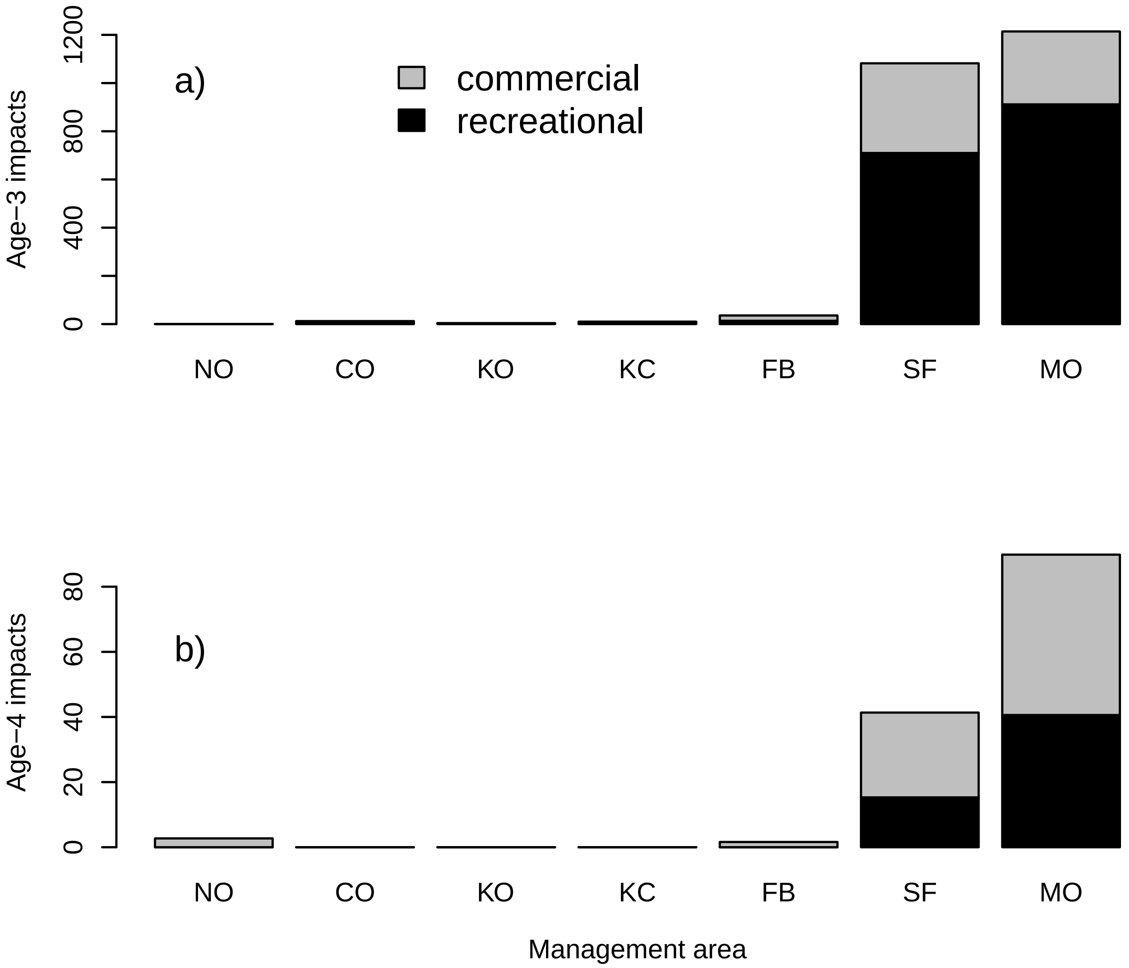

Figure 2. Ocean fishery impacts for hatchery-origin (a) age-3 and (b) age-4 Sacramento River winter Chinook estimated by ocean fishery management area. Total impacts by area are the sum of impacts over calendar years 2000–2009.

highest age-3 impacts occurred in 2004 and 2005, and these anomalies were apparent as age-4 impacts in 2005 and 2006. Nearly all ocean salmon fisheries were closed in 2008 and 2009, for those years impacts are zero. A clear pattern in the spatial distribution of ocean fishery impacts is evident in Figure 2. Impacts in areas north of the SF management area are rare or absent for both age-3 and age-4 SRWC; the SF and MO areas contribute the great majority of ocean fishery impacts.

The reconstruction of cohorts from brood years 1998–2007 enabled the estimation of maturation rates, the SRR, and ocean fishery impact rates. Table 3 displays estimated maturation rates for age-2 through age-4. Of particular relevance is the consistently high age-3 maturation rate. The

Table 3. Estimated age specific maturation rates (m_a), impact rates (i_a), and the spawner reduction rate (SRR). Maturation rate and SRR estimates reported only for complete broods 1998–2005.

Brood year	m_2	m_3	m_4	i_3	i_4	SRR
1998	0.0419	0.8542	0.8274	0.2338	0.1247	0.2641
1999	0.1639	0.9545	1.0000	0.2512	0.7163	0.2278
2000	0.0632	0.9453	1.0000	0.2183	0.5471	0.2322
2001	0.0605	0.9739	1.0000	0.1034	0.6721	0.1131
2002	0.0345	0.9305	1.0000	0.2559	0.3827	0.2759
2003	0.0403	0.9487	0.9467	0.1717	0.2306	0.1803
2004	0.0227	0.9590	1.0000	0.1505	0.0000	0.1538
2005	0.0101	1.0000	1.0000	0.1778	0.0000	0.1861
2006	–	–	–	0.0000	0.0000	–
2007	–	–	–	0.0000	–	–

high age-3 maturation rate results in relatively low age-4 ocean abundance (see Appendix D), since the preponderance of SRWC return to spawn at age-3. This maturation schedule also contributes to the high level of age-3 ocean fishery impacts relative to age-4 impacts.

The SRR, estimated for complete broods 1998–2005, ranged from 11.31% to 27.59% (Figure 3; Table 3). Brood year 2006 is incomplete because it is missing the age-5 river harvest and escapement components and therefore the potential SRR is expressed as a range of possible values. Potential SRR values are very low for this brood because nearly all ocean salmon fisheries were closed in 2008 and 2009, when this brood would be vulnerable as age-3 and age-4, respectively. Furthermore, the range of potential SRR is very small for this brood owing to the the very small contribution of age-5 spawners; reconstructed ocean abundances are either very small or zero after age-4 escapement (Appendix D). The 2007 brood is also incomplete, with no estimates of age-4 and age-5 river harvest and escapement. Since assumptions must be made for age-3 and age-4 maturation rates, as well as the unobserved age-4 and age-5 ocean harvest, the range of possible SRR for this cohort is larger.

Annual impact rates (i_{oa}), estimated using equation (16) for age-3 and age-4 SRWC, are displayed in Table 3 and Figure 4. When ocean fisheries have been open (2000–2007), age-3 impact rates have ranged from 10.34% to 25.59%, with little obvious trend. In contrast, age-4 impact rates have been much more variable and can be quite high. Substantial uncertainty exists for the

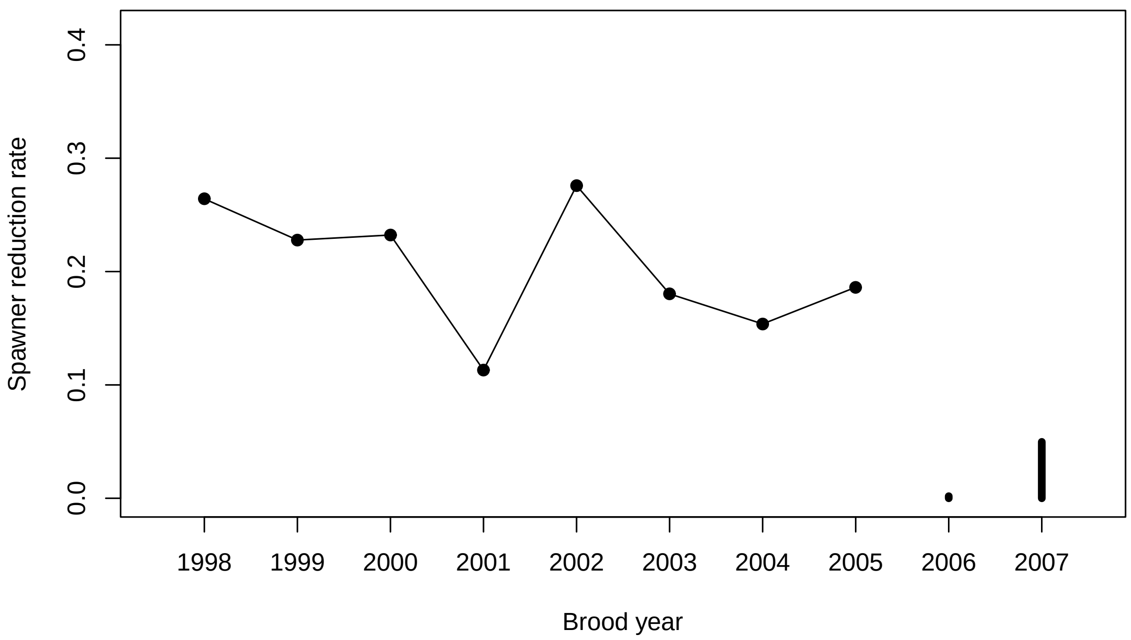

Figure 3. The spawner reduction rate for brood years 1998–2007. Brood years 2006 and 2007 are incomplete and estimates are expressed as a range of potential outcomes.

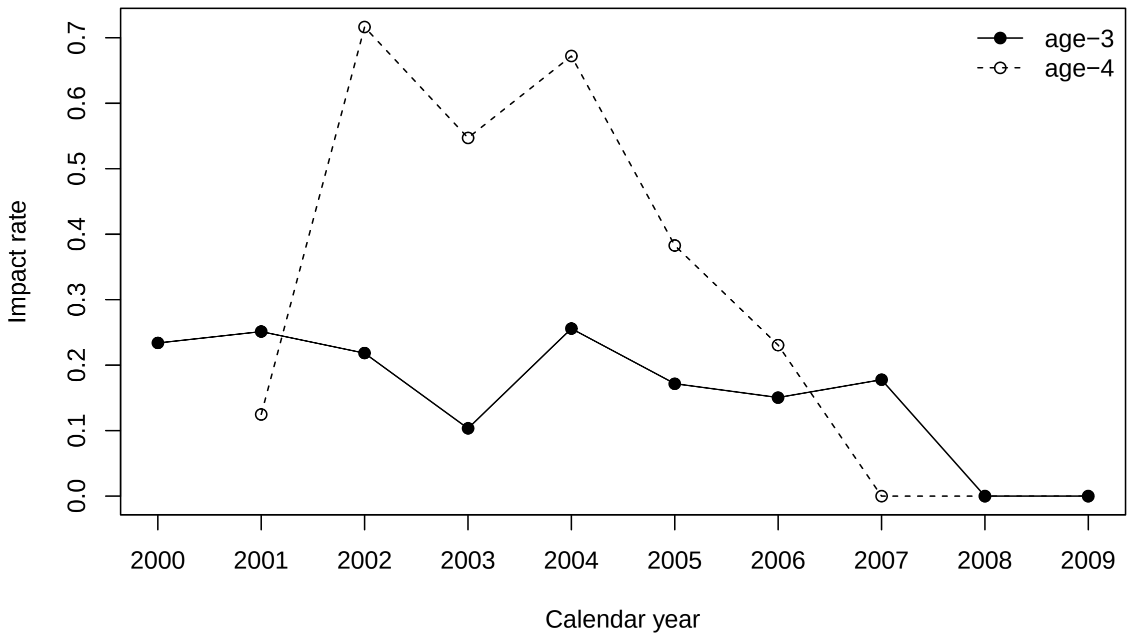

Figure 4. Ocean fishery impact rates for age-3 and age-4 plotted by calendar year.

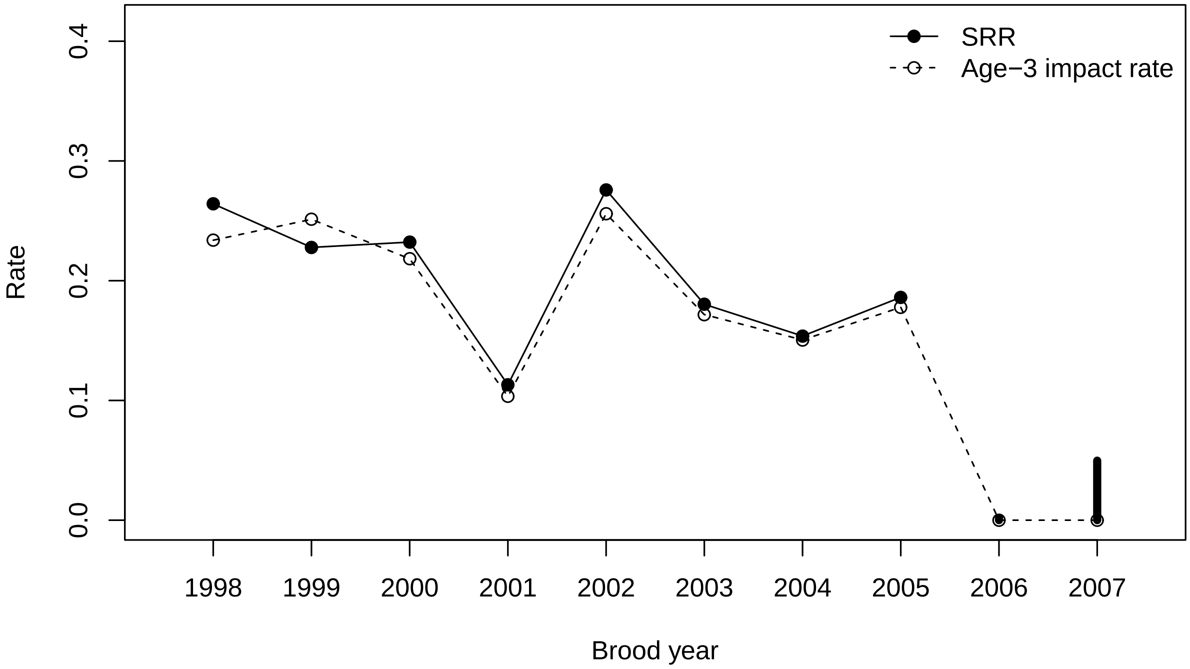

Figure 5. The spawner reduction rate (SRR) and age-3 impact rate plotted by by brood year.

age-4 impact rate estimates owing to the very low numbers of CWT recoveries that contribute to these estimates. Note that such high impact rates do not translate into very large age-4 impacts (Figure 1). This result can be explained by the low age-4 abundance of SRWC, a byproduct of the high age-3 maturation rate. The high age-3 maturation rate also suggests that the age-3 impact rate and the SRR should be concordant. Figure 5 demonstrates this to be the case as the trend and actual values of the SRR and the age-3 impact rate (here plotted by brood year) coincide with each other.

Stratifying the instances of nonzero impact rates by fishery, month, and management area (i_{oatzx}), enables additional inference about how ocean fisheries have affected SRWC. Figure 6 displays these rates (estimated by equation (15)) for the recreational fishery. Very few CWT recoveries from age-3 SRWC exist from management areas north of SF, resulting in few estimates of nonzero impact rates in these areas. Zero CWTs from age-4 SRWC were recovered in areas north of SF. For age-3, the bulk of the CWT recoveries and highest impact rates occur in the SF and MO areas between the months of April and July. Age-4 impacts are also clustered in the SF and MO areas and estimated age-4 impact rates can be much higher than age-3 impact rates (note y-axis scale differences between age-3 and age-4). Note also that very few CWT recoveries contributed to these age-4 estimates, as indicated by color coding of the impact rate estimates. For the commercial fishery (Figure 7), a similar spatiotemporal pattern is observed, yet with fewer nonzero impact rate estimates. Impacts north of SF are rare or absent. Nonzero age-3 impact rates are observed in SF and MO, with the highest rates observed from June–August. This pattern holds for age-4, though estimates are relatively sparse.

The relationship between the age-3 ocean fishery impact rates and fishing effort for recreational and commercial fisheries is displayed in Figures 8 and 9, respectively. A zero-intercept linear model representing the average impact rate per unit of effort was fit to these estimates using the ratio estimator, $\beta_{o(3)tzx} = avg\{i_{o(3)tzx}\}/avg\{f_{otzx}\}$, where f denotes fishing effort and the average is over years. Effort in recreational fisheries is defined as *angler days*, while effort in the commercial fishery is defined as *boat days*. Since the two effort metrics are not equivalent, comparisons of fishing effort between recreational and commercial fisheries are not valid. For the recreational fishery, it is clear that the highest impact rates per unit of fishing effort occur in the SF and MO areas. Recreational fishing effort was comparable between SF and MO through the month of June. After June, the SF region has experienced higher effort relative to MO, though impact rates tend to be low in SF after August. We note that recreational fisheries do not continue to operate in February and March and therefore SRWC are not currently "sampled" by the fishery in these months. The sparsity of data points in March indicate how infrequently fisheries have operated in this month for the cohorts examined here. A similar pattern to the one described above exists for the commercial fishery. It is clear that for this fishery, the highest age-3 impact rates per unit effort are clustered in the SF and MO areas from June–August.

Cohort reconstructions rebuild the abundance of SRWC broods to age-2, March 1. Using the age-2 March abundance ($N_{o(2)(Mar1)}$)and the number of hatchery SRWC released from LSNFH (N_{rel}), it is possible to estimate an early life survival rate ($N_{o(2)(Mar1)}/N_{rel}$). The early life survival rate includes all sources of mortality, both in the river and the ocean from hatchery release to age-2 in the ocean. This survival rate is most likely completely independent of ocean fishery sources of mortality as SRWC prior to age-2 are unlikely to be contacted by ocean fisheries. Estimates of

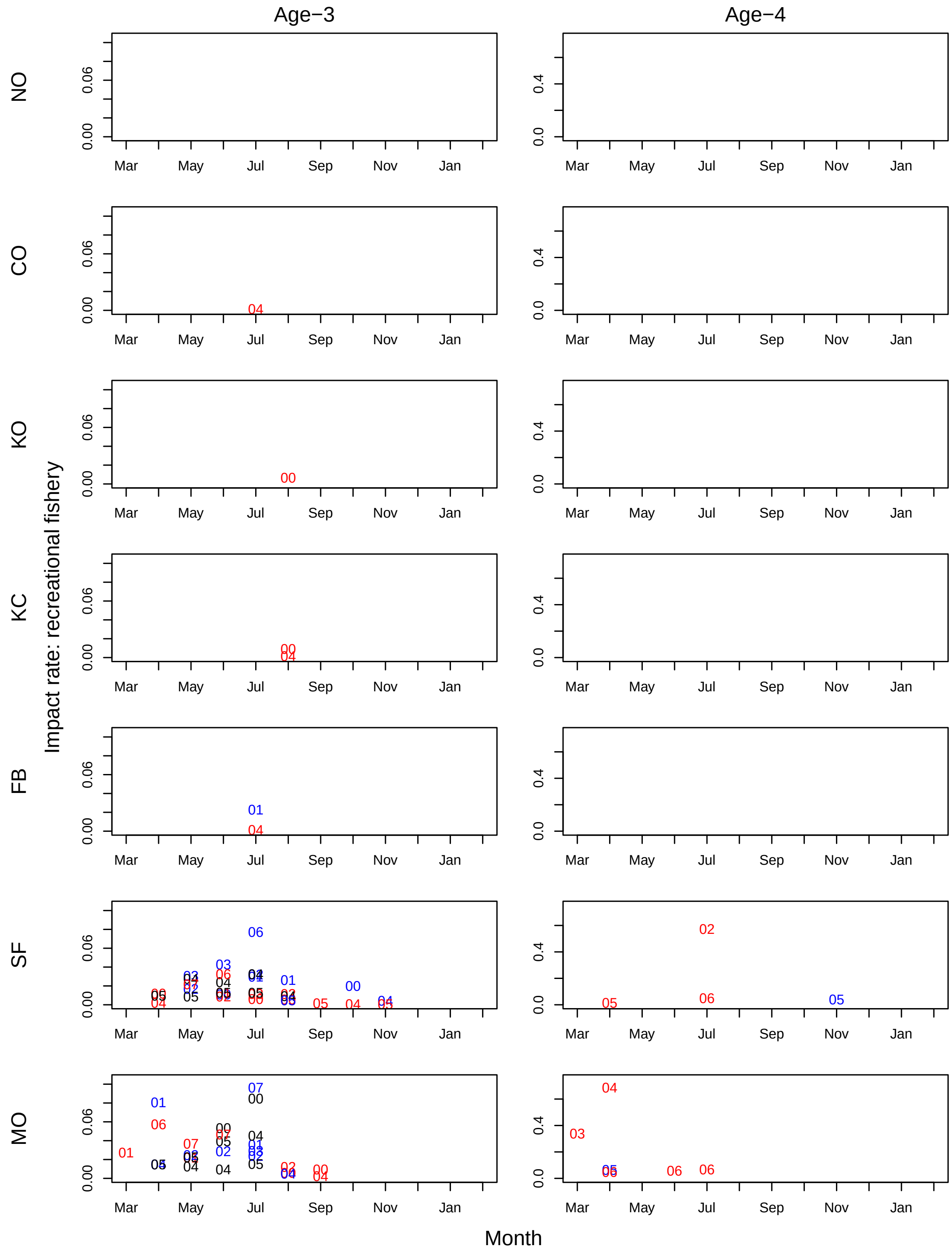

Figure 6. Recreational fishery impact rates for age-3 and age-4 Sacramento River winter Chinook, by month and management area, plotted for instances when rates are nonzero. Two-digit values in plots represent calendar years. Red text indicates that the impact rate estimate is the result of one coded wire tag (CWT) recovery. Blue represents two–five CWT recoveries. Black indicates greater than five CWT recoveries contributed to the estimate.

