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# The winter-run harvest model (WRHM)

**DRAFT REPORT**

Michael R. O'Farrell

Shanae Allen

Michael S. Mohr

Fisheries Ecology Division

Southwest Fisheries Science Center

National Marine Fisheries Service

110 Shaffer Road, Santa Cruz, CA 95060

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# 1 Abstract

The Winter Run Harvest Model (WRHM) forecasts the annual age-3 ocean impact rate on Sacramento River winter Chinook resulting from fisheries south of Point Arena, CA. This impact rate includes both landed and non-landed mortality attributable to fisheries. The model is a tool developed for use in the Pacific Fishery Management Council (PFMC) arena for managing fisheries to comply with the National Marine Fisheries Service Endangered Species Act consultation standard for Sacramento River winter Chinook beginning in 2012. Analogous to other models used for assessment and management of salmon through the PFMC process, the WRHM is temporally and spatially stratified. Impact rates are forecast for each month, area, and sector (commercial, recreational) to capture variation in exploitation patterns and fishery management measures that occur at that scale. A forecast of the total age-3 impact rate is then made by aggregating impacts over all strata where fishing occurred. The WRHM is capable of accounting for the customary fishery management measures used by the PFMC (e.g., time/area/sector closures, quotas, and minimum size limits). Hence, the WRHM will readily integrate into the PFMC salmon management process.

## 2 Introduction

Sacramento River winter Chinook (SRWC) is an endangered salmon stock harvested incidentally in ocean fisheries. SRWC were first listed as threatened in 1989, and then downgraded to endangered in 1994. Most recently, in the 2010 Biological Opinion for ocean fisheries (NMFS 2010), the National Marine Fisheries Service (NMFS) found that ocean fisheries are likely to jeopardize the continued existence of SRWC owing to a lack of measures and tools to constrain or reduce fishery impacts when SRWC population status is poor. NMFS offered a reasonable and prudent alternative (RPA) to comply with the ESA, which included (1) establishing thresholds related to the status of SRWC, (2) establishing fishery management objectives, and (3) development of analytical tools and assessment models that can implement the fishery management objectives in the salmon fishery management process. This report documents one portion of component (3): the Winter Run Harvest Model (WRHM).

Development of the new SRWC fishery management objectives is in progress and the final form of the ocean fishery management framework rule is not known as of September 2011. However, some aspects of the framework are known at this time. In particular, a control rule will annually specify a maximum allowable age-3 ocean fishery impact rate, and this age-3 impact rate will apply only to fisheries occurring south of Point Arena, California. The impact rate includes both landed and non-landed mortality attributable to fisheries, and the region covered includes the San Francisco (SF) management area (Point Arena to Pigeon Point), and the Monterey (MO) management area (Pigeon Point to the US/Mexico border).

For SRWC, the age-3 ocean fishery impact rate is an appropriate metric for use in controlling overall fisheries exploitation. The age-3 impact rate closely approximates the cohort's spawner reduction rate, which is the fraction of a cohort's potential spawners that are eliminated by the fishery (see Figure 5 in O'Farrell et al. 2011). The concordance between the age-3 impact rate and the spawner reduction rate is due to the very high ($>$ 85 percent) age-3 maturation rates SRWC exhibit (O'Farrell et al. 2011). In addition, the age-3 impact rate can be forecast in the absence of a SRWC preseason abundance forecast. A preseason abundance forecast cannot be made for SRWC