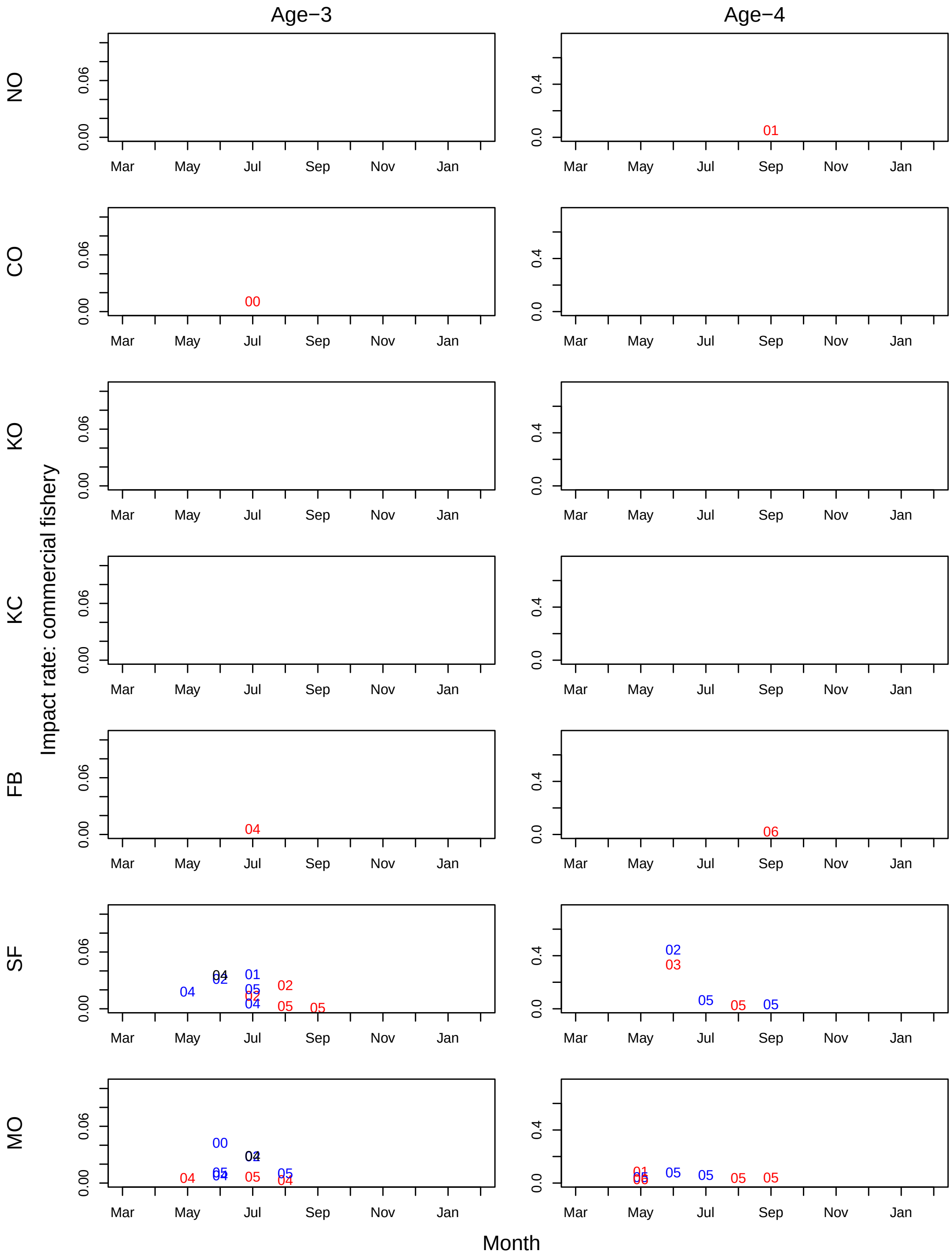

Figure 7. Commercial fishery impact rates for age-3 and age-4 Sacramento River winter Chinook, by month and management area, plotted for instances when rates are nonzero. Two-digit values in plots represent calendar years. Red text indicates that the impact rate estimate is the result of one coded wire tag (CWT) recovery. Blue represents two–five CWT recoveries. Black indicates greater than five CWT recoveries contributed to the estimate.

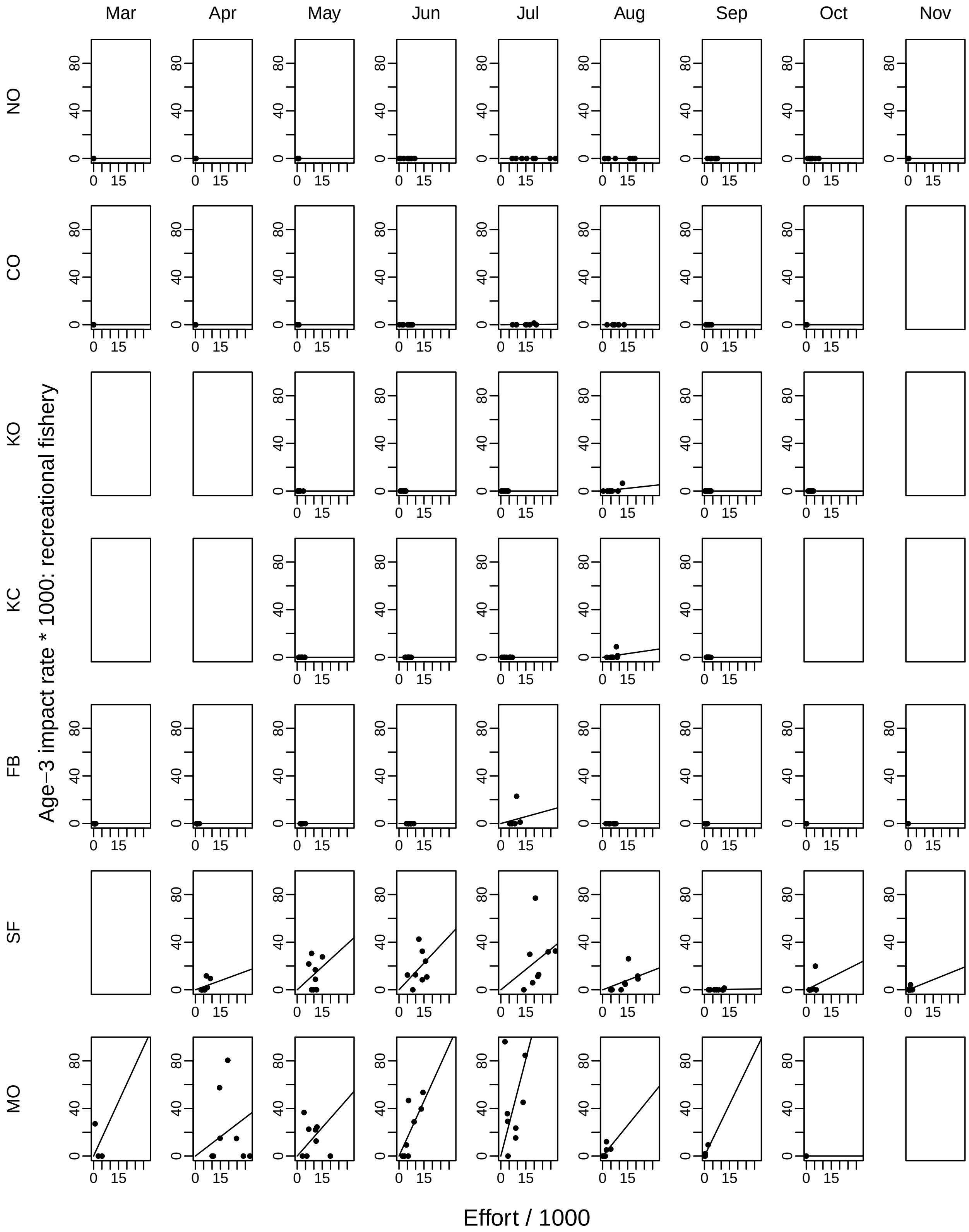

Figure 8. Recreational fishery age-3 impact rates, plotted as a function of fishing effort, by month and management area. Each point represents one year of estimates.

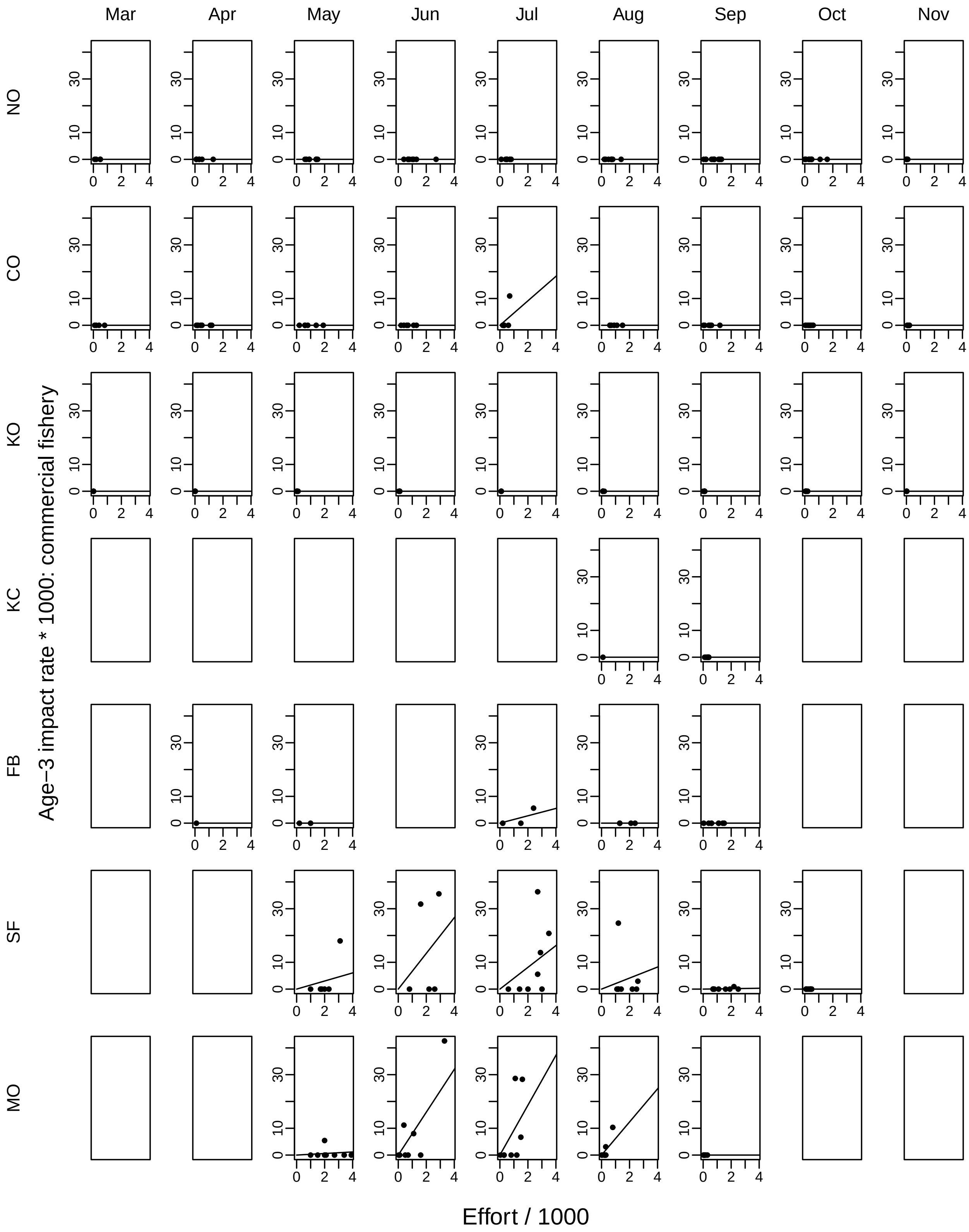

Figure 9. Commercial fishery age-3 impact rates, plotted as a function of fishing effort, by month and management area. Each point represents one year of estimates.

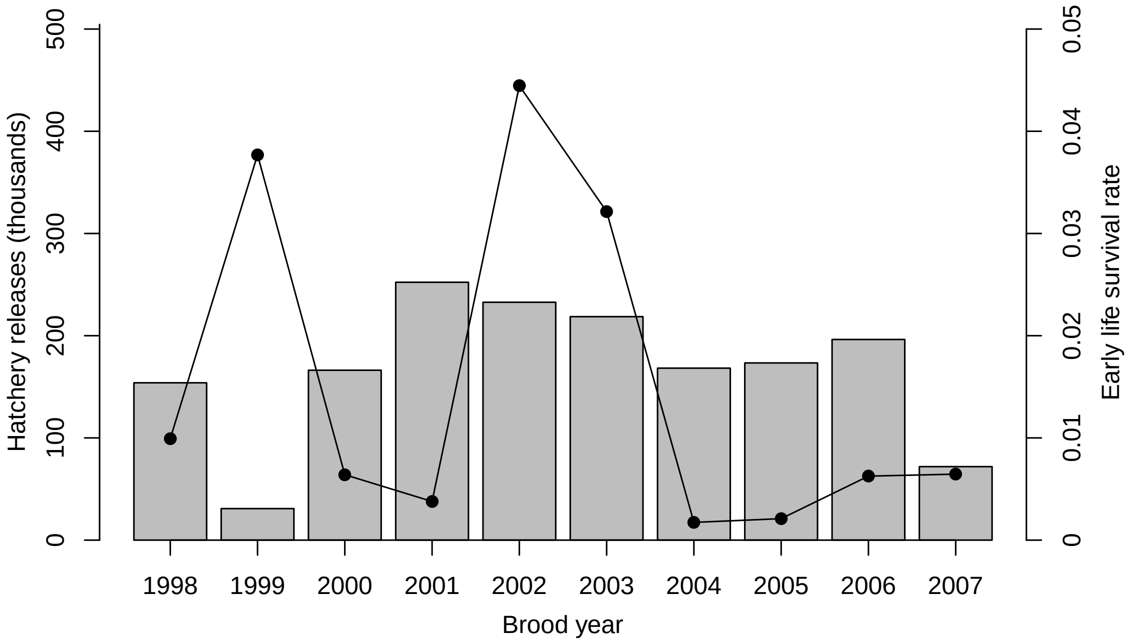

Figure 10. The number of Sacramento River winter Chinook released from the hatchery (bars) and the early life survival rate (line) for brood years 1998–2007.

early life survival, and the number of SRWC released from the hatchery, are presented in Figure 10. With the exception of brood years 1999 and 2007, hatchery release numbers have been fairly consistent. Conversely, early life survival estimates have varied considerably. The highest survival rates occurred for brood years 1999, 2002, and 2003. The relatively high survival rates for the 2002 and 2003 broods coincided with relatively high levels of hatchery releases. These broods in turn incurred the relatively high age-3 ocean impacts observed in 2004 and 2005 (Figure 1). These results suggest that the relatively high age-3 impacts observed in 2004 and 2005 were the result of relatively good early life survival and slightly higher than average hatchery releases, since the age-3 ocean fishery impact rate varied little over the 2000–2007 period (Figure 4).

5 Discussion

The estimation of hatchery-origin SRWC harvest and impacts for brood years 1998–2007 allows for comparison of harvest estimates made at various times since brood year 1969. Furthermore, cohort reconstructions and the estimates of maturation rates, the SRR, and ocean fishery impact rates derived from these reconstructions can be compared to estimates derived from the prior cohort analysis performed in support of the 2004 Biological Opinion (Grover et al. 2004).

With the exception of the 2004 cohort reconstructions completed for brood years 1998–2000, past work using ocean fishery data has focused on the estimation of SRWC ocean harvest by time and area. Figure 11 displays ocean harvest estimates by month for (a) fin-clipped marked SRWC from the pooled 1969–1970 broods (b) tagged SRWC from CNFH in pooled brood years 1991–1995, and (c) the hatchery-origin harvest of pooled brood years 1998–2007 considered in this report. Examination of estimates from the three time periods allows for some inference regarding the effect that ocean fishery regulations have had on the SRWC stock. Recreational ocean fisheries that contacted the 1969–1970 cohorts opened in mid February in areas south of Point Arena. The relatively high marked SRWC ocean harvest estimates from February and March (28% of the total estimated harvest) noted for these broods was largely absent in the harvest estimates for broods 1991–1995 and 1998–2007, owing to regulatory measures requiring salmon fisheries south of Point Arena to be closed for much of February and March for the express purpose of protecting SRWC. Since 2004, the recreational fishery south of Point Arena has been closed the entire month of February and March. As a result, the small or nonexistent recent estimates of harvest in February and March are reflective of regulations that have constrained the fisheries in these months. Given the SRWC run timing, with peak returns of mature adults to the river mouth in March, and the temporal distribution of harvest estimates from the 1969–1970 broods, it would be reasonable to expect that SRWC fishery impacts would be significant in February and March if fisheries were again allowed during that time frame.

For SRWC, the pattern of ocean fishery impacts, the SRR, impact rates, and maturation rates has maintained a consistent pattern. Ocean impacts are dominated by age-3, are taken primarily in the recreational fishery, and are nearly all the result of fisheries in areas south of Point Arena. The SRR and the age-3 annual impact rate have been consistent with each other and have ranged from approximately 10% to 28%. One reason for the consistency between the SRR and the age-3 impact rate is the high ($>$ 85%) and stable age-3 maturation rate. The bulk of the CWT recoveries that contributed to impact rate estimates were recovered in MO and SF, from April–July, and in

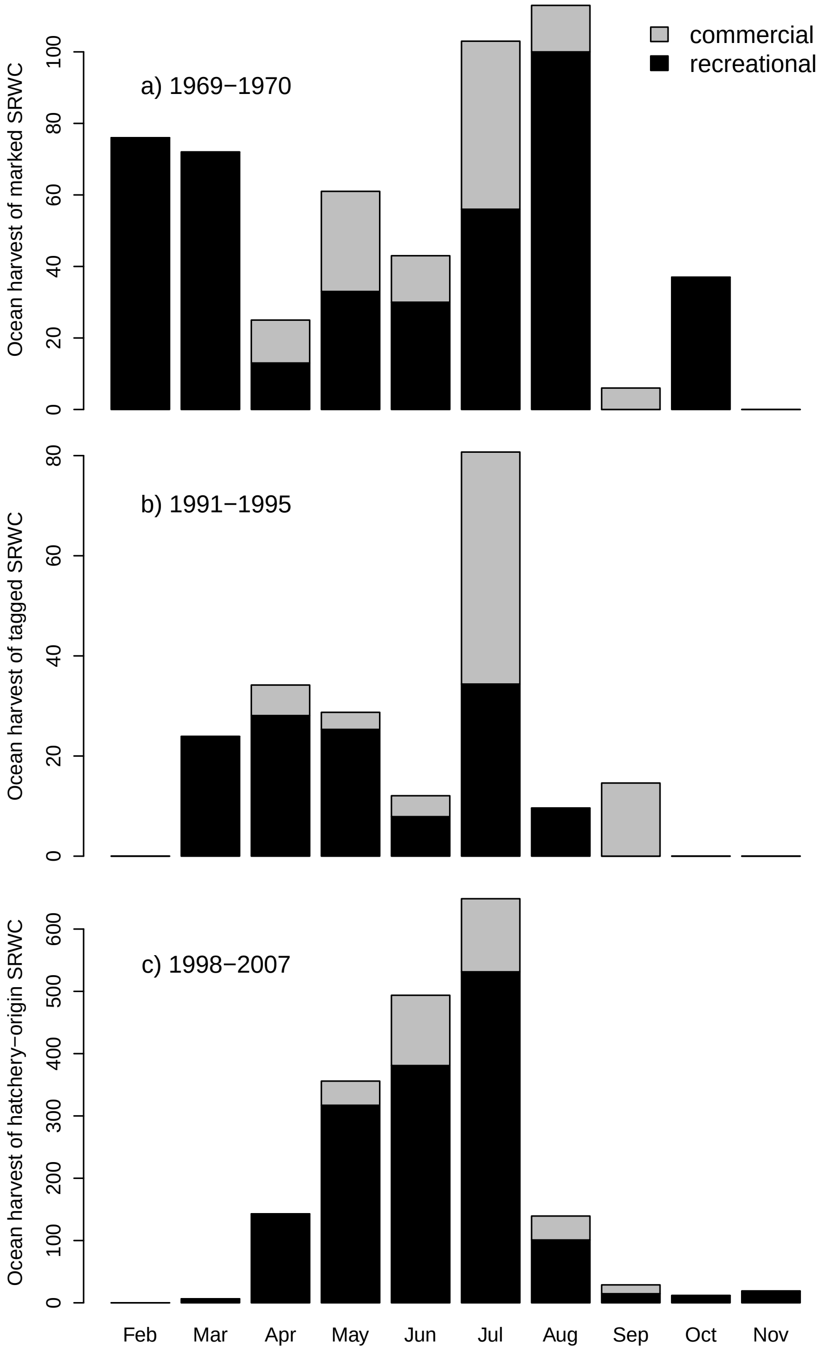

Figure 11. Estimated harvest of a) marked SRWC from pooled brood years 1969–1970, b) coded wire tagged SRWC from pooled brood years 1991–1995, and c) hatchery-origin SRWC from pooled brood years 1998–2007.

the recreational fishery. Fewer CWTs were recovered for age-4 and the commercial fishery. In particular, very few CWTs were recovered in ocean management areas north of Point Arena. All of these results are consistent with those presented in the Grover et al. (2004) report for a subset of the brood years considered here.

One weakness of using fishery-dependent CWT data for cohort analysis is that impacts on tagged fish may be underestimated for subsets of the population that are not retained in fisheries. This is the case for age-2 SRWC, which are too small to be retained in salmon fisheries with minimum size limits, yet may incur release and dropoff mortality. The data available do not allow for quantification of the magnitude of these mortalities. However, we note that errors in fishing impacts on age-2 would only affect the estimate of the SRR and the age-2 maturation rate. Age-3 and 4 impact and maturation rates would not be affected by additional age-2 mortality than what is accounted for herein.

Figure 1 in this report demonstrates that age-3 fishery impacts for hatchery-origin SRWC were much greater in calendar years 2004 and 2005 relative to other years, and these relatively high levels of impacts were observed in 2005 and 2006 for age-4. Coupling this information with the results presented in Figure 10 suggests that pre-fishing recruitment of the 2002 and 2003 hatchery-origin broods was relatively strong, and that this resulted from normal to high levels of hatchery releases and relatively high early life survival rates. The strength of these broods was clearly apparent in the associated estimates of ocean impacts and spawning escapement. Similarly, for the SRWC stock composite (hatchery- and natural-origin), the two highest spawner escapement estimates over the analysis period were in 2005 and 2006 (Figure 12), corresponding primarily to brood years 2002 and 2003, respectively. Together, these results suggest that early life survival (pre-fishery) plays a strong role in determining SRWC realized ocean abundance, ocean fishery impacts, and spawning escapement.

Spawner escapement of SRWC has experienced a precipitous decline, very low abundances, and more recently, a modest increase and subsequent decline (Figure 12). During the period of steep declines (1970 through the early 1980s) it was likely that ocean fishery impact rates were higher than they were after the early 1990s because recreational fishing seasons commenced in

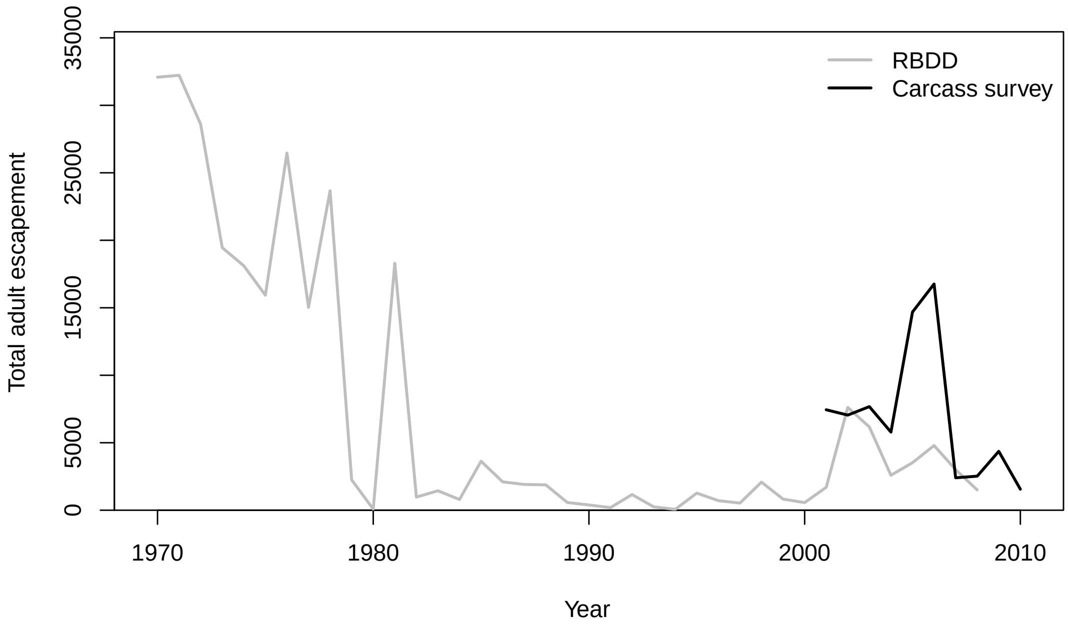

Figure 12. Escapement of combined natural and hatchery-origin adult Sacramento River winter Chinook. The grey line represents estimates based on counts at Red Bluff Diversion Dam (RBDD). The black line represents estimates based on the carcass survey. Carcass survey escapement estimates are considered to be of higher quality than RBDD estimates and are used to determine the "official" SRWC escapement.

February, when impacts would likely be high. During the end of the period with very low escapement (the 1990s) fisheries began to be contracted, with little to no recreational fishing occurring in SF and MO in February or March and restrictions on commercial fisheries owing to conservation concerns for other stocks. In the time since 2000, the period for which this cohort analysis has estimated exploitation rates, escapement has generally increased, with the exception of very recent years. This modest increase has occurred as SRRs have remained relatively stable. Finally, commercial and recreational fishing was closed in the SF and MO areas in 2008 and 2009, hence spawners in 2009 and 2010 were exposed to little or no fishing mortality. Despite fisheries closures, the spawner escapement has decreased in recent years relative to the early to mid 2000s. In sum, recent increases in escapement have occurred under a "typical" modern level of fishing, while the very recent decreases in escapement have occurred in spite of the closure of all salmon fisheries that typically contact SRWC.

Hatchery-origin SRWC make up a very small portion of the ocean salmon harvest off California and Oregon. Were it not for the 100% marking and tagging of LSNFH production, coupled with the ocean fishery and river escapement sampling programs' practice of processing the heads of all observed adipose fin clipped salmon for CWT extraction and decoding, it would not have been possible to conduct the cohort analyses described in this report—the recovery of SRWC CWTs would simply be too rare to support meaningful analysis and inference. Because of these programs, in core month and area strata, SRWC ocean fishery impact rate estimates based on multiple tag recoveries are common (e.g., see Figure 6). Tag recoveries are less frequent when ocean abundance of the hatchery-origin stock is low (such as for age-4) or outside of the core distribution of the stock (i.e., north of Point Arena). The raw CWT recovery pattern observed for SRWC imparts confidence in our core estimates.

6 Conclusions

Based on the results developed here, and those derived from earlier studies, we identify the following conclusions.

1. Cohort analysis results suggest stability in the SRR and ocean fishery impact rate estimates by management area, month, and fishery.

2. Changes in ocean fishing regulations that have limited or eliminated February and March recreational fisheries south of Point Arena, California, have likely been effective in reducing SRWC impacts. The estimates for marked SRWC from the pooled 1969–1970 broods approximate the temporal distribution of harvest that would be expected without these restrictions.

3. Early life survival (pre-fishery) plays a strong role in determining SRWC realized ocean abundance, ocean fishery impacts, and spawning escapement.

4. Recent increases, and subsequent declines, in SRWC adult escapement since 2000 cannot be readily explained by trends in ocean fishery exploitation rates.

5. Current SRWC tagging/marking and monitoring programs should be continued so that future updates of the cohort analysis can be made as these data accumulate. In particular, the collection of heads for CWT recovery from all adipose fin clipped salmon in ocean and river sampling programs should continue to receive high priority. Without such data and analysis, it is impossible to provide a direct estimate of the realized impacts of ocean salmon fisheries on SRWC.

7 Acknowledgements

We wish to acknowledge all those who contributed to the collection of the data used here in both ocean and river monitoring programs. In particular, thanks go to Melodie Palmer-Zwahlen (CDFG) for assistance with ocean CWT data. We sincerely thank Kevin Offill (USFWS) and Doug Killam (CDFG) for answering our questions about the SRWC escapement carcass survey, and for readily providing the data necessary for us to develop estimates of the effective sampling fraction for the survey's CWT recoveries. Our cohort reconstruction work would not have been possible without their cooperation and contribution. Finally, we thank three reviewers from the Center for Independent Experts (Mike Bradford, Marc Labelle, and David Levy) for their thoughtful comments on a previous version of this report.

References

Bolker, B. (2010). *bbmle: Tools for general maximum likelihood estimation.* R package version 0.9.5.1.

CDFG (1989). Description of the Winter Chinook Ocean Harvest Model. Unpublished report. Ocean Salmon Project, California Department of Fish and Game.

Fisher, F. W. (1994). Past and present status of Central Valley Chinook salmon. *Conservation Biology 8*, 870–873.

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. M., A. Low, P. Ward, J. Smith, M. Mohr, D. Viele, and C. Tracy (2004). Recommendations for developing fishery management plan conservation objectives for Sacramento River winter Chinook and Sacramento River spring Chinook. Unpublished Progress Report.

Grover, A. M., M. S. Mohr, and M. L. Palmer-Zwahlen (2002). Hook-and-release mortality of Chinook salmon from drift mooching with circle hooks: management implications for California's ocean sport fishery. In J. A. Lucy and A. L. Studholme (Eds.), *Catch and release in marine recreational fisheries*, pp. 39–53. American Fisheries Society, Bethesda, Maryland.

Healey, M. C. (1991). Life history of chinook salmon *Oncorhynchus tshawytscha*. In C. Groot and L. Margolis (Eds.), *Pacific salmon life histories*, pp. 311–391. UBC Press, Vancouver.

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.

Morita, K., S. H. Morita, M. Fukuwaka, and H. Matsuda (2005). Rule of age and size at maturity of chum salmon (*Oncorhynchus keta*): implications of recent trends among *Oncorhynchus* spp.

Canadian Journal of Fisheries and Aquatic Sciences 62, 2752–2759.

PFMC (2011). Review of 2010 ocean salmon fisheries. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

R Development Core Team (2011). *R: A Language and Environment for Statistical Computing*. Vienna, Austria: R Foundation for Statistical Computing. ISBN 3-900051-07-0.

STT (2000). STT recommendations for hooking mortality rates in 2000 recreational ocean Chinook and coho fisheries. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

USFWS (2008). Upper Sacramento River winter Chinook salmon carcass survey. U.S. Fish and Wildlife Service Report, Red Bluff, CA.

Appendix A Proportion legal size

A.1 Introduction

Most ocean salmon fisheries have a minimum size (length) limit provision. Salmon below this minimum size limit must be released while salmon larger than the limit can be retained for harvest. Data on the number of released fish are generally not available, particularly at the individual stock level, yet this information is needed to account for all sources of mortality since some released fish will die. To estimate the proportion of fish that were greater than or equal to the minimum legal size in each year, month, area, and fishery, we utilize a length-at-age model and the minimum size limit in place for that particular year/month/area/fishery.

Previous cohort reconstructions used a length-at-age model developed for this purpose by CDFG (1989). The model is age- and month-specific and was constructed by using adult river recoveries of fin-clipped broods (1969–1970) to estimate the mean length of age-2 and age-3 spawners, which was assumed to be representative of ocean fish as well. Linear interpolation of these ocean mean length-at-age "endpoints" was then used to derive mean length for the in-between months, with a further assumption that 50 percent of the annual increase in length-at-age occurs during the April–June period. Individual lengths-at-age were assumed to be normally distributed with a constant coefficient of variation which was estimated from adult river recoveries of Sacramento River fall Chinook CWT broods (1975–1978).

Since the time of the CDFG (1989) model formulation, a CWT program for Sacramento River winter Chinook has been established by Livingston Stone National Fish Hatchery. With these data we have developed a new length-at-age model for Sacramento River winter Chinook as described below.

A.2 Data

The RMPC database[2] was queried for all available Sacramento River winter Chinook CWT recoveries from recreational and commercial ocean fisheries off the coast of California and Oregon. Recoveries were screened to include only fish with a fork length measurement, and this yielded a dataset of 507 observations, of which 6 were in 1980 and the remainder spanned calendar years 1993–2007, with no recoveries in 1998. Recorded fork length (FL), measured in mm, was converted to total length (TL) in inches using the equation (M. Palmer-Zwahlen[3], personal communication, 2011)

$$TL = 1.04346 + (0.04096 \cdot FL), \tag{A-1}$$

and individual fish were assigned to management area based on the port of landing. The minimum size limit l^* associated with the year, month, area, and fishery in effect at the time of recovery was also determined for each fish. The ageing convention used for ocean recoveries was the same as that used in the cohort reconstruction, with a "birthday" of March 1 (age increments by one year on March 1). Finally, days-at-age of recoveries (number of days between recovery date and previous March 1) was calculated for each fish. No fish were recovered during the December–February period or exceeded four years of age.

Fisheries with minimum size limits provide a truncated sample of the ocean size distribution, and an analysis of size-at-age must take this truncation into account. Of the 507 fish in this dataset, 486 were at or above the legal size limit in effect at their time and place of capture. Our analysis was limited to these fish. However, we found that including fish as much as 0.5 inches below the minimum size limit (to account for possible measurement error) only changed our mean length estimates for March at each age by a maximum of 0.012 inches.

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[2] http://www.rmpc.org/

[3] Melodie Palmer-Zwahlen, CDFG, Ocean Salmon Project, 475 Aviation Blvd, Suite 130, Santa Rosa, CA, 95403.

A.3 Model

Our model assumes that length-at-age (l) on a particular day is normally distributed with mean μ, standard deviation σ, and probability density

$$f(l|\mu,\sigma) = \frac{1}{\sqrt{2\pi}\sigma} e^{-(l-\mu)^2/2\sigma^2}. \tag{A-2}$$

We further assumed a constant daily mean growth rate (g) and coefficient of variation $(CV = \sigma/\mu)$, so that at τ days-at-age the mean length and standard deviation in length are given by

$$\mu_{a,\tau} = \mu_{a,0} + g_a \cdot \tau, \tag{A-3}$$

$$\sigma_{a,\tau} = CV_a \cdot \mu_{a,\tau}, \tag{A-4}$$

where $\mu_{a,0}$ is the mean length of age-a fish on March 1 (day 0)[4]. This model was assumed to apply independently to age-3 and age-4 fish over the March–November period (the period for which CWT recovery data exist). For completeness, the above model was extended to the intervening age-3 December–February period by assuming a constant daily mean growth rate between these two mean "end points". We did not model age-4 length-at-age beyond the month of November (no CWT fish this old or older have been recovered).

Given this model, the proportion of fish-at-age greater than or equal to a particular minimum size limit (l^*) is

$$P\{l \geq l^*|\mu,\sigma\} = 1 - P\{l < l^*|\mu,\sigma\} = 1 - \int_{-\infty}^{l^*} f(l|\mu,\sigma)dl = 1 - \Phi(l^*|\mu,\sigma), \tag{A-5}$$

where $P\{A\}$ denotes the probability of event A, and $\Phi(\cdot)$ is the cumulative probability distribution function for the normal density $f(\cdot)$.

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[4] We increment the age on March 1 at 12:00 A.M., but set $\tau = 0$ at 12:00 P.M. (day midpoint) to better reflect the capture (recovery) process.

Table A-1. Maximum likelihood estimates for March–November length-at-age model parameters.

Age (a)	$\mu_{a,0}$	g_a	CV_a
3	20.2372	0.0355	0.0820
4	28.5064	0.0317	0.0868

A.4 Estimation

The parameters of the length-at-age model were estimated using the method of maximum likelihood. Because of the minimum size limit, the sampling density for the length-at-age of a recovery is truncated at l^*, and is therefore given by equation (A-2) normalized over the observable range (Goldwasser et al. 2001),

$$f(l|l \geq l^*, \mu, \sigma) = \frac{f(l|\mu,\sigma)}{P\{l \geq l^*|\mu,\sigma\}} = \frac{f(l|\mu,\sigma)}{1-\Phi(l^*|\mu,\sigma)}. \tag{A-6}$$

The likelihood function for each age ($\mathscr{L}_a$) is the joint density over the recoveries, viewed as a function of the parameters conditional on the data. For an individual recovery i the data are $\{l_i, l_i^*, \tau_i\}$ and the likelihood over the n_a recoveries is thus

$$\mathscr{L}_a(\mu_{a,0}, g_a, CV_a|\{l_i, l_i^*, \tau_i\}) = \prod_{i=1}^{n_a} f\left(l_i|l_i \geq l_i^*, [\mu_{a,0} + g_a \cdot \tau_i], CV_a[\mu_{a,0} + g_a \cdot \tau_i]\right). \tag{A-7}$$

The maximum likelihood estimates for age-a are those values of $\mu_{a,0}$, g_a, and CV_a that together maximize the $\mathscr{L}_a$ function. This was found numerically with the R (R Development Core Team 2011) statistical computing software using the functions "dnorm" to calculate $f(\cdot)$ and "pnorm" to calculate $\Phi(\cdot)$, respectively. Numerical optimization was performed using function "mle2" (Bolker 2010). The resulting parameter estimates are given in Table A-1, and the fitted model is displayed with the observations in Figure A-1.