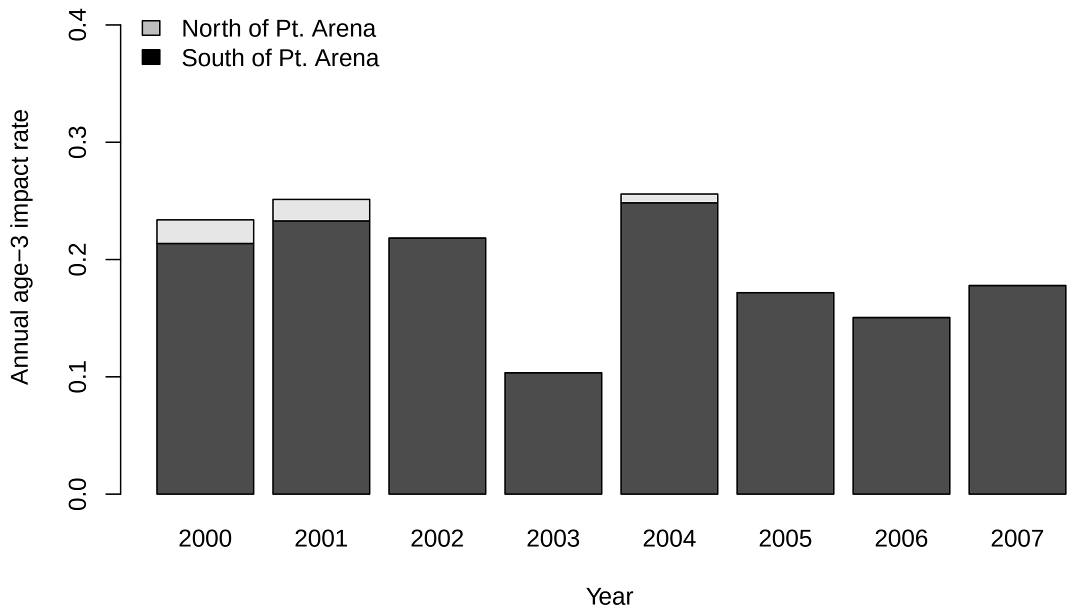


**Figure 1.** Age-3 ocean fishery impact rate, partitioned by contributions from fisheries north and south of Point Arena, CA.

in time for the PFMC preseason management process due to the timing of SRWC spawning and the timing of annual ocean salmon fisheries. The age-2 (jack) river return data that would be necessary to forecast age-3 abundance prior to spring/summer ocean salmon fisheries are not available until the fall or winter following those fisheries, and therefore are not useful for making a timely age-3 ocean abundance forecast.

Forecasts of the age-3 impact rate will be confined to fisheries occurring in management areas south of Point Arena because the overwhelming majority of SRWC impacts occur in this region. Figure 1 demonstrates that in most years for which the age-3 impact rate has been estimated, zero impacts resulted from fisheries north of Point Arena, and when they did occur, they represented a very small portion of the overall age-3 impact rate. Between years 2000 and 2007, the age-3 impact rate attributed to fisheries north of Point Arena averaged 0.0058.

The WRHM consists of projecting an age-3 cohort abundance through ocean fisheries on a monthly basis between March 1 (year $y$) and the last day of February ($y+1$). The starting abundance is arbitrary and does not affect the forecast of the annual age-3 impact rate; hereafter we assume that the March 1 ($y$) ocean abundance is equal to 1. March 1 was chosen as the "birth date" for SRWC, based on the reported peak migration period into the Sacramento River basin from Fisher (1994). Monthly age-3 impacts, forecast by area (SF, MO), and sector (commercial, recreational) under the proposed fishery management measures, are deducted from the monthly abundance. The total, age-3 impact rate is then computed by totaling the month/area/sector impacts and dividing by the assumed March 1 ($y$) ocean abundance. The WRHM is able to accommodate days-open (fisheries specified as the number of days open to fishing and not as a harvest limit) and quota fishery management measures, with one exception that is explained in more detail in section 4.2. The WRHM is also able to account for variation in minimum size limits. Hence, management measures such as month/area/sector closures and minimum size limits commonly used by the PFMC to constrain the salmon fishery can be directly accounted for in the WRHM-derived forecast of the age-3 impact rate.