For the age-3 December–February period, day-specific mean length was modeled by linearly

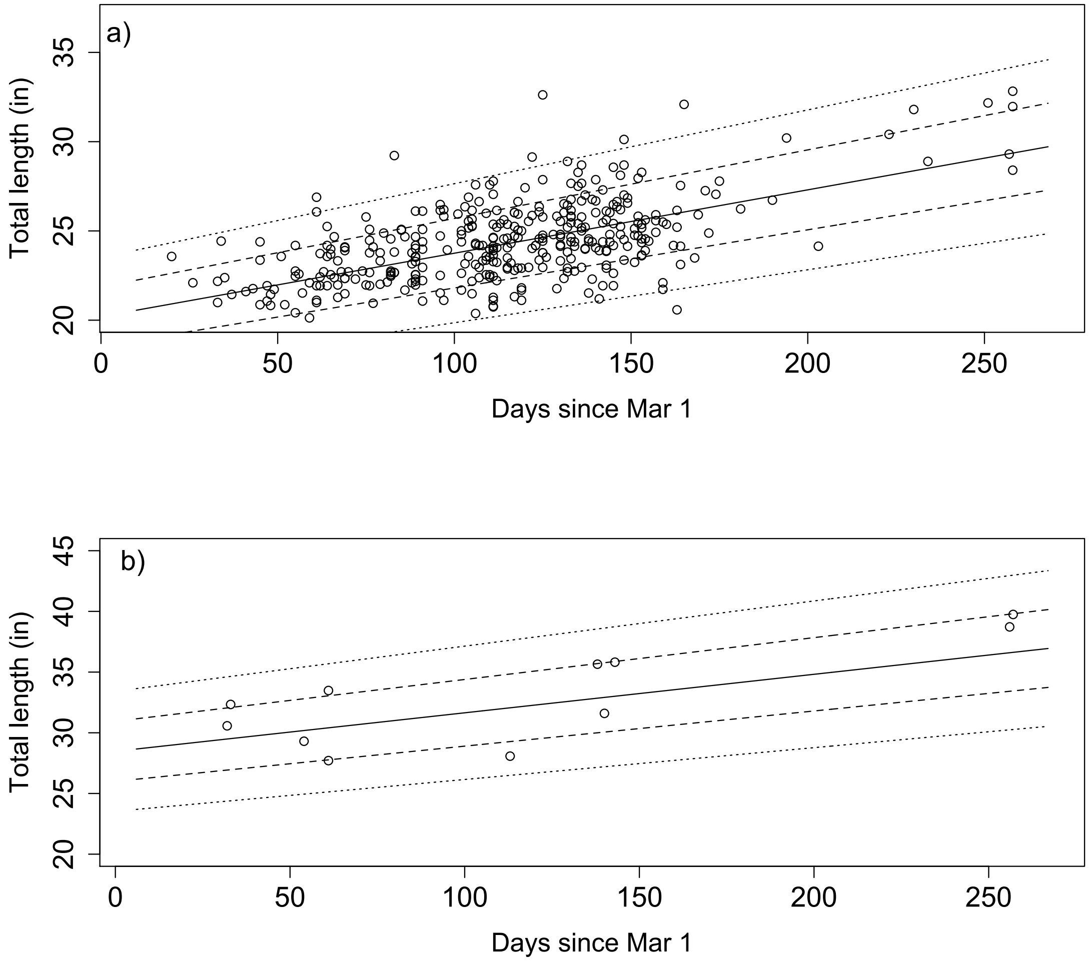

Figure A-1. Fitted March–November length-at-age model for a) age-3 and b) age-4 fish. Solid line is the estimated mean length-at-age; dashed lines represent one and two standard deviations from the mean. Only observations from fisheries with a 20 inch minimum size limit are shown for the clearest interpretation of model fit.

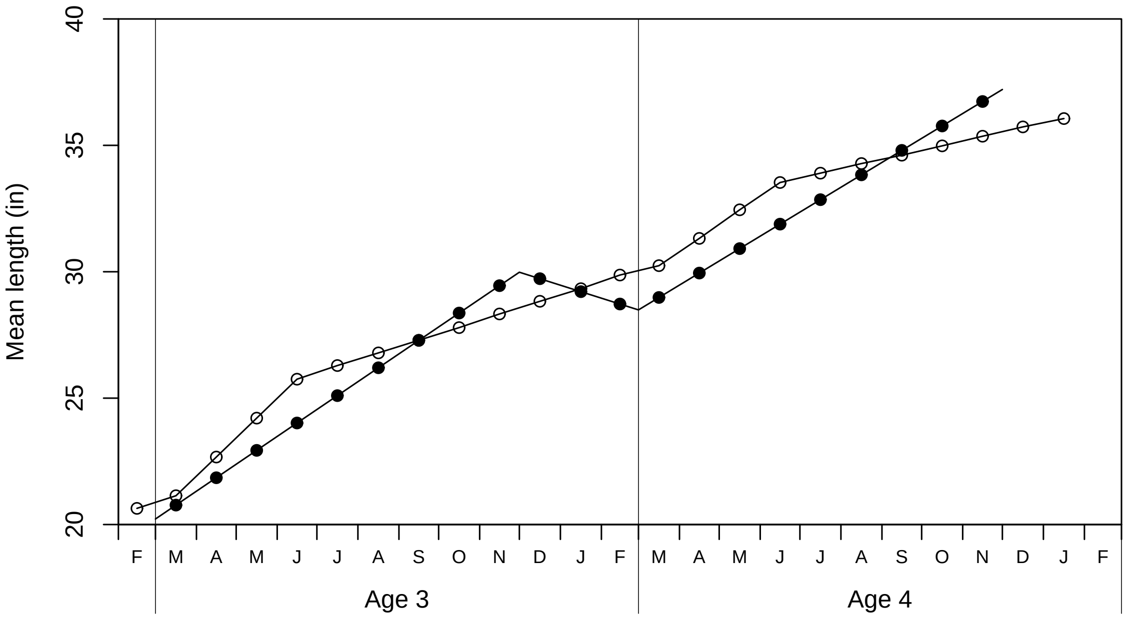

Figure A-2. Estimated mean length-at-age by our model (solid circles) and that specified by CDFG (open circles). For our model, the line traces the daily mean values and the solid circles are the midpoint values reported in Table A-2. For the CDFG model, the line connects their monthly mean values (CDFG 1989, Table 2) (open circles) plotted at the monthly midpoint.

interpolating between the December 1 and March 1 mean lengths[5]:

$$\mu_{3,\tau} = \mu_{3,\tau(\text{Dec 1})} + \left(\mu_{4,\tau(\text{Mar 1})} - \mu_{3,\tau(\text{Dec 1})}\right)\left(\frac{\tau - \tau(\text{Dec 1})}{\tau(\text{Mar 1}) - \tau(\text{Dec 1})}\right), \quad \tau(\text{Dec 1}) \leq \tau \leq \tau(\text{Mar 1}). \tag{A-8}$$

Figure A-2 displays our estimated mean length-at-age relationship for age-3 and age-4 fish, and the monthly midpoint values are listed in Table A-2 along with the corresponding standard deviation and proportion legal size, assuming minimum size limits typical for the recreational (≥ 20 inches, ≥ 24 inches) and commercial (≥ 26 inches) fisheries. For age-4 fish beyond November, and all older age fish, it is assumed that the proportion legal size equals one, noting that an estimated 99.69% of age-4 fish in November exceed 28 inches in total length.

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[5] (at 12:00 A.M.)

Table A-2. Length-at-age model and proportion legal size at the midpoint of each month (t) over the modeled period. Mean and standard deviation is for total length in inches. Proportion legal size was computed using equation (A-5). The 20 and 24 inch minimum size limits are typical for the recreational fishery, and the 26 inch minimum size limit is typical for the commercial fishery.

Age (a)	Month (t)	μ_{at}	σ_{at}	$P\{l \geq 20 \text{ in}\}$	$P\{l \geq 24 \text{ in}\}$	$P\{l \geq 26 \text{ in}\}$
3	Mar	20.7697	1.7029	0.67	0.03	0.00
3	Apr	21.8524	1.7917	0.85	0.12	0.01
3	May	22.9351	1.8804	0.94	0.29	0.05
3	Jun	24.0178	1.9692	0.98	0.50	0.16
3	Jul	25.1004	2.0580	0.99	0.70	0.33
3	Aug	26.2009	2.1482	1.00	0.85	0.54
3	Sep	27.2836	2.2370	1.00	0.93	0.72
3	Oct	28.3663	2.3257	1.00	0.97	0.85
3	Nov	29.4490	2.4145	1.00	0.99	0.92
3	Dec	29.7247	2.4371	1.00	0.99	0.94
3	Jan	29.2111	2.3950	1.00	0.99	0.91
3	Feb	28.7224	2.3549	1.00	0.98	0.88
4	Mar	28.9820	2.5155	1.00	0.98	0.88
4	Apr	29.9490	2.5994	1.00	0.99	0.94
4	May	30.9161	2.6834	1.00	1.00	0.97
4	Jun	31.8831	2.7673	1.00	1.00	0.98
4	Jul	32.8502	2.8512	1.00	1.00	0.99
4	Aug	33.8331	2.9366	1.00	1.00	1.00
4	Sep	34.8001	3.0205	1.00	1.00	1.00
4	Oct	35.7672	3.1044	1.00	1.00	1.00
4	Nov	36.7343	3.1884	1.00	1.00	1.00

A.5 Discussion

Recoveries were not equally distributed among months, with the majority occurring during the May–July period. While this period is the most important one to model for the purpose of cohort reconstruction (since it is when most harvest occurs), we explored the potential impacts of uneven temporal representation on the model parameter estimates for age-3 fish by fitting the model to bootstrapped replicate datasets consisting of: (a) 35 samples for each month April–August (all of which had at least 35 recoveries); and (b) five samples each month March–November (except for October, which had only three data points). In both cases, the March 1 length estimated by the complete dataset was close to the mode of the bootstrapped estimates. Fitting the April–August data implied slightly slower growth (with an approximate 0.7 inch difference by the end of November) than the full dataset, while fitting the data from March–November implied faster growth by a similar amount. Thus, our fit to the full dataset seems appropriate.

We evaluated alternate models of growth allowing for lognormally distributed individual lengths, exponential growth in length, or von Bertalanffy growth in length. However these alternative formulations did not substantially improve model fit (or decreased it in the case of von Bertalanffy) and yielded very similar predictions of the proportion of the population above minimum size limits for the various fisheries. There was little evidence for seasonal variation in growth rate (Figure A-1) and a comparison of size-at-age curves for other Central Valley Chinook runs (spring, fall, and late-fall) with more data available suggested that seasonal variation in size-at-age was mostly driven by the timing of return to freshwater by spawning adults. Apparent growth in mean size slows, stops, or even reverses during this period (as we found for winter Chinook, Figure A-2), likely owing to the preferential loss of large fish at age to spawning (Healey 1991; Morita et al. 2005). Thus the assumption of linear growth within age classes during the non-spawning period when the fishery is operational, and linear interpolation over the intervening period, is well supported.

Limited sample sizes and uneven temporal and spatial coverage limited our ability to model the effects of year or ocean management area. Had we been able to include such effects, we would likely have estimated slightly different means for each year/location, with a smaller standard deviation around that year/location's estimated mean. Thus in any one year, we might expect the standard deviation in length to be smaller than that implied by our model which excludes year or spatial effects. However, without an ability to predict the mean for a given year or location, our approach provides a simple method of averaging over our uncertainty about year and location effects. Inspection of data for other Chinook stocks did show a smaller mean size-at-age for fall and late-fall Chinook from the Central Valley during 1983, 1993, and 1998, which correspond to El Nino conditions in the ocean. Unfortunately, the SRWC CWT dataset does not include data from these years to allow for such a comparison.

Our fitted model of SRWC size-at-age was not radically different from CDFG (1989), but there were some small yet potentially important differences in estimated mean size, estimated variation in individual sizes, and resultant proportion of the population that can be legally retained. Our estimated mean lengths of age-3 fish in March were 0.37" smaller than CDFG's estimate, with the difference growing to 1.73" by June and then shrinking with our model predicting larger fish by October due to CDFG (1989)'s assumption that 50 percent of growth occurs between April and June. The assumption of accelerated growth in spring does not appear to be well supported for SRWC (see below). In addition, CDFG assumed a larger coefficient of variation in mean length (0.107, based on SRFC data) than we fit for either age-3 (0.082) or age-4 (0.087) SRWC.

These different predictions of size-at-age result in different calculations of the proportion legal and thus change our estimates of fishery impacts when taking non-landed mortalities into account. Fishery impacts on SRWC are most significant for age-3 fish in May, June, and July. Due to the larger mean and standard deviation in fish sizes predicted for this time period by the CDFG (1989) model, it would predict a larger fraction of fish can be retained than our model does (e.g., 46 percent of age-3 fish legal sized with a 26" limit in June compared to 16 percent predicted by our model). Differences are also pronounced for a 26" limit in May (24 percent vs. 5 percent) and July (54 percent vs. 33 percent). The smaller fraction legal predicted by our model suggests more non-landed mortality per sampled fish, and thus increases our estimated total impact of the fishery. Predicted differences in a 20" limit recreational fishery are smaller since most fish are of legal size for either model (e.g. 94 percent legal in May according to our model and 95 percent according to

CDFG, both models predict 99 percent or more legal by July and predictions for March and April also agree within 2 percent). However, when the recreational fishery size limit is 24”, the situation becomes more like the 26” size limit evaluated for the commercial fishery. For age-4 fish, either model predicts a large fraction legal (at least 97 percent for a 26” size limit by May).

Appendix B Carcass survey sample expansion factor: derivation

Formulas for determining the *effective sampling fraction* (λ) for carcass survey decoded recoveries, and its inverse the *sample expansion factor* ($1/\lambda$), are presented in this Appendix. The sampling fraction λ is specific to the natural area SRWC carcass survey (it does not pertain to fish caught in the Keswick fish trap and used for hatchery broodstock). The sampling fraction λ is also year-specific, but it is not age-specific, not CWT code-specific, and not stock-specific[6]. Table B-1 provides a list of the notation used in the development of the CWT expansion formulas presented in this section.

Table B-1. Notation used to derive carcass survey sample expansion factor.

Symbol	Definition
E	natural area escapement (SRWC + strays)
E_{cwt}	number of E with CWT
R	number of E_{cwt} recovered and CWT decoded
λ	effective sampling fraction for CWTs
$p_{\text{ad-clipped}}$	proportion of E that is adipose fin clipped
p_{cwt}	proportion of E with CWT
$p_{\text{cwt}\mid\text{ad-clipped}}$	proportion of E ad-clipped fish with CWT
n_{fresh}	number of fresh carcasses sampled in survey (SRWC + strays)
$n_{\text{fresh,ad-clipped}}$	number of n_{fresh} that are adipose fin clipped
$n_{\text{fresh,head-processed}}$	number of $n_{\text{fresh,ad-clipped}}$ heads processed for CWT detection
$n_{\text{fresh,cwt-detected}}$	number of $n_{\text{fresh,head-processed}}$ in which CWT was detected
$n_{\text{fresh,cwt-decoded}}$	number of $n_{\text{fresh,cwt-detected}}$ in which CWT was decoded

By definition, λ is equal to the number of decoded CWT sample recoveries divided by the

---

[6] Stray fall or late-fall CWT'd Chinook have occasionally (less than or equal to five per year) been recovered in the SRWC survey. These fish and their respective non-CWT counterparts are part of the overall pool of carcasses on which CWT recovery sampling is performed, and they are therefore included in the estimation of λ (as they are in the estimation of SRWC escapement).

number of CWT fish present in the escapement:

$$\lambda = R/E_{\text{cwt}}. \tag{B-1}$$

R is known from the survey, but E_{cwt} must be estimated and we do this by appealing to the product

$$E_{\text{cwt}} = E \times p_{\text{cwt}}, \tag{B-2}$$

where E is the natural area escapement, and p_{cwt} is the proportion of E that are CWT'd. For E we substitute the survey's Jolly-Seber estimate of overall natural area escapement. For p_{cwt}, because the probability of misclassification of ad-clipped status in a non-fresh carcass is appreciable (due to the carcass's deteriorated state), we restrict ourselves to the fresh carcass portion of the survey data and make the following three assumptions:

1. A fresh carcass that is adipose fin clipped (ad-clipped) may not have a CWT, but not vice-versa: a fresh carcass that has a CWT is ad-clipped. That is,

   $$P\{\text{CWT present} \mid \text{fresh, not ad-clipped}\} = 0,$$

   where $P\{A|B\}$ denotes the probability of event A given that event B occurs.

2. There is no misclassification of ad-clipped status for a sampled fresh carcass:

   $$P\{\text{classify carcass as ad-clipped} \mid \text{sampled, fresh, ad-clipped}\} = 1,$$
   $$P\{\text{classify carcass as not ad-clipped} \mid \text{sampled, fresh, not ad-clipped}\} = 1.$$

3. There is no CWT detection failure for a sampled fresh carcass whose head has been pro-

cessed for CWT recovery[7]:

$$P\{\text{CWT detected} \mid \text{sampled, fresh, head processed, CWT present}\} = 1.$$

We then re-express p_{cwt} as

$$p_{\text{cwt}} = p_{\text{ad-clipped}} \times p_{\text{cwt}|\text{ad-clipped}} \tag{B-3}$$

since $p_{\text{cwt}|\text{not ad-clipped}} = 0$ (assumption 1), and use the fresh carcass survey data to estimate these component proportions:

$$p_{\text{ad-clipped}} = \frac{n_{\text{fresh,ad-clipped}}}{n_{\text{fresh}}} \tag{B-4}$$

(assumption 2), and

$$p_{\text{cwt}|\text{ad-clipped}} = \frac{n_{\text{fresh,cwt-detected}}}{n_{\text{fresh,head-processed}}} \tag{B-5}$$

(assumption 3). In summary, equations (B-4) and (B-5) are used in (B-3) to estimate p_{cwt}, and this is multiplied by the Jolly-Seber estimate of natural area escapement E to estimate E_{cwt} (equation (B-2)), and λ is then estimated as R/E_{cwt} (equation (B-1)).

We note that while the non-fresh CWT decoded recoveries contribute to R, and hence the estimate of λ, the assumptions made above are not similarly required for the non-fresh portion of the survey data, in particular, assumptions 2 and 3. Thus, for sampled non-fresh carcasses, misclassification of ad-clipped status and CWT detection failure are not an issue with respect to the estimation of λ. Indeed, because it can be difficult to accurately determine whether a non-fresh carcass is ad-clipped, samplers are encouraged to collect heads for CWT processing from non-fresh carcasses considered to be “potentially” ad-clipped. The effect of this practice is to increase the magnitude of R which increases the effective sampling fraction λ, which in turn increases the precision of all cohort reconstruction derived quantities and estimates. This strategy implicitly assumes that the percent composition of CWT codes among fresh and non-fresh carcasses does not differ for the overall survey, but this is warranted given that all non-fresh carcasses were once

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[7] The head of a fresh carcass is collected for CWT processing if and only if the carcass is ad-clipped.

fresh carcasses and that sampling is conducted throughout the SRWC spawning period.

The derivation of λ could be simplified if we limited our analysis entirely to the fresh carcass portion of the survey results, i.e. by excluding the non-fresh carcass CWT recoveries. For a fresh carcass only analysis, the CWT effective sampling fraction is simply the fraction of the escapement examined after adjusting for the fraction of ad-clipped carcass heads not processed and the fraction of detected CWTs not decoded[8]:

$$\frac{n_{\text{fresh}}}{E} \times \frac{n_{\text{fresh,head-processed}}}{n_{\text{fresh,ad-clipped}}} \times \frac{n_{\text{fresh,cwt-decoded}}}{n_{\text{fresh,cwt-detected}}}.$$

While restricting the analysis to the fresh carcass only data would not inherently bias the analysis results, it would substantially reduce the precision of the analysis by reducing the CWT effective sampling fraction (by a factor of $n_{\text{fresh,cwt-decoded}}/R$).