Documentation of the WRHM follows in sections 3 and 4. Section 3 defines the main model structure and methods used to project the age-3 cohort through ocean fisheries, and the expression used to forecast the age-3 impact rate. Section 4 describes the submodels and input variables used to parameterize the WRHM. The report ends with a discussion of key components of the model and a comparison to existing PFMC harvest models for Chinook salmon.

# 3 Main model

The age-3 SRWC cohort abundance is projected through ocean fisheries sequentially from $t =$ March ($y$) through $t =$ February ($y+1$). The method of forward projection of the age-3 cohort is consistent with the backward reconstruction of cohorts described for SRWC in O'Farrell et al. (2011).

For each month $t$, the following metrics are computed by area $z$ and sector $x$:

$$C_{tzx} = c_{tzx} \times N_t \tag{1}$$

$$H_{tzx} = C_{tzx} \times p_{tzx} \tag{2}$$

$$S_{tzx} = (C_{tzx} - H_{tzx}) \times s_{tzx} \tag{3}$$

$$D_{tzx} = C_{tzx} \times d \tag{4}$$

$$I_{tzx} = H_{tzx} + S_{tzx} + D_{tzx}, \tag{5}$$

with cohort abundance ($N$), contacts ($C$), harvest ($H$), release mortality ($S$), dropoff mortality ($D$), and impacts ($I$) dependent on the contact rate ($c$), the proportion of fish that are greater than or equal to the minimum size limit ($p$), the release mortality rate ($s$), and the dropoff mortality rate ($d$). Because the model confines itself to age-3, we have for simplicity suppressed the use of a subscript denoting age for these quantities.

To project the cohort abundance forward in one month increments, total monthly impacts

$$I_t = \sum_{z,x} I_{tzx} \tag{6}$$

are first deducted from $N_t$, followed by application of the monthly natural survival rate

$$N_{t+1} = (N_t - I_t) \times (1 - v), \tag{7}$$

where $v$ denotes the monthly natural mortality rate.

Following projection of the cohort abundance across months, the age-3 impact rate ($i_3$) is forecast as

$$i_3 = \frac{\sum_t I_t}{N_{\text{March}}}. \tag{8}$$

In practice, $N_{\text{March}}$ is specified as 1, and $i_3$ reduces to the numerator in (8).

In the following section, the submodels and input variables used to parameterize the $c$, $p$, $s$, and $d$ rates are described.

# 4 Submodels and input variables

## 4.1 Contact rate

Age-3 month/area/sector contact rates have been estimated for years 2000–2009 through cohort reconstruction (O'Farrell et al. 2011). Pairing postseason estimates of $c_{tzx}$ with postseason fishing effort estimates $f_{tzx}$ allows for forecasting the contact rate per unit effort ($\beta_{tzx}$), and ultimately, the contact rate expectation in proposed fisheries.

Forecasts of $\beta_{tzx}$ are determined by the slope of a zero-intercept linear model fitted to historical $c_{tzx}$ and $f_{tzx}$ data. Figures 2 and 3 displays these relationships for the commercial and recreational sectors, respectively. A ratio estimator is used to determine the month/area/sector contact rate per unit effort forecast,

$$\beta_{tzx} = \frac{\bar{c}_{tzx}}{\bar{f}_{tzx}} \tag{9}$$

following the methodology used for the KOHM (Mohr 2006a), where $\bar{c}_{tzx}$ and $\bar{f}_{tzx}$ denote the respective average of these quantities over the historical data.

Expected contact rates are then forecast using $\beta_{tzx}$ and the effort forecast for that month/area/sector:

$$c_{tzx} = \beta_{tzx} \times f_{tzx}, \tag{10}$$

with the effort forecast determined as described in the following section.