---

[8] The formulation of λ previously provided reduces to this product for a fresh carcass only data set, with $R = n_{\text{fresh,cwt-decoded}}$.

Appendix C Carcass survey sample expansion factor: data and derived values

The U.S. Fish & Wildlife Service (USFWS) and California Department of Fish and Game (CDFG) have co-operatively performed the SRWC spawning escapement carcass survey since 1996. CDFG has primary responsibility for the collection of information relevant to the estimation of spawning escapement. USFWS has primary responsibility for the collection of information relevant to the estimation of temporal/spatial/gender/age/length/origin-composition of the escapement, which includes the collection and processing of heads from carcasses for CWT recovery. The spawning escapement estimates (E) reported in this Appendix were provided to us by CDFG (D. Killam[9], personal communication, 2011). All other data reported in this Appendix were provided to us by USFWS (K. Offill[10], personal communication, 2011).

Summary data for the 2001–2010 surveys and the estimates resulting from application of our Appendix B formulas are presented in Table C-0 below. While the estimated escapement ranged from approximately 1500 to 17200 fish over the 2001–2010 period, the CWT effective sampling fraction was fairly consistent over the period, ranging from approximately 0.34 to 0.49 (except for 2007 when it reached 0.63). CWT expansion factors range from approximately 1.6 to 3.4 over the period, which is rather remarkable given the scope and complexity of the SRWC carcass survey. We note that, had the analysis been restricted to fresh carcass CWT recoveries only, this would have reduced the CWT effective sampling fraction by a factor ranging from 0.49 to 0.75.

The basic data and calculations that result in the Table C-0 values are presented in sections C.1–C.10 of this Appendix for survey years 2001–2010, respectively. An electronic file[11]of the data and estimates reported in this Appendix is available from the authors of this report.

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[9] Doug Killam, CDFG, Red Bluff Field Office, P.O. Box 578, Red Bluff, CA, 96080.

[10] Kevin Offill, USFWS, Red Bluff Fish & Wildlife Office, 10950 Tyler Road, Red Bluff, CA, 96080

[11] SRWC.cwt.expansion.factors.NMFS.29jun2011.xls

Table C-0. Carcass survey CWT expansion summary data and results.

	Year									
Quantity	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
					Survey					
R	117	141	125	164	1266	767	66	46	115	95
E	8120	7360	8133	7784	15730	17197	2487	2725	4416	1533
n_{fresh}	2235	2021	2423	1621	4177	3083	785	547	802	472
$n_{\text{fresh,ad-clipped}}$	116	108	138	140	840	440	48	34	91	74
$n_{\text{fresh,head-processed}}$	113	106	138	139	832	437	48	34	91	73
$n_{\text{fresh,cwt-detected}}$	92	81	91	97	699	385	33	27	72	59
					Estimates					
$p_{\text{ad-clipped}}$	0.0519	0.0534	0.0570	0.0864	0.2011	0.1427	0.0611	0.0622	0.1135	0.1568
$p_{\text{cwt}\mid\text{ad-clipped}}$	0.8142	0.7642	0.6594	0.6978	0.8401	0.8810	0.6875	0.7941	0.7912	0.8082
p_{cwt}	0.0423	0.0408	0.0376	0.0603	0.1690	0.1257	0.0420	0.0494	0.0898	0.1267
E_{cwt}	343.1199	300.5484	305.4490	469.1425	2657.6475	2162.2760	104.5490	134.5064	396.4489	194.2500
λ	0.3410	0.4691	0.4092	0.3496	0.4764	0.3547	0.6313	0.3420	0.2901	0.4891
$1/\lambda$	2.9326	2.1315	2.4436	2.8606	2.0992	2.8191	1.5841	2.9241	3.4474	2.0447

C.1 2001 survey: basic data and calculations

Table C-1. Carcass survey CWT expansion basic data, 2001 (source: USFWS).

Gender	Carcass condition	Adipose fin	Head not taken	Head taken, but not processed or lost	Head processed, but CWT not detected	CWT detected, but not extracted or lost	CWT extracted, but unreadable	CWT decoded, SRWC	CWT decoded, not SRWC	Total
Female	Fresh	Hatchery	0	1	15	3	0	43	0	62
Female	Fresh	Unknown	0	0	0	0	0	0	0	0
Female	Non-fresh	Hatchery	0	1	6	0	0	14	0	21
Female	Non-fresh	Unknown	6	0	0	0	0	0	0	6
Female	Unknown	Hatchery	0	0	0	0	0	1	0	1
Female	Unknown	Unknown	0	0	0	0	0	0	0	0
Male	Fresh	Hatchery	0	0	6	1	0	44	0	51
Male	Fresh	Unknown	1	0	0	0	0	0	0	1
Male	Non-fresh	Hatchery	0	0	4	1	0	10	0	15
Male	Non-fresh	Unknown	0	0	0	0	0	0	0	0
Male	Unknown	Hatchery	0	0	0	0	0	1	0	1
Male	Unknown	Unknown	0	0	0	0	0	0	0	0
Unknown	Fresh	Hatchery	0	0	0	0	0	1	0	1
Unknown	Fresh	Unknown	1	0	0	0	0	0	0	1
Unknown	Non-fresh	Hatchery	0	0	0	0	0	0	0	0
Unknown	Non-fresh	Unknown	0	0	0	0	0	0	0	0
Unknown	Unknown	Hatchery	0	0	0	0	0	3	0	3
Unknown	Unknown	Unknown	0	0	0	0	0	0	0	0
Total			8	2	31	5	0	117	0	163
	Fresh		2	1	21	4	0	88	0	116

Survey

$$
\begin{aligned}
R &= (\textit{Total}\text{: CWT decoded, SRWC}) + (\textit{Total}\text{: CWT decoded, not SRWC}) \\
&= 117 + 0 = 117 \\
E &= 8120 \quad \text{(source: CDFG)} \\
n_{\text{fresh}} &= 2235 \quad \text{(source: USFWS)} \\
n_{\text{fresh,ad-clipped}} &= (\textit{Fresh}\text{: Total}) \\
&= 116 \\
n_{\text{fresh,head-processed}} &= n_{\text{fresh,ad-clipped}} - (\textit{Fresh}\text{: Head not taken}) - (\textit{Fresh}\text{: Head taken, but not processed or lost}) \\
&= 116 - 2 - 1 = 113 \\
n_{\text{fresh,cwt-detected}} &= n_{\text{fresh,head-processed}} - (\textit{Fresh}\text{: Head processed, but CWT not detected}) \\
&= 113 - 21 = 92
\end{aligned}
$$

Estimates

$$
\begin{aligned}
p_{\text{ad-clipped}} &= n_{\text{fresh,ad-clipped}} / n_{\text{fresh}} = 0.0519 \\
p_{\text{cwt|ad-clipped}} &= n_{\text{fresh,cwt-detected}} / n_{\text{fresh,head-processed}} = 0.8142 \\
p_{\text{cwt}} &= p_{\text{ad-clipped}} \times p_{\text{cwt|ad-clipped}} = 0.0423 \\
E_{\text{cwt}} &= E \times p_{\text{cwt}} = 343.1199 \\
\lambda &= R / E_{\text{cwt}} = 0.3410 \\
1/\lambda &= 2.9326
\end{aligned}
$$

C.2 2002 survey: basic data and calculations

Table C-2. Carcass survey CWT expansion basic data, 2002 (source: USFWS).

Gender	Carcass condition	Adipose fin	Head not taken	Head taken, but not processed or lost	Head processed, but CWT not detected	CWT detected, but not extracted or lost	CWT extracted, but unreadable	CWT decoded, SRWC	CWT decoded, not SRWC	Total
Female	Fresh	Hatchery	0	0	18	5	0	57	1	81
Female	Fresh	Unknown	0	0	1	0	0	1	0	2
Female	Non-fresh	Hatchery	0	0	32	0	0	60	0	92
Female	Non-fresh	Unknown	0	0	1	0	0	0	0	1
Female	Unknown	Hatchery	0	0	0	0	0	2	0	2
Female	Unknown	Unknown	0	0	0	0	0	0	0	0
Male	Fresh	Hatchery	0	0	5	2	0	15	0	22
Male	Fresh	Unknown	0	0	1	0	0	0	0	1
Male	Non-fresh	Hatchery	0	0	1	0	0	4	0	5
Male	Non-fresh	Unknown	0	0	1	0	0	1	0	2
Male	Unknown	Hatchery	0	0	0	0	0	0	0	0
Male	Unknown	Unknown	0	0	0	0	0	0	0	0
Unknown	Fresh	Hatchery	0	0	0	0	0	0	0	0
Unknown	Fresh	Unknown	0	2	0	0	0	0	0	2
Unknown	Non-fresh	Hatchery	0	0	0	0	0	0	0	0
Unknown	Non-fresh	Unknown	0	0	0	0	0	0	0	0
Unknown	Unknown	Hatchery	0	0	0	0	0	0	0	0
Unknown	Unknown	Unknown	0	0	0	0	0	0	0	0
Total			0	2	60	7	0	140	1	210
	Fresh		0	2	25	7	0	73	1	108

Survey

$$\begin{aligned} R &= (\textit{Total}\text{: CWT decoded, SRWC}) + (\textit{Total}\text{: CWT decoded, not SRWC}) \\ &= 140 + 1 = 141 \end{aligned}$$

$$E = 7360 \quad \text{(source: CDFG)}$$

$$n_{\text{fresh}} = 2021 \quad \text{(source: USFWS)}$$

$$\begin{aligned} n_{\text{fresh,ad-clipped}} &= (\textit{Fresh}\text{: Total}) \\ &= 108 \end{aligned}$$

$$\begin{aligned} n_{\text{fresh,head-processed}} &= n_{\text{fresh,ad-clipped}} - (\textit{Fresh}\text{: Head not taken}) - (\textit{Fresh}\text{: Head taken, but not processed or lost}) \\ &= 108 - 0 - 2 = 106 \end{aligned}$$

$$\begin{aligned} n_{\text{fresh,cwt-detected}} &= n_{\text{fresh,head-processed}} - (\textit{Fresh}\text{: Head processed, but CWT not detected}) \\ &= 106 - 25 = 81 \end{aligned}$$

Estimates

$$p_{\text{ad-clipped}} = n_{\text{fresh,ad-clipped}} / n_{\text{fresh}} = 0.0534$$

$$p_{\text{cwt}|\text{ad-clipped}} = n_{\text{fresh,cwt-detected}} / n_{\text{fresh,head-processed}} = 0.7642$$

$$p_{\text{cwt}} = p_{\text{ad-clipped}} \times p_{\text{cwt}|\text{ad-clipped}} = 0.0408$$

$$E_{\text{cwt}} = E \times p_{\text{cwt}} = 300.5484$$

$$\lambda = R / E_{\text{cwt}} = 0.4691$$

$$1/\lambda = 2.1315$$

C.3 2003 survey: basic data and calculations

Table C-3. Carcass survey CWT expansion basic data, 2003 (source: USFWS).

Gender	Carcass condition	Adipose fin	Head not taken	Head taken, but not processed or lost	Head processed, but CWT not detected	CWT detected, but not extracted or lost	CWT extracted, but unreadable	CWT decoded, SRWC	CWT decoded, not SRWC	Total
Female	Fresh	Hatchery	0	0	26	0	6	65	0	97
Female	Fresh	Unknown	0	0	16	0	0	1	0	17
Female	Non-fresh	Hatchery	0	0	17	0	2	32	0	51
Female	Non-fresh	Unknown	0	0	10	0	0	3	0	13
Female	Unknown	Hatchery	0	0	0	0	0	0	0	0
Female	Unknown	Unknown	0	0	0	0	0	0	0	0
Male	Fresh	Hatchery	0	0	4	0	1	18	0	23
Male	Fresh	Unknown	0	0	1	0	0	0	0	1
Male	Non-fresh	Hatchery	0	0	1	0	0	5	0	6
Male	Non-fresh	Unknown	0	0	1	0	0	1	0	2
Male	Unknown	Hatchery	0	0	0	0	0	0	0	0
Male	Unknown	Unknown	0	0	0	0	0	0	0	0
Unknown	Fresh	Hatchery	0	0	0	0	0	0	0	0
Unknown	Fresh	Unknown	0	0	0	0	0	0	0	0
Unknown	Non-fresh	Hatchery	0	0	0	0	0	0	0	0
Unknown	Non-fresh	Unknown	0	0	0	0	0	0	0	0
Unknown	Unknown	Hatchery	0	0	0	0	0	0	0	0
Unknown	Unknown	Unknown	0	0	0	0	0	0	0	0
Total			0	0	76	0	9	125	0	210
	Fresh		0	0	47	0	7	84	0	138

Survey

$$\begin{aligned}
R &= (\textit{Total}\text{: CWT decoded, SRWC}) + (\textit{Total}\text{: CWT decoded, not SRWC}) \\
&= 125 + 0 = 125 \\
E &= 8133 \quad \text{(source: CDFG)} \\
n_{\text{fresh}} &= 2423 \quad \text{(source: USFWS)} \\
n_{\text{fresh,ad-clipped}} &= (\textit{Fresh}\text{: Total}) \\
&= 138 \\
n_{\text{fresh,head-processed}} &= n_{\text{fresh,ad-clipped}} - (\textit{Fresh}\text{: Head not taken}) - (\textit{Fresh}\text{: Head taken, but not processed or lost}) \\
&= 138 - 0 - 0 = 138 \\
n_{\text{fresh,cwt-detected}} &= n_{\text{fresh,head-processed}} - (\textit{Fresh}\text{: Head processed, but CWT not detected}) \\
&= 138 - 47 = 91
\end{aligned}$$

Estimates

$$\begin{aligned}
p_{\text{ad-clipped}} &= n_{\text{fresh,ad-clipped}} / n_{\text{fresh}} = 0.0570 \\
p_{\text{cwt}|\text{ad-clipped}} &= n_{\text{fresh,cwt-detected}} / n_{\text{fresh,head-processed}} = 0.6594 \\
p_{\text{cwt}} &= p_{\text{ad-clipped}} \times p_{\text{cwt}|\text{ad-clipped}} = 0.0376 \\
E_{\text{cwt}} &= E \times p_{\text{cwt}} = 305.4490 \\
\lambda &= R / E_{\text{cwt}} = 0.4092 \\
1/\lambda &= 2.4436
\end{aligned}$$

C.4 2004 survey: basic data and calculations

Table C-4. Carcass survey CWT expansion basic data, 2004 (source: USFWS).

Gender	Carcass condition	Adipose fin	Head not taken	Head taken, but not processed or lost	Head processed, but CWT not detected	CWT detected, but not extracted or lost	CWT extracted, but unreadable	CWT decoded, SRWC	CWT decoded, not SRWC	Total
Female	Fresh	Hatchery	0	0	22	0	1	51	1	75
Female	Fresh	Unknown	0	0	7	0	0	0	0	7
Female	Non-fresh	Hatchery	0	0	19	0	3	34	0	56
Female	Non-fresh	Unknown	0	0	8	0	0	2	0	10
Female	Unknown	Hatchery	0	0	0	0	0	1	0	1
Female	Unknown	Unknown	0	0	0	0	0	0	0	0
Male	Fresh	Hatchery	1	0	11	0	0	43	0	55
Male	Fresh	Unknown	0	0	2	0	0	1	0	3
Male	Non-fresh	Hatchery	0	0	11	0	0	31	0	42
Male	Non-fresh	Unknown	0	0	1	0	0	0	0	1
Male	Unknown	Hatchery	0	0	0	0	0	0	0	0
Male	Unknown	Unknown	0	0	0	0	0	0	0	0
Unknown	Fresh	Hatchery	0	0	0	0	0	0	0	0
Unknown	Fresh	Unknown	0	0	0	0	0	0	0	0
Unknown	Non-fresh	Hatchery	0	0	0	0	0	0	0	0
Unknown	Non-fresh	Unknown	0	0	0	0	0	0	0	0
Unknown	Unknown	Hatchery	0	0	0	0	0	0	0	0
Unknown	Unknown	Unknown	0	0	0	0	0	0	0	0
Total			1	0	81	0	4	163	1	250
	Fresh		1	0	42	0	1	95	1	140

Survey

$$\begin{aligned} R &= (\textit{Total}\text{: CWT decoded, SRWC}) + (\textit{Total}\text{: CWT decoded, not SRWC}) \\ &= 163 + 1 = 164 \end{aligned}$$

$$E = 7784 \quad \text{(source: CDFG)}$$

$$n_{\text{fresh}} = 1621 \quad \text{(source: USFWS)}$$

$$\begin{aligned} n_{\text{fresh,ad-clipped}} &= (\textit{Fresh}\text{: Total}) \\ &= 140 \end{aligned}$$

$$\begin{aligned} n_{\text{fresh,head-processed}} &= n_{\text{fresh,ad-clipped}} - (\textit{Fresh}\text{: Head not taken}) - (\textit{Fresh}\text{: Head taken, but not processed or lost}) \\ &= 140 - 1 - 0 = 139 \end{aligned}$$

$$\begin{aligned} n_{\text{fresh,cwt-detected}} &= n_{\text{fresh,head-processed}} - (\textit{Fresh}\text{: Head processed, but CWT not detected}) \\ &= 139 - 42 = 97 \end{aligned}$$

Estimates

$$p_{\text{ad-clipped}} = n_{\text{fresh,ad-clipped}} / n_{\text{fresh}} = 0.0864$$

$$p_{\text{cwt}|\text{ad-clipped}} = n_{\text{fresh,cwt-detected}} / n_{\text{fresh,head-processed}} = 0.6978$$

$$p_{\text{cwt}} = p_{\text{ad-clipped}} \times p_{\text{cwt}|\text{ad-clipped}} = 0.0603$$

$$E_{\text{cwt}} = E \times p_{\text{cwt}} = 469.1425$$

$$\lambda = R / E_{\text{cwt}} = 0.3496$$

$$1/\lambda = 2.8606$$

C.5 2005 survey: basic data and calculations

Table C-5. Carcass survey CWT expansion basic data, 2005 (source: USFWS).

Gender	Carcass condition	Adipose fin	Head not taken	Head taken, but not processed or lost	Head processed, but CWT not detected	CWT detected, but not extracted or lost	CWT extracted, but unreadable	CWT decoded, SRWC	CWT decoded, not SRWC	Total
Female	Fresh	Hatchery	0	2	86	1	0	508	0	597
Female	Fresh	Unknown	0	0	27	0	0	3	0	30
Female	Non-fresh	Hatchery	6	3	96	0	0	405	0	510
Female	Non-fresh	Unknown	0	0	31	0	0	5	0	36
Female	Unknown	Hatchery	0	0	0	0	0	3	0	3
Female	Unknown	Unknown	0	0	0	0	0	0	0	0
Male	Fresh	Hatchery	2	3	16	0	0	184	1	206
Male	Fresh	Unknown	0	1	4	0	0	0	0	5
Male	Non-fresh	Hatchery	2	0	19	0	0	148	0	169
Male	Non-fresh	Unknown	0	0	3	0	0	2	0	5
Male	Unknown	Hatchery	0	0	0	0	0	1	0	1
Male	Unknown	Unknown	0	0	0	0	0	0	0	0
Unknown	Fresh	Hatchery	0	0	0	0	0	2	0	2
Unknown	Fresh	Unknown	0	0	0	0	0	0	0	0
Unknown	Non-fresh	Hatchery	0	0	0	0	0	1	0	1
Unknown	Non-fresh	Unknown	0	0	1	0	0	0	0	1
Unknown	Unknown	Hatchery	0	0	0	0	0	3	0	3
Unknown	Unknown	Unknown	0	0	0	0	0	0	0	0
Total			10	9	283	1	0	1265	1	1569
	Fresh		2	6	133	1	0	697	1	840

Survey

$$\begin{aligned} R &= (\textit{Total}\text{: CWT decoded, SRWC}) + (\textit{Total}\text{: CWT decoded, not SRWC}) \\ &= 1265 + 1 = 1266 \end{aligned}$$

$$E = 15730 \quad \text{(source: CDFG)}$$

$$n_{\text{fresh}} = 4177 \quad \text{(source: USFWS)}$$

$$\begin{aligned} n_{\text{fresh,ad-clipped}} &= (\textit{Fresh}\text{: Total}) \\ &= 840 \end{aligned}$$

$$\begin{aligned} n_{\text{fresh,head-processed}} &= n_{\text{fresh,ad-clipped}} - (\textit{Fresh}\text{: Head not taken}) - (\textit{Fresh}\text{: Head taken, but not processed or lost}) \\ &= 840 - 2 - 6 = 832 \end{aligned}$$

$$\begin{aligned} n_{\text{fresh,cwt-detected}} &= n_{\text{fresh,head-processed}} - (\textit{Fresh}\text{: Head processed, but CWT not detected}) \\ &= 832 - 133 = 699 \end{aligned}$$

Estimates

$$\begin{aligned} p_{\text{ad-clipped}} &= n_{\text{fresh,ad-clipped}} / n_{\text{fresh}} = 0.2011 \\ p_{\text{cwt}|\text{ad-clipped}} &= n_{\text{fresh,cwt-detected}} / n_{\text{fresh,head-processed}} = 0.8401 \\ p_{\text{cwt}} &= p_{\text{ad-clipped}} \times p_{\text{cwt}|\text{ad-clipped}} = 0.1690 \\ E_{\text{cwt}} &= E \times p_{\text{cwt}} = 2657.6475 \\ \lambda &= R / E_{\text{cwt}} = 0.4764 \\ 1/\lambda &= 2.0992 \end{aligned}$$

C.6 2006 survey: basic data and calculations

Table C-6. Carcass survey CWT expansion basic data, 2006 (source: USFWS).

Gender	Carcass condition	Adipose fin	Head not taken	Head taken, but not processed or lost	Head processed, but CWT not detected	CWT detected, but not extracted or lost	CWT extracted, but unreadable	CWT decoded, SRWC	CWT decoded, not SRWC	Total
Female	Fresh	Hatchery	0	1	35	4	2	282	0	324
Female	Fresh	Unknown	0	0	13	0	0	0	0	13
Female	Non-fresh	Hatchery	0	3	53	5	0	267	0	328
Female	Non-fresh	Unknown	0	0	16	0	0	7	0	23
Female	Unknown	Hatchery	0	0	0	0	0	0	0	0
Female	Unknown	Unknown	0	0	0	0	0	0	0	0
Male	Fresh	Hatchery	0	2	3	0	1	96	0	102
Male	Fresh	Unknown	0	0	1	0	0	0	0	1
Male	Non-fresh	Hatchery	0	4	10	2	0	106	0	122
Male	Non-fresh	Unknown	0	0	4	0	0	4	0	8
Male	Unknown	Hatchery	0	0	0	0	0	0	0	0
Male	Unknown	Unknown	0	0	0	0	0	0	0	0
Unknown	Fresh	Hatchery	0	0	0	0	0	0	0	0
Unknown	Fresh	Unknown	0	0	0	0	0	0	0	0
Unknown	Non-fresh	Hatchery	0	0	0	0	0	0	0	0
Unknown	Non-fresh	Unknown	0	0	0	0	0	0	0	0
Unknown	Unknown	Hatchery	0	0	0	0	0	0	0	0
Unknown	Unknown	Unknown	0	0	0	0	0	5	0	5
Total			0	10	135	11	3	767	0	926
	Fresh		0	3	52	4	3	378	0	440

Survey

$$\begin{aligned} R &= (\textit{Total}\text{: CWT decoded, SRWC}) + (\textit{Total}\text{: CWT decoded, not SRWC}) \\ &= 767 + 0 = 767 \end{aligned}$$

$$E = 17197 \quad \text{(source: CDFG)}$$

$$n_{\text{fresh}} = 3083 \quad \text{(source: USFWS)}$$

$$\begin{aligned} n_{\text{fresh,ad-clipped}} &= (\textit{Fresh}\text{: Total}) \\ &= 440 \end{aligned}$$

$$\begin{aligned} n_{\text{fresh,head-processed}} &= n_{\text{fresh,ad-clipped}} - (\textit{Fresh}\text{: Head not taken}) - (\textit{Fresh}\text{: Head taken, but not processed or lost}) \\ &= 440 - 0 - 3 = 437 \end{aligned}$$

$$\begin{aligned} n_{\text{fresh,cwt-detected}} &= n_{\text{fresh,head-processed}} - (\textit{Fresh}\text{: Head processed, but CWT not detected}) \\ &= 437 - 52 = 385 \end{aligned}$$

Estimates

$$p_{\text{ad-clipped}} = n_{\text{fresh,ad-clipped}} / n_{\text{fresh}} = 0.1427$$

$$p_{\text{cwt}|\text{ad-clipped}} = n_{\text{fresh,cwt-detected}} / n_{\text{fresh,head-processed}} = 0.8810$$

$$p_{\text{cwt}} = p_{\text{ad-clipped}} \times p_{\text{cwt}|\text{ad-clipped}} = 0.1257$$

$$E_{\text{cwt}} = E \times p_{\text{cwt}} = 2162.2760$$

$$\lambda = R / E_{\text{cwt}} = 0.3547$$

$$1/\lambda = 2.8191$$

C.7 2007 survey: basic data and calculations

Table C-7. Carcass survey CWT expansion basic data, 2007 (source: USFWS).

Gender	Carcass condition	Adipose fin	Head not taken	Head taken, but not processed or lost	Head processed, but CWT not detected	CWT detected, but not extracted or lost	CWT extracted, but unreadable	CWT decoded, SRWC	CWT decoded, not SRWC	Total
Female	Fresh	Hatchery	0	0	9	0	0	27	1	37
Female	Fresh	Unknown	0	0	5	0	0	0	0	5
Female	Non-fresh	Hatchery	0	0	5	0	0	29	0	34
Female	Non-fresh	Unknown	0	0	2	0	0	0	0	2
Female	Unknown	Hatchery	0	0	0	0	0	0	0	0
Female	Unknown	Unknown	0	0	0	0	0	0	0	0
Male	Fresh	Hatchery	0	0	0	0	0	5	0	5
Male	Fresh	Unknown	0	0	1	0	0	0	0	1
Male	Non-fresh	Hatchery	0	0	3	0	0	4	0	7
Male	Non-fresh	Unknown	0	0	0	0	0	0	0	0
Male	Unknown	Hatchery	0	0	0	0	0	0	0	0
Male	Unknown	Unknown	0	0	0	0	0	0	0	0
Unknown	Fresh	Hatchery	0	0	0	0	0	0	0	0
Unknown	Fresh	Unknown	0	0	0	0	0	0	0	0
Unknown	Non-fresh	Hatchery	0	0	0	0	0	0	0	0
Unknown	Non-fresh	Unknown	0	0	0	0	0	0	0	0
Unknown	Unknown	Hatchery	0	0	0	0	0	0	0	0
Unknown	Unknown	Unknown	0	0	0	0	0	0	0	0
Total			0	0	25	0	0	65	1	91
	Fresh		0	0	15	0	0	32	1	48

Survey

$$\begin{aligned}
R &= (\textit{Total}\text{: CWT decoded, SRWC}) + (\textit{Total}\text{: CWT decoded, not SRWC}) \\
&= 65 + 1 = 66 \\
E &= 2487 \quad \text{(source: CDFG)} \\
n_{\text{fresh}} &= 785 \quad \text{(source: USFWS)} \\
n_{\text{fresh,ad-clipped}} &= (\textit{Fresh}\text{: Total}) \\
&= 48 \\
n_{\text{fresh,head-processed}} &= n_{\text{fresh,ad-clipped}} - (\textit{Fresh}\text{: Head not taken}) - (\textit{Fresh}\text{: Head taken, but not processed or lost}) \\
&= 48 - 0 - 0 = 48 \\
n_{\text{fresh,cwt-detected}} &= n_{\text{fresh,head-processed}} - (\textit{Fresh}\text{: Head processed, but CWT not detected}) \\
&= 48 - 15 = 33
\end{aligned}$$

Estimates

$$\begin{aligned}
p_{\text{ad-clipped}} &= n_{\text{fresh,ad-clipped}} / n_{\text{fresh}} = 0.0611 \\
p_{\text{cwt|ad-clipped}} &= n_{\text{fresh,cwt-detected}} / n_{\text{fresh,head-processed}} = 0.6875 \\
p_{\text{cwt}} &= p_{\text{ad-clipped}} \times p_{\text{cwt|ad-clipped}} = 0.0420 \\
E_{\text{cwt}} &= E \times p_{\text{cwt}} = 104.5490 \\
\lambda &= R / E_{\text{cwt}} = 0.6313 \\
1/\lambda &= 1.5841
\end{aligned}$$

C.8 2008 survey: basic data and calculations

Table C-8. Carcass survey CWT expansion basic data, 2008 (source: USFWS).

Gender	Carcass condition	Adipose fin	Head not taken	Head taken, but not processed or lost	Head processed, but CWT not detected	CWT detected, but not extracted or lost	CWT extracted, but unreadable	CWT decoded, SRWC	CWT decoded, not SRWC	Total
Female	Fresh	Hatchery	0	0	5	0	0	20	1	26
Female	Fresh	Unknown	0	0	0	0	0	0	0	0
Female	Non-fresh	Hatchery	0	0	5	0	0	11	0	16
Female	Non-fresh	Unknown	0	0	5	0	0	0	0	5
Female	Unknown	Hatchery	0	0	0	0	0	0	0	0
Female	Unknown	Unknown	0	0	0	0	0	0	0	0
Male	Fresh	Hatchery	0	0	1	0	0	6	0	7
Male	Fresh	Unknown	0	0	1	0	0	0	0	1
Male	Non-fresh	Hatchery	0	0	3	0	0	8	0	11
Male	Non-fresh	Unknown	0	0	0	0	0	0	0	0
Male	Unknown	Hatchery	0	0	0	0	0	0	0	0
Male	Unknown	Unknown	0	0	0	0	0	0	0	0
Unknown	Fresh	Hatchery	0	0	0	0	0	0	0	0
Unknown	Fresh	Unknown	0	0	0	0	0	0	0	0
Unknown	Non-fresh	Hatchery	0	0	0	0	0	0	0	0
Unknown	Non-fresh	Unknown	0	0	0	0	0	0	0	0
Unknown	Unknown	Hatchery	0	0	0	0	0	0	0	0
Unknown	Unknown	Unknown	0	0	0	0	0	0	0	0
Total			0	0	20	0	0	45	1	66
	Fresh		0	0	7	0	0	26	1	34

Survey

$$
\begin{aligned}
R &= (\textit{Total}\text{: CWT decoded, SRWC}) + (\textit{Total}\text{: CWT decoded, not SRWC}) \\
&= 45 + 1 = 46
\end{aligned}
$$

$$E = 2725 \quad \text{(source: CDFG)}$$

$$n_{\text{fresh}} = 547 \quad \text{(source: USFWS)}$$

$$
\begin{aligned}
n_{\text{fresh,ad-clipped}} &= (\textit{Fresh}\text{: Total}) \\
&= 34
\end{aligned}
$$

$$
\begin{aligned}
n_{\text{fresh,head-processed}} &= n_{\text{fresh,ad-clipped}} - (\textit{Fresh}\text{: Head not taken}) - (\textit{Fresh}\text{: Head taken, but not processed or lost}) \\
&= 34 - 0 - 0 = 34
\end{aligned}
$$

$$
\begin{aligned}
n_{\text{fresh,cwt-detected}} &= n_{\text{fresh,head-processed}} - (\textit{Fresh}\text{: Head processed, but CWT not detected}) \\
&= 34 - 7 = 27
\end{aligned}
$$

Estimates

$$
\begin{aligned}
p_{\text{ad-clipped}} &= n_{\text{fresh,ad-clipped}} / n_{\text{fresh}} = 0.0622 \\
p_{\text{cwt}|\text{ad-clipped}} &= n_{\text{fresh,cwt-detected}} / n_{\text{fresh,head-processed}} = 0.7941 \\
p_{\text{cwt}} &= p_{\text{ad-clipped}} \times p_{\text{cwt}|\text{ad-clipped}} = 0.0494 \\
E_{\text{cwt}} &= E \times p_{\text{cwt}} = 134.5064 \\
\lambda &= R / E_{\text{cwt}} = 0.3420 \\
1/\lambda &= 2.9241
\end{aligned}
$$

C.9 2009 survey: basic data and calculations

Table C-9. Carcass survey CWT expansion basic data, 2009 (source: USFWS).

Gender	Carcass condition	Adipose fin	Head not taken	Head taken, but not processed or lost	Head processed, but CWT not detected	CWT detected, but not extracted or lost	CWT extracted, but unreadable	CWT decoded, SRWC	CWT decoded, not SRWC	Total
Female	Fresh	Hatchery	0	0	9	1	0	50	1	61
Female	Fresh	Unknown	0	0	6	0	0	4	0	10
Female	Non-fresh	Hatchery	0	0	5	0	0	28	0	33
Female	Non-fresh	Unknown	0	0	5	0	0	2	0	7
Female	Unknown	Hatchery	0	0	0	0	0	0	0	0
Female	Unknown	Unknown	0	0	0	0	0	0	0	0
Male	Fresh	Hatchery	0	0	3	0	0	13	0	16
Male	Fresh	Unknown	0	0	1	0	0	3	0	4
Male	Non-fresh	Hatchery	0	0	4	0	0	11	0	15
Male	Non-fresh	Unknown	0	0	2	0	0	3	0	5
Male	Unknown	Hatchery	0	0	0	0	0	0	0	0
Male	Unknown	Unknown	0	0	0	0	0	0	0	0
Unknown	Fresh	Hatchery	0	0	0	0	0	0	0	0
Unknown	Fresh	Unknown	0	0	0	0	0	0	0	0
Unknown	Non-fresh	Hatchery	0	0	0	0	0	0	0	0
Unknown	Non-fresh	Unknown	0	0	0	0	0	0	0	0
Unknown	Unknown	Hatchery	0	0	0	0	0	0	0	0
Unknown	Unknown	Unknown	0	0	0	0	0	0	0	0
Total			0	0	35	1	0	114	1	151
	Fresh		0	0	19	1	0	70	1	91

Survey

$$\begin{aligned} R &= (\textit{Total}\text{: CWT decoded, SRWC}) + (\textit{Total}\text{: CWT decoded, not SRWC}) \\ &= 114 + 1 = 115 \end{aligned}$$

$$E = 4416 \quad \text{(source: CDFG)}$$

$$n_{\text{fresh}} = 802 \quad \text{(source: USFWS)}$$

$$\begin{aligned} n_{\text{fresh,ad-clipped}} &= (\textit{Fresh}\text{: Total}) \\ &= 91 \end{aligned}$$

$$\begin{aligned} n_{\text{fresh,head-processed}} &= n_{\text{fresh,ad-clipped}} - (\textit{Fresh}\text{: Head not taken}) - (\textit{Fresh}\text{: Head taken, but not processed or lost}) \\ &= 91 - 0 - 0 = 91 \end{aligned}$$

$$\begin{aligned} n_{\text{fresh,cwt-detected}} &= n_{\text{fresh,head-processed}} - (\textit{Fresh}\text{: Head processed, but CWT not detected}) \\ &= 91 - 19 = 72 \end{aligned}$$

Estimates

$$\begin{aligned} p_{\text{ad-clipped}} &= n_{\text{fresh,ad-clipped}} / n_{\text{fresh}} = 0.1135 \\ p_{\text{cwt}|\text{ad-clipped}} &= n_{\text{fresh,cwt-detected}} / n_{\text{fresh,head-processed}} = 0.7912 \\ p_{\text{cwt}} &= p_{\text{ad-clipped}} \times p_{\text{cwt}|\text{ad-clipped}} = 0.0898 \\ E_{\text{cwt}} &= E \times p_{\text{cwt}} = 396.4489 \\ \lambda &= R / E_{\text{cwt}} = 0.2901 \\ 1/\lambda &= 3.4474 \end{aligned}$$

C.10 2010 survey: basic data and calculations

Table C-10. Carcass survey CWT expansion basic data, 2010 (source: USFWS).

Gender	Carcass condition	Adipose fin	Head not taken	Head taken, but not processed or lost	Head processed, but CWT not detected	CWT detected, but not extracted or lost	CWT extracted, but unreadable	CWT decoded, SRWC	CWT decoded, not SRWC	Total
Female	Fresh	Hatchery	0	1	5	1	0	33	3	43
Female	Fresh	Unknown	0	0	8	1	0	0	0	9
Female	Non-fresh	Hatchery	0	1	6	1	0	30	0	38
Female	Non-fresh	Unknown	0	0	12	0	0	0	0	12
Female	Unknown	Hatchery	0	0	0	0	0	0	0	0
Female	Unknown	Unknown	0	0	0	0	0	0	0	0
Male	Fresh	Hatchery	0	0	0	2	0	18	1	20
Male	Fresh	Unknown	0	0	1	0	0	0	0	1
Male	Non-fresh	Hatchery	0	0	0	0	0	9	1	9
Male	Non-fresh	Unknown	0	0	3	0	0	0	0	3
Male	Unknown	Hatchery	0	0	0	0	0	0	0	0
Male	Unknown	Unknown	0	0	0	0	0	0	0	0
Unknown	Fresh	Hatchery	0	0	0	0	0	0	0	0
Unknown	Fresh	Unknown	0	0	0	0	0	0	0	0
Unknown	Non-fresh	Hatchery	0	0	0	0	0	0	0	0
Unknown	Non-fresh	Unknown	0	0	0	0	0	0	0	0
Unknown	Unknown	Hatchery	0	0	0	0	0	0	0	0
Unknown	Unknown	Unknown	0	0	0	0	0	0	0	0
Total			0	2	35	5	0	90	5	135
	Fresh		0	1	14	4	0	51	4	74

Survey

$$\begin{aligned}
R &= (\textit{Total}\text{: CWT decoded, SRWC}) + (\textit{Total}\text{: CWT decoded, not SRWC}) \\
&= 90 + 5 = 95 \\
E &= 1533 \quad \text{(source: CDFG)} \\
n_{\text{fresh}} &= 472 \quad \text{(source: USFWS)} \\
n_{\text{fresh,ad-clipped}} &= (\textit{Fresh}\text{: Total}) \\
&= 74 \\
n_{\text{fresh,head-processed}} &= n_{\text{fresh,ad-clipped}} - (\textit{Fresh}\text{: Head not taken}) - (\textit{Fresh}\text{: Head taken, but not processed or lost}) \\
&= 74 - 0 - 1 = 73 \\
n_{\text{fresh,cwt-detected}} &= n_{\text{fresh,head-processed}} - (\textit{Fresh}\text{: Head processed, but CWT not detected}) \\
&= 73 - 14 = 59
\end{aligned}$$

Estimates

$$\begin{aligned}
p_{\text{ad-clipped}} &= n_{\text{fresh,ad-clipped}} / n_{\text{fresh}} = 0.1568 \\
p_{\text{cwt}|\text{ad-clipped}} &= n_{\text{fresh,cwt-detected}} / n_{\text{fresh,head-processed}} = 0.8082 \\
p_{\text{cwt}} &= p_{\text{ad-clipped}} \times p_{\text{cwt}|\text{ad-clipped}} = 0.1267 \\
E_{\text{cwt}} &= E \times p_{\text{cwt}} = 194.2500 \\
\lambda &= R / E_{\text{cwt}} = 0.4891 \\
1/\lambda &= 2.0447
\end{aligned}$$

Appendix D Reconstructed cohorts: 1998–2007 broods

Tables D-1 through D-10 display the cohort reconstructions of hatchery-origin SRWC, brood years 1998–2007. Notation used for column headings: BY is brood year; CY is calendar year; N is ocean-wide abundance at the beginning of the month; I_{com} is ocean commercial fishery impacts; I_{rec} is ocean recreational fishery impacts; V is natural mortalities; H_r is river harvest; E_{hat} is hatchery escapement; E_{nat} is natural area escapement. For a given Age/Month combination, the sum of the columns to the right of N equals the decrement in abundance for that Age/Month.

Table D-1. Reconstructed cohort: 1998 brood.

				Ocean				River		
BY	CY	Age	Month	N	I_{com}	I_{rec}	V	H_r	E_{hat}	E_{nat}
1998	1999	2	3	1528.38	0.00	0.00	85.78	0.00	0.00	0.00
1998	1999	2	4	1442.60	0.00	0.00	80.97	0.00	0.00	0.00
1998	1999	2	5	1361.63	0.00	0.00	76.42	0.00	0.00	0.00
1998	1999	2	6	1285.21	0.00	0.00	72.13	0.00	0.00	0.00
1998	1999	2	7	1213.08	0.00	0.00	68.08	0.00	0.00	0.00
1998	1999	2	8	1144.99	0.00	8.68	63.78	0.00	0.00	0.00
1998	1999	2	9	1072.53	0.00	0.00	60.20	0.00	0.00	0.00
1998	1999	2	10	1012.34	0.00	0.00	56.82	0.00	0.00	0.00
1998	1999	2	11	955.52	0.00	0.00	53.63	0.00	0.00	0.00
1998	1999	2	12	901.89	0.00	0.00	50.62	0.00	0.00	0.00
1998	2000	2	1	851.27	0.00	0.00	47.78	0.00	0.00	0.00
1998	2000	2	2	803.49	0.00	0.00	45.10	23.48	8.29	0.00
1998	2000	3	3	726.63	0.00	0.00	13.39	0.00	0.00	0.00
1998	2000	3	4	713.24	0.00	8.37	12.99	0.00	0.00	0.00
1998	2000	3	5	691.88	0.00	0.00	12.75	0.00	0.00	0.00
1998	2000	3	6	679.14	28.93	43.65	11.17	0.00	0.00	0.00
1998	2000	3	7	595.38	6.52	53.84	9.86	0.00	0.00	0.00
1998	2000	3	8	525.16	0.00	14.14	9.41	0.00	0.00	0.00
1998	2000	3	9	501.60	0.00	4.73	9.15	0.00	0.00	0.00
1998	2000	3	10	487.72	0.00	9.71	8.81	0.00	0.00	0.00
1998	2000	3	11	469.20	0.00	0.00	8.64	0.00	0.00	0.00
1998	2000	3	12	460.56	0.00	0.00	8.49	0.00	0.00	0.00
1998	2001	3	1	452.07	0.00	0.00	8.33	0.00	0.00	0.00
1998	2001	3	2	443.74	0.00	0.00	8.18	90.83	13.18	268.04
1998	2001	4	3	63.52	0.00	0.00	1.17	0.00	0.00	0.00
1998	2001	4	4	62.35	0.00	0.00	1.15	0.00	0.00	0.00
1998	2001	4	5	61.20	5.21	0.00	1.03	0.00	0.00	0.00
1998	2001	4	6	54.96	0.00	0.00	1.01	0.00	0.00	0.00
1998	2001	4	7	53.95	0.00	0.00	0.99	0.00	0.00	0.00
1998	2001	4	8	52.95	0.00	0.00	0.98	0.00	0.00	0.00
1998	2001	4	9	51.98	2.71	0.00	0.91	0.00	0.00	0.00
1998	2001	4	10	48.36	0.00	0.00	0.89	0.00	0.00	0.00
1998	2001	4	11	47.47	0.00	0.00	0.87	0.00	0.00	0.00
1998	2001	4	12	46.59	0.00	0.00	0.86	0.00	0.00	0.00
1998	2002	4	1	45.74	0.00	0.00	0.84	0.00	0.00	0.00
1998	2002	4	2	44.89	0.00	0.00	0.83	31.54	0.00	4.92
1998	2002	5	3	7.61	0.00	0.00	0.14	0.00	0.00	0.00
1998	2002	5	4	7.47	0.00	0.00	0.14	0.00	0.00	0.00
1998	2002	5	5	7.33	7.33	0.00	0.00	0.00	0.00	0.00
1998	2002	5	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	2002	5	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	2002	5	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	2002	5	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	2002	5	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	2002	5	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	2002	5	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	2003	5	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1998	2003	5	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D-2. Reconstructed cohort: 1999 brood.

				Ocean				River		
BY	CY	Age	Month	N	I_{com}	I_{rec}	V	H_r	E_{hat}	E_{nat}
1999	2000	2	3	1162.47	0.00	0.00	65.24	0.00	0.00	0.00
1999	2000	2	4	1097.23	0.00	0.00	61.58	0.00	0.00	0.00
1999	2000	2	5	1035.65	0.00	0.00	58.13	0.00	0.00	0.00
1999	2000	2	6	977.52	0.00	0.00	54.86	0.00	0.00	0.00
1999	2000	2	7	922.65	0.00	0.00	51.78	0.00	0.00	0.00
1999	2000	2	8	870.87	0.00	0.00	48.88	0.00	0.00	0.00
1999	2000	2	9	821.99	0.00	0.00	46.13	0.00	0.00	0.00
1999	2000	2	10	775.86	0.00	0.00	43.55	0.00	0.00	0.00
1999	2000	2	11	732.31	0.00	0.00	41.10	0.00	0.00	0.00
1999	2000	2	12	691.21	0.00	0.00	38.79	0.00	0.00	0.00
1999	2001	2	1	652.42	0.00	0.00	36.62	0.00	0.00	0.00
1999	2001	2	2	615.80	0.00	0.00	34.56	0.00	0.00	95.27
1999	2001	3	3	485.97	0.00	13.19	8.71	0.00	0.00	0.00
1999	2001	3	4	464.07	0.00	37.31	7.86	0.00	0.00	0.00
1999	2001	3	5	418.89	0.00	9.25	7.55	0.00	0.00	0.00
1999	2001	3	6	402.10	0.00	5.03	7.32	0.00	0.00	0.00
1999	2001	3	7	389.76	14.15	34.44	6.29	0.00	0.00	0.00
1999	2001	3	8	334.89	0.00	8.74	6.01	0.00	0.00	0.00
1999	2001	3	9	320.14	0.00	0.00	5.90	0.00	0.00	0.00
1999	2001	3	10	314.24	0.00	0.00	5.79	0.00	0.00	0.00
1999	2001	3	11	308.45	0.00	0.00	5.68	0.00	0.00	0.00
1999	2001	3	12	302.77	0.00	0.00	5.58	0.00	0.00	0.00
1999	2002	3	1	297.19	0.00	0.00	5.48	0.00	0.00	0.00
1999	2002	3	2	291.72	0.00	0.00	5.37	0.00	5.06	268.24
1999	2002	4	3	13.04	0.00	0.00	0.24	0.00	0.00	0.00
1999	2002	4	4	12.80	0.00	0.00	0.24	0.00	0.00	0.00
1999	2002	4	5	12.56	0.00	0.00	0.23	0.00	0.00	0.00
1999	2002	4	6	12.33	5.49	0.00	0.13	0.00	0.00	0.00
1999	2002	4	7	6.72	0.00	3.85	0.05	0.00	0.00	0.00
1999	2002	4	8	2.81	0.00	0.00	0.05	0.00	0.00	0.00
1999	2002	4	9	2.76	0.00	0.00	0.05	0.00	0.00	0.00
1999	2002	4	10	2.71	0.00	0.00	0.05	0.00	0.00	0.00
1999	2002	4	11	2.66	0.00	0.00	0.05	0.00	0.00	0.00
1999	2002	4	12	2.61	0.00	0.00	0.05	0.00	0.00	0.00
1999	2003	4	1	2.56	0.00	0.00	0.05	0.00	0.00	0.00
1999	2003	4	2	2.52	0.00	0.00	0.05	0.00	0.00	2.47
1999	2003	5	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	2003	5	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	2003	5	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	2003	5	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	2003	5	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	2003	5	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	2003	5	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	2003	5	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	2003	5	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	2003	5	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	2004	5	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1999	2004	5	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D-3. Reconstructed cohort: 2000 brood.

				Ocean				River		
BY	CY	Age	Month	N	I_{com}	I_{rec}	V	H_r	E_{hat}	E_{nat}
2000	2001	2	3	1063.81	0.00	0.00	59.71	0.00	0.00	0.00
2000	2001	2	4	1004.11	0.00	0.00	56.36	0.00	0.00	0.00
2000	2001	2	5	947.75	0.00	0.00	53.19	0.00	0.00	0.00
2000	2001	2	6	894.56	0.00	0.00	50.21	0.00	0.00	0.00
2000	2001	2	7	844.35	0.00	0.00	47.39	0.00	0.00	0.00
2000	2001	2	8	796.96	0.00	0.00	44.73	0.00	0.00	0.00
2000	2001	2	9	752.23	0.00	0.00	42.22	0.00	0.00	0.00
2000	2001	2	10	710.01	0.00	0.00	39.85	0.00	0.00	0.00
2000	2001	2	11	670.16	0.00	0.00	37.61	0.00	0.00	0.00
2000	2001	2	12	632.55	0.00	0.00	35.50	0.00	0.00	0.00
2000	2002	2	1	597.05	0.00	0.00	33.51	0.00	0.00	0.00
2000	2002	2	2	563.54	0.00	0.00	31.63	0.00	3.11	30.50
2000	2002	3	3	498.30	0.00	0.00	9.18	0.00	0.00	0.00
2000	2002	3	4	489.12	0.00	0.00	9.01	0.00	0.00	0.00
2000	2002	3	5	480.11	0.00	19.81	8.48	0.00	0.00	0.00
2000	2002	3	6	451.82	14.33	16.81	7.75	0.00	0.00	0.00
2000	2002	3	7	412.93	17.30	22.86	6.87	0.00	0.00	0.00
2000	2002	3	8	365.91	9.01	8.66	6.42	0.00	0.00	0.00
2000	2002	3	9	341.82	0.00	0.00	6.30	0.00	0.00	0.00
2000	2002	3	10	335.53	0.00	0.00	6.18	0.00	0.00	0.00
2000	2002	3	11	329.35	0.00	0.00	6.07	0.00	0.00	0.00
2000	2002	3	12	323.28	0.00	0.00	5.96	0.00	0.00	0.00
2000	2003	3	1	317.32	0.00	0.00	5.85	0.00	0.00	0.00
2000	2003	3	2	311.48	0.00	0.00	5.74	0.00	6.13	282.88
2000	2003	4	3	16.73	0.00	5.65	0.20	0.00	0.00	0.00
2000	2003	4	4	10.88	0.00	0.00	0.20	0.00	0.00	0.00
2000	2003	4	5	10.68	0.00	0.00	0.20	0.00	0.00	0.00
2000	2003	4	6	10.48	3.50	0.00	0.13	0.00	0.00	0.00
2000	2003	4	7	6.85	0.00	0.00	0.13	0.00	0.00	0.00
2000	2003	4	8	6.72	0.00	0.00	0.12	0.00	0.00	0.00
2000	2003	4	9	6.60	0.00	0.00	0.12	0.00	0.00	0.00
2000	2003	4	10	6.47	0.00	0.00	0.12	0.00	0.00	0.00
2000	2003	4	11	6.36	0.00	0.00	0.12	0.00	0.00	0.00
2000	2003	4	12	6.24	0.00	0.00	0.11	0.00	0.00	0.00
2000	2004	4	1	6.12	0.00	0.00	0.11	0.00	0.00	0.00
2000	2004	4	2	6.01	0.00	0.00	0.11	0.00	0.00	5.90
2000	2004	5	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	2004	5	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	2004	5	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	2004	5	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	2004	5	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	2004	5	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	2004	5	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	2004	5	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	2004	5	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	2004	5	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	2005	5	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2000	2005	5	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D-4. Reconstructed cohort: 2001 brood.

				Ocean				River		
BY	CY	Age	Month	N	I_{com}	I_{rec}	V	H_r	E_{hat}	E_{nat}
2001	2002	2	3	954.19	0.00	0.00	53.55	0.00	0.00	0.00
2001	2002	2	4	900.63	0.00	0.00	50.55	0.00	0.00	0.00
2001	2002	2	5	850.09	0.00	0.00	47.71	0.00	0.00	0.00
2001	2002	2	6	802.37	0.00	0.00	45.03	0.00	0.00	0.00
2001	2002	2	7	757.34	0.00	0.00	42.51	0.00	0.00	0.00
2001	2002	2	8	714.83	0.00	0.00	40.12	0.00	0.00	0.00
2001	2002	2	9	674.71	0.00	0.00	37.87	0.00	0.00	0.00
2001	2002	2	10	636.84	0.00	0.00	35.74	0.00	0.00	0.00
2001	2002	2	11	601.10	0.00	0.00	33.74	0.00	0.00	0.00
2001	2002	2	12	567.36	0.00	0.00	31.84	0.00	0.00	0.00
2001	2003	2	1	535.52	0.00	0.00	30.06	0.00	0.00	0.00
2001	2003	2	2	505.46	0.00	0.00	28.37	0.00	1.09	27.76
2001	2003	3	3	448.24	0.00	0.00	8.26	0.00	0.00	0.00
2001	2003	3	4	439.99	0.00	0.00	8.11	0.00	0.00	0.00
2001	2003	3	5	431.88	0.00	13.19	7.71	0.00	0.00	0.00
2001	2003	3	6	410.98	0.00	17.51	7.25	0.00	0.00	0.00
2001	2003	3	7	386.22	0.00	15.64	6.83	0.00	0.00	0.00
2001	2003	3	8	363.75	0.00	0.00	6.70	0.00	0.00	0.00
2001	2003	3	9	357.05	0.00	0.00	6.58	0.00	0.00	0.00
2001	2003	3	10	350.47	0.00	0.00	6.46	0.00	0.00	0.00
2001	2003	3	11	344.01	0.00	0.00	6.34	0.00	0.00	0.00
2001	2003	3	12	337.68	0.00	0.00	6.22	0.00	0.00	0.00
2001	2004	3	1	331.46	0.00	0.00	6.11	0.00	0.00	0.00
2001	2004	3	2	325.35	0.00	0.00	5.99	0.00	8.21	302.82
2001	2004	4	3	8.32	0.00	0.00	0.15	0.00	0.00	0.00
2001	2004	4	4	8.17	0.00	5.59	0.05	0.00	0.00	0.00
2001	2004	4	5	2.53	0.00	0.00	0.05	0.00	0.00	0.00
2001	2004	4	6	2.48	0.00	0.00	0.05	0.00	0.00	0.00
2001	2004	4	7	2.44	0.00	0.00	0.04	0.00	0.00	0.00
2001	2004	4	8	2.39	0.00	0.00	0.04	0.00	0.00	0.00
2001	2004	4	9	2.35	0.00	0.00	0.04	0.00	0.00	0.00
2001	2004	4	10	2.30	0.00	0.00	0.04	0.00	0.00	0.00
2001	2004	4	11	2.26	0.00	0.00	0.04	0.00	0.00	0.00
2001	2004	4	12	2.22	0.00	0.00	0.04	0.00	0.00	0.00
2001	2005	4	1	2.18	0.00	0.00	0.04	0.00	0.00	0.00
2001	2005	4	2	2.14	0.00	0.00	0.04	0.00	0.00	2.10
2001	2005	5	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	2005	5	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	2005	5	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	2005	5	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	2005	5	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	2005	5	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	2005	5	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	2005	5	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	2005	5	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	2005	5	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	2006	5	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001	2006	5	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D-5. Reconstructed cohort: 2002 brood.

				Ocean				River		
BY	CY	Age	Month	N	I_{com}	I_{rec}	V	H_r	E_{hat}	E_{nat}
2002	2003	2	3	10345.83	0.00	0.00	580.67	0.00	0.00	0.00
2002	2003	2	4	9765.16	0.00	0.00	548.08	0.00	0.00	0.00
2002	2003	2	5	9217.09	0.00	0.00	517.32	0.00	0.00	0.00
2002	2003	2	6	8699.77	0.00	0.00	488.28	0.00	0.00	0.00
2002	2003	2	7	8211.49	0.00	0.00	460.88	0.00	0.00	0.00
2002	2003	2	8	7750.61	0.00	0.00	435.01	0.00	0.00	0.00
2002	2003	2	9	7315.61	0.00	0.00	410.59	0.00	0.00	0.00
2002	2003	2	10	6905.01	0.00	0.00	387.55	0.00	0.00	0.00
2002	2003	2	11	6517.46	0.00	0.00	365.80	0.00	0.00	0.00
2002	2003	2	12	6151.67	0.00	0.00	345.27	0.00	0.00	0.00
2002	2004	2	1	5806.40	0.00	0.00	325.89	0.00	0.00	0.00
2002	2004	2	2	5480.51	0.00	0.00	307.60	0.00	0.00	178.45
2002	2004	3	3	4994.46	0.00	0.00	92.02	0.00	0.00	0.00
2002	2004	3	4	4902.45	0.00	81.23	88.82	0.00	0.00	0.00
2002	2004	3	5	4732.39	110.61	190.31	81.64	0.00	0.00	0.00
2002	2004	3	6	4349.84	189.42	145.65	73.97	0.00	0.00	0.00
2002	2004	3	7	3940.81	156.66	316.65	63.88	0.00	0.00	0.00
2002	2004	3	8	3403.61	10.42	53.77	61.52	0.00	0.00	0.00
2002	2004	3	9	3277.89	0.00	7.04	60.26	0.00	0.00	0.00
2002	2004	3	10	3210.59	0.00	2.58	59.10	0.00	0.00	0.00
2002	2004	3	11	3148.90	0.00	13.49	57.77	0.00	0.00	0.00
2002	2004	3	12	3077.65	0.00	0.00	56.70	0.00	0.00	0.00
2002	2005	3	1	3020.95	0.00	0.00	55.66	0.00	0.00	0.00
2002	2005	3	2	2965.29	0.00	0.00	54.63	0.00	3.12	2705.25
2002	2005	4	3	202.29	0.00	0.00	3.73	0.00	0.00	0.00
2002	2005	4	4	198.56	0.00	15.06	3.38	0.00	0.00	0.00
2002	2005	4	5	180.12	8.20	0.00	3.17	0.00	0.00	0.00
2002	2005	4	6	168.76	13.28	0.00	2.86	0.00	0.00	0.00
2002	2005	4	7	152.61	19.05	0.00	2.46	0.00	0.00	0.00
2002	2005	4	8	131.10	8.71	0.00	2.25	0.00	0.00	0.00
2002	2005	4	9	120.13	8.75	0.00	2.05	0.00	0.00	0.00
2002	2005	4	10	109.33	0.00	0.00	2.01	0.00	0.00	0.00
2002	2005	4	11	107.32	0.00	4.37	1.90	0.00	0.00	0.00
2002	2005	4	12	101.05	0.00	0.00	1.86	0.00	0.00	0.00
2002	2006	4	1	99.19	0.00	0.00	1.83	0.00	0.00	0.00
2002	2006	4	2	97.36	0.00	0.00	1.79	0.00	1.03	94.54
2002	2006	5	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	2006	5	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	2006	5	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	2006	5	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	2006	5	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	2006	5	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	2006	5	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	2006	5	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	2006	5	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	2006	5	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	2007	5	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2002	2007	5	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D-6. Reconstructed cohort: 2003 brood.

				Ocean				River		
BY	CY	Age	Month	N	I_{com}	I_{rec}	V	H_r	E_{hat}	E_{nat}
2003	2004	2	3	7026.64	0.00	0.00	394.37	0.00	0.00	0.00
2003	2004	2	4	6632.26	0.00	0.00	372.24	0.00	0.00	0.00
2003	2004	2	5	6260.02	0.00	0.00	351.35	0.00	0.00	0.00
2003	2004	2	6	5908.67	0.00	0.00	331.63	0.00	0.00	0.00
2003	2004	2	7	5577.05	0.00	0.00	313.02	0.00	0.00	0.00
2003	2004	2	8	5264.03	0.00	0.00	295.45	0.00	0.00	0.00
2003	2004	2	9	4968.58	0.00	0.00	278.87	0.00	0.00	0.00
2003	2004	2	10	4689.72	0.00	0.00	263.21	0.00	0.00	0.00
2003	2004	2	11	4426.50	0.00	0.00	248.44	0.00	0.00	0.00
2003	2004	2	12	4178.06	0.00	0.00	234.50	0.00	0.00	0.00
2003	2005	2	1	3943.57	0.00	0.00	221.34	0.00	0.00	0.00
2003	2005	2	2	3722.23	0.00	0.00	208.91	0.00	0.00	141.67
2003	2005	3	3	3371.65	0.00	0.00	62.12	0.00	0.00	0.00
2003	2005	3	4	3309.53	0.00	81.20	59.48	0.00	0.00	0.00
2003	2005	3	5	3168.86	0.00	99.43	56.55	0.00	0.00	0.00
2003	2005	3	6	3012.88	33.68	157.09	51.99	0.00	0.00	0.00
2003	2005	3	7	2770.12	76.05	77.48	48.21	0.00	0.00	0.00
2003	2005	3	8	2568.38	34.15	12.01	46.47	0.00	0.00	0.00
2003	2005	3	9	2475.76	2.28	3.59	45.50	0.00	0.00	0.00
2003	2005	3	10	2424.38	0.00	0.00	44.67	0.00	0.00	0.00
2003	2005	3	11	2379.72	0.00	2.01	43.81	0.00	0.00	0.00
2003	2005	3	12	2333.91	0.00	0.00	43.00	0.00	0.00	0.00
2003	2006	3	1	2290.91	0.00	0.00	42.21	0.00	0.00	0.00
2003	2006	3	2	2248.70	0.00	0.00	41.43	0.00	2.02	2092.10
2003	2006	4	3	113.15	0.00	0.00	2.08	0.00	0.00	0.00
2003	2006	4	4	111.07	0.00	5.33	1.95	0.00	0.00	0.00
2003	2006	4	5	103.79	3.11	0.00	1.85	0.00	0.00	0.00
2003	2006	4	6	98.82	0.00	5.52	1.72	0.00	0.00	0.00
2003	2006	4	7	91.57	0.00	10.51	1.49	0.00	0.00	0.00
2003	2006	4	8	79.57	0.00	0.00	1.47	0.00	0.00	0.00
2003	2006	4	9	78.10	1.61	0.00	1.41	0.00	0.00	0.00
2003	2006	4	10	75.09	0.00	0.00	1.38	0.00	0.00	0.00
2003	2006	4	11	73.70	0.00	0.00	1.36	0.00	0.00	0.00
2003	2006	4	12	72.35	0.00	0.00	1.33	0.00	0.00	0.00
2003	2007	4	1	71.01	0.00	0.00	1.31	0.00	0.00	0.00
2003	2007	4	2	69.70	0.00	0.00	1.28	0.00	2.18	62.59
2003	2007	5	3	3.65	0.00	0.00	0.07	0.00	0.00	0.00
2003	2007	5	4	3.58	0.00	0.00	0.07	0.00	0.00	0.00
2003	2007	5	5	3.52	0.00	0.00	0.06	0.00	0.00	0.00
2003	2007	5	6	3.45	0.00	0.00	0.06	0.00	0.00	0.00
2003	2007	5	7	3.39	0.00	0.00	0.06	0.00	0.00	0.00
2003	2007	5	8	3.33	0.00	0.00	0.06	0.00	0.00	0.00
2003	2007	5	9	3.26	0.00	0.00	0.06	0.00	0.00	0.00
2003	2007	5	10	3.20	0.00	0.00	0.06	0.00	0.00	0.00
2003	2007	5	11	3.15	0.00	0.00	0.06	0.00	0.00	0.00
2003	2007	5	12	3.09	0.00	0.00	0.06	0.00	0.00	0.00
2003	2008	5	1	3.03	0.00	0.00	0.06	0.00	0.00	0.00
2003	2008	5	2	2.97	0.00	0.00	0.05	0.00	0.00	2.92

Table D-7. Reconstructed cohort: 2004 brood.

				Ocean				River		
BY	CY	Age	Month	N	I_{com}	I_{rec}	V	H_r	E_{hat}	E_{nat}
2004	2005	2	3	291.71	0.00	0.00	16.37	0.00	0.00	0.00
2004	2005	2	4	275.34	0.00	0.00	15.45	0.00	0.00	0.00
2004	2005	2	5	259.88	0.00	0.00	14.59	0.00	0.00	0.00
2004	2005	2	6	245.30	0.00	0.00	13.77	0.00	0.00	0.00
2004	2005	2	7	231.53	0.00	0.00	12.99	0.00	0.00	0.00
2004	2005	2	8	218.54	0.00	0.00	12.27	0.00	0.00	0.00
2004	2005	2	9	206.27	0.00	0.00	11.58	0.00	0.00	0.00
2004	2005	2	10	194.69	0.00	0.00	10.93	0.00	0.00	0.00
2004	2005	2	11	183.77	0.00	0.00	10.31	0.00	0.00	0.00
2004	2005	2	12	173.45	0.00	0.00	9.74	0.00	0.00	0.00
2004	2006	2	1	163.72	0.00	0.00	9.19	0.00	0.00	0.00
2004	2006	2	2	154.53	0.00	0.00	8.67	0.00	0.00	3.31
2004	2006	3	3	142.55	0.00	0.00	2.63	0.00	0.00	0.00
2004	2006	3	4	139.92	0.00	8.04	2.43	0.00	0.00	0.00
2004	2006	3	5	129.45	0.00	0.00	2.38	0.00	0.00	0.00
2004	2006	3	6	127.06	0.00	4.12	2.27	0.00	0.00	0.00
2004	2006	3	7	120.68	0.00	9.29	2.05	0.00	0.00	0.00
2004	2006	3	8	109.33	0.00	0.00	2.01	0.00	0.00	0.00
2004	2006	3	9	107.32	0.00	0.00	1.98	0.00	0.00	0.00
2004	2006	3	10	105.34	0.00	0.00	1.94	0.00	0.00	0.00
2004	2006	3	11	103.40	0.00	0.00	1.90	0.00	0.00	0.00
2004	2006	3	12	101.49	0.00	0.00	1.87	0.00	0.00	0.00
2004	2007	3	1	99.62	0.00	0.00	1.84	0.00	0.00	0.00
2004	2007	3	2	97.79	0.00	0.00	1.80	0.00	7.62	84.43
2004	2007	4	3	3.94	0.00	0.00	0.07	0.00	0.00	0.00
2004	2007	4	4	3.86	0.00	0.00	0.07	0.00	0.00	0.00
2004	2007	4	5	3.79	0.00	0.00	0.07	0.00	0.00	0.00
2004	2007	4	6	3.72	0.00	0.00	0.07	0.00	0.00	0.00
2004	2007	4	7	3.66	0.00	0.00	0.07	0.00	0.00	0.00
2004	2007	4	8	3.59	0.00	0.00	0.07	0.00	0.00	0.00
2004	2007	4	9	3.52	0.00	0.00	0.06	0.00	0.00	0.00
2004	2007	4	10	3.46	0.00	0.00	0.06	0.00	0.00	0.00
2004	2007	4	11	3.39	0.00	0.00	0.06	0.00	0.00	0.00
2004	2007	4	12	3.33	0.00	0.00	0.06	0.00	0.00	0.00
2004	2008	4	1	3.27	0.00	0.00	0.06	0.00	0.00	0.00
2004	2008	4	2	3.21	0.00	0.00	0.06	0.00	0.00	3.15
2004	2008	5	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	2008	5	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	2008	5	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	2008	5	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	2008	5	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	2008	5	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	2008	5	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	2008	5	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	2008	5	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	2008	5	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	2009	5	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2004	2009	5	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D-8. Reconstructed cohort: 2005 brood.

				Ocean				River		
BY	CY	Age	Month	N	I_{com}	I_{rec}	V	H_r	E_{hat}	E_{nat}
2005	2006	2	3	364.07	0.00	0.00	20.43	0.00	0.00	0.00
2005	2006	2	4	343.64	0.00	0.00	19.29	0.00	0.00	0.00
2005	2006	2	5	324.35	0.00	0.00	18.20	0.00	0.00	0.00
2005	2006	2	6	306.14	0.00	0.00	17.18	0.00	0.00	0.00
2005	2006	2	7	288.96	0.00	0.00	16.22	0.00	0.00	0.00
2005	2006	2	8	272.74	0.00	0.00	15.31	0.00	0.00	0.00
2005	2006	2	9	257.44	0.00	0.00	14.45	0.00	0.00	0.00
2005	2006	2	10	242.99	0.00	0.00	13.64	0.00	0.00	0.00
2005	2006	2	11	229.35	0.00	0.00	12.87	0.00	0.00	0.00
2005	2006	2	12	216.48	0.00	0.00	12.15	0.00	0.00	0.00
2005	2007	2	1	204.33	0.00	0.00	11.47	0.00	0.00	0.00
2005	2007	2	2	192.86	0.00	0.00	10.82	0.00	0.00	1.83
2005	2007	3	3	180.20	0.00	0.00	3.32	0.00	0.00	0.00
2005	2007	3	4	176.88	0.00	0.00	3.26	0.00	0.00	0.00
2005	2007	3	5	173.63	0.00	10.12	3.01	0.00	0.00	0.00
2005	2007	3	6	160.50	0.00	7.50	2.82	0.00	0.00	0.00
2005	2007	3	7	150.18	0.00	14.43	2.50	0.00	0.00	0.00
2005	2007	3	8	133.25	0.00	0.00	2.45	0.00	0.00	0.00
2005	2007	3	9	130.80	0.00	0.00	2.41	0.00	0.00	0.00
2005	2007	3	10	128.39	0.00	0.00	2.37	0.00	0.00	0.00
2005	2007	3	11	126.02	0.00	0.00	2.32	0.00	0.00	0.00
2005	2007	3	12	123.70	0.00	0.00	2.28	0.00	0.00	0.00
2005	2008	3	1	121.42	0.00	0.00	2.24	0.00	0.00	0.00
2005	2008	3	2	119.19	0.00	0.00	2.20	0.00	4.29	112.70
2005	2008	4	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2008	4	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2008	4	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2008	4	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2008	4	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2008	4	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2008	4	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2008	4	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2008	4	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2008	4	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2009	4	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2009	4	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2009	5	3	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2009	5	4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2009	5	5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2009	5	6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2009	5	7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2009	5	8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2009	5	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2009	5	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2009	5	11	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2009	5	12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2010	5	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2005	2010	5	2	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D-9. Reconstructed cohort: 2006 brood.

				Ocean				River		
BY	CY	Age	Month	N	I_{com}	I_{rec}	V	H_r	E_{hat}	E_{nat}
2006	2007	2	3	1228.82	0.00	0.00	68.97	0.00	0.00	0.00
2006	2007	2	4	1159.85	0.00	0.00	65.10	0.00	0.00	0.00
2006	2007	2	5	1094.75	0.00	0.00	61.44	0.00	0.00	0.00
2006	2007	2	6	1033.31	0.00	0.00	58.00	0.00	0.00	0.00
2006	2007	2	7	975.31	0.00	0.00	54.74	0.00	0.00	0.00
2006	2007	2	8	920.57	0.00	0.00	51.67	0.00	0.00	0.00
2006	2007	2	9	868.90	0.00	0.00	48.77	0.00	0.00	0.00
2006	2007	2	10	820.14	0.00	0.00	46.03	0.00	0.00	0.00
2006	2007	2	11	774.11	0.00	0.00	43.45	0.00	0.00	0.00
2006	2007	2	12	730.66	0.00	0.00	41.01	0.00	0.00	0.00
2006	2008	2	1	689.65	0.00	0.00	38.71	0.00	0.00	0.00
2006	2008	2	2	650.94	0.00	0.00	36.53	8.70	3.35	22.35
2006	2008	3	3	580.01	0.00	0.00	10.69	0.00	0.00	0.00
2006	2008	3	4	569.32	0.00	0.00	10.49	0.00	0.00	0.00
2006	2008	3	5	558.83	0.00	0.00	10.30	0.00	0.00	0.00
2006	2008	3	6	548.54	0.00	0.00	10.11	0.00	0.00	0.00
2006	2008	3	7	538.43	0.00	0.00	9.92	0.00	0.00	0.00
2006	2008	3	8	528.51	0.00	0.00	9.74	0.00	0.00	0.00
2006	2008	3	9	518.77	0.00	0.00	9.56	0.00	0.00	0.00
2006	2008	3	10	509.22	0.00	0.00	9.38	0.00	0.00	0.00
2006	2008	3	11	499.84	0.00	0.00	9.21	0.00	0.00	0.00
2006	2008	3	12	490.63	0.00	0.00	9.04	0.00	0.00	0.00
2006	2009	3	1	481.59	0.00	0.00	8.87	0.00	0.00	0.00
2006	2009	3	2	472.72	0.00	0.00	8.71	0.00	6.23	423.12
2006	2009	4	3	34.66	0.00	0.00	0.64	0.00	0.00	0.00
2006	2009	4	4	34.02	0.00	0.00	0.63	0.00	0.00	0.00
2006	2009	4	5	33.39	0.00	0.00	0.62	0.00	0.00	0.00
2006	2009	4	6	32.78	0.00	0.00	0.60	0.00	0.00	0.00
2006	2009	4	7	32.17	0.00	0.00	0.59	0.00	0.00	0.00
2006	2009	4	8	31.58	0.00	0.00	0.58	0.00	0.00	0.00
2006	2009	4	9	31.00	0.00	0.00	0.57	0.00	0.00	0.00
2006	2009	4	10	30.43	0.00	0.00	0.56	0.00	0.00	0.00
2006	2009	4	11	29.87	0.00	0.00	0.55	0.00	0.00	0.00
2006	2009	4	12	29.32	0.00	0.00	0.54	0.00	0.00	0.00
2006	2010	4	1	28.78	0.00	0.00	0.53	0.00	0.00	0.00
2006	2010	4	2	28.25	0.00	0.00	0.52	0.00	0.00	26.83
2006	2010	5	3	NA	NA	NA	NA	NA	NA	NA
2006	2010	5	4	NA	NA	NA	NA	NA	NA	NA
2006	2010	5	5	NA	NA	NA	NA	NA	NA	NA
2006	2010	5	6	NA	NA	NA	NA	NA	NA	NA
2006	2010	5	7	NA	NA	NA	NA	NA	NA	NA
2006	2010	5	8	NA	NA	NA	NA	NA	NA	NA
2006	2010	5	9	NA	NA	NA	NA	NA	NA	NA
2006	2010	5	10	NA	NA	NA	NA	NA	NA	NA
2006	2010	5	11	NA	NA	NA	NA	NA	NA	NA
2006	2010	5	12	NA	NA	NA	NA	NA	NA	NA
2006	2011	5	1	NA	NA	NA	NA	NA	NA	NA
2006	2011	5	2	NA	NA	NA	NA	NA	NA	NA

Table D-10. Reconstructed cohort: 2007 brood.

				Ocean				River		
BY	CY	Age	Month	N	I_{com}	I_{rec}	V	H_r	E_{hat}	E_{nat}
2007	2008	2	3	464.03	0.00	0.00	26.04	0.00	0.00	0.00
2007	2008	2	4	437.99	0.00	0.00	24.58	0.00	0.00	0.00
2007	2008	2	5	413.40	0.00	0.00	23.20	0.00	0.00	0.00
2007	2008	2	6	390.20	0.00	0.00	21.90	0.00	0.00	0.00
2007	2008	2	7	368.30	0.00	0.00	20.67	0.00	0.00	0.00
2007	2008	2	8	347.63	0.00	0.00	19.51	0.00	0.00	0.00
2007	2008	2	9	328.12	0.00	0.00	18.42	0.00	0.00	0.00
2007	2008	2	10	309.70	0.00	0.00	17.38	0.00	0.00	0.00
2007	2008	2	11	292.32	0.00	0.00	16.41	0.00	0.00	0.00
2007	2008	2	12	275.91	0.00	0.00	15.49	0.00	0.00	0.00
2007	2009	2	1	260.43	0.00	0.00	14.62	0.00	0.00	0.00
2007	2009	2	2	245.81	0.00	0.00	13.80	15.72	0.00	0.00
2007	2009	3	3	216.29	0.00	0.00	3.98	0.00	0.00	0.00
2007	2009	3	4	212.31	0.00	0.00	3.91	0.00	0.00	0.00
2007	2009	3	5	208.40	0.00	0.00	3.84	0.00	0.00	0.00
2007	2009	3	6	204.56	0.00	0.00	3.77	0.00	0.00	0.00
2007	2009	3	7	200.79	0.00	0.00	3.70	0.00	0.00	0.00
2007	2009	3	8	197.09	0.00	0.00	3.63	0.00	0.00	0.00
2007	2009	3	9	193.46	0.00	0.00	3.56	0.00	0.00	0.00
2007	2009	3	10	189.90	0.00	0.00	3.50	0.00	0.00	0.00
2007	2009	3	11	186.40	0.00	0.00	3.43	0.00	0.00	0.00
2007	2009	3	12	182.96	0.00	0.00	3.37	0.00	0.00	0.00
2007	2010	3	1	179.59	0.00	0.00	3.31	0.00	0.00	0.00
2007	2010	3	2	176.28	0.00	0.00	3.25	0.00	0.00	163.65
2007	2010	4	3	NA	NA	NA	NA	NA	NA	NA
2007	2010	4	4	NA	NA	NA	NA	NA	NA	NA
2007	2010	4	5	NA	NA	NA	NA	NA	NA	NA
2007	2010	4	6	NA	NA	NA	NA	NA	NA	NA
2007	2010	4	7	NA	NA	NA	NA	NA	NA	NA
2007	2010	4	8	NA	NA	NA	NA	NA	NA	NA
2007	2010	4	9	NA	NA	NA	NA	NA	NA	NA
2007	2010	4	10	NA	NA	NA	NA	NA	NA	NA
2007	2010	4	11	NA	NA	NA	NA	NA	NA	NA
2007	2010	4	12	NA	NA	NA	NA	NA	NA	NA
2007	2011	4	1	NA	NA	NA	NA	NA	NA	NA
2007	2011	4	2	NA	NA	NA	NA	NA	NA	NA
2007	2011	5	3	NA	NA	NA	NA	NA	NA	NA
2007	2011	5	4	NA	NA	NA	NA	NA	NA	NA
2007	2011	5	5	NA	NA	NA	NA	NA	NA	NA
2007	2011	5	6	NA	NA	NA	NA	NA	NA	NA
2007	2011	5	7	NA	NA	NA	NA	NA	NA	NA
2007	2011	5	8	NA	NA	NA	NA	NA	NA	NA
2007	2011	5	9	NA	NA	NA	NA	NA	NA	NA
2007	2011	5	10	NA	NA	NA	NA	NA	NA	NA
2007	2011	5	11	NA	NA	NA	NA	NA	NA	NA
2007	2011	5	12	NA	NA	NA	NA	NA	NA	NA
2007	2012	5	1	NA	NA	NA	NA	NA	NA	NA
2007	2012	5	2	NA	NA	NA	NA	NA	NA	NA