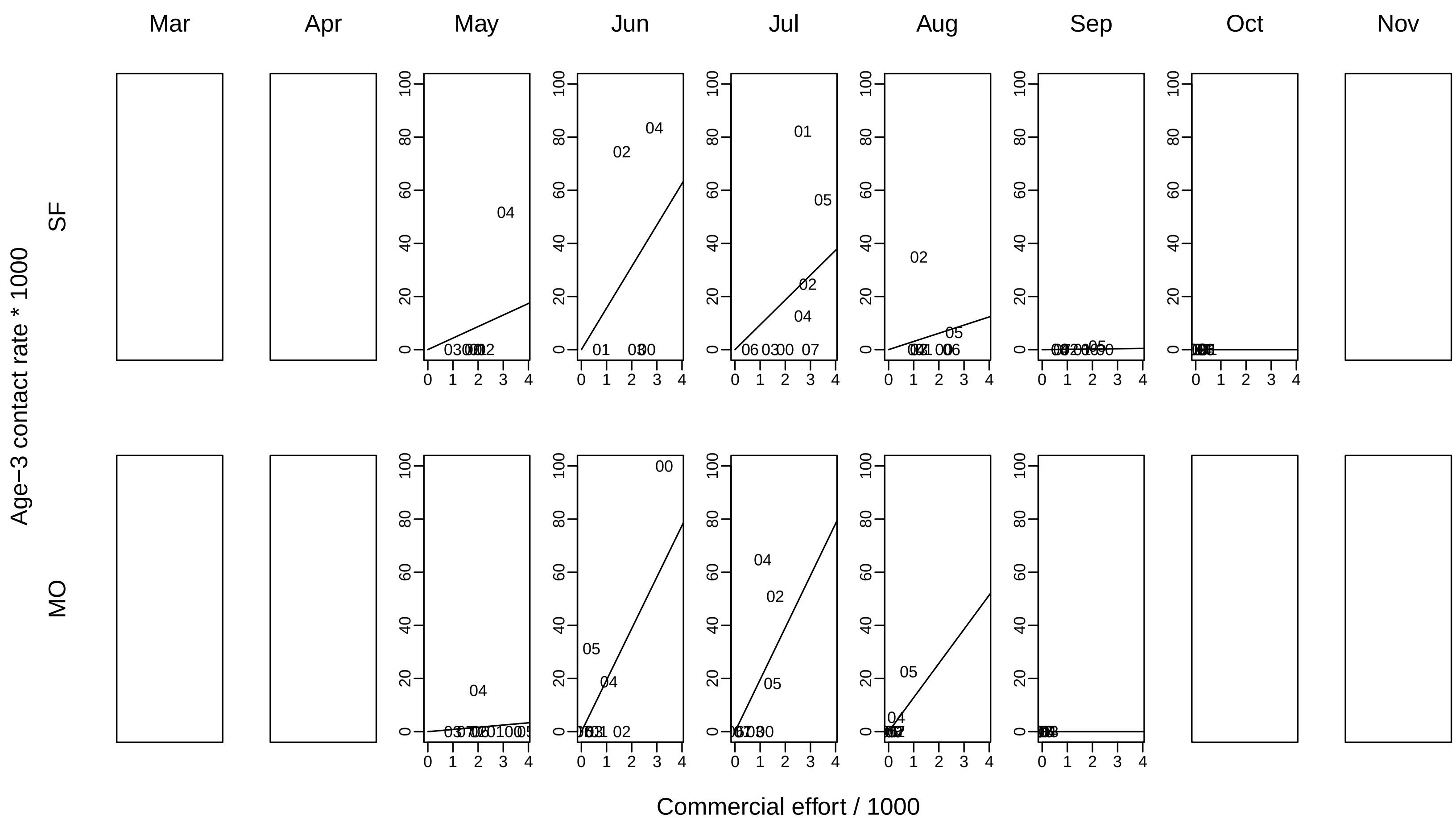


**Figure 2.** Commercial sector age-3 contact rates, plotted as a function of fishing effort, by month and management area. Numbers in the plot are the last two digits of the calendar year for the contact rate and effort estimates.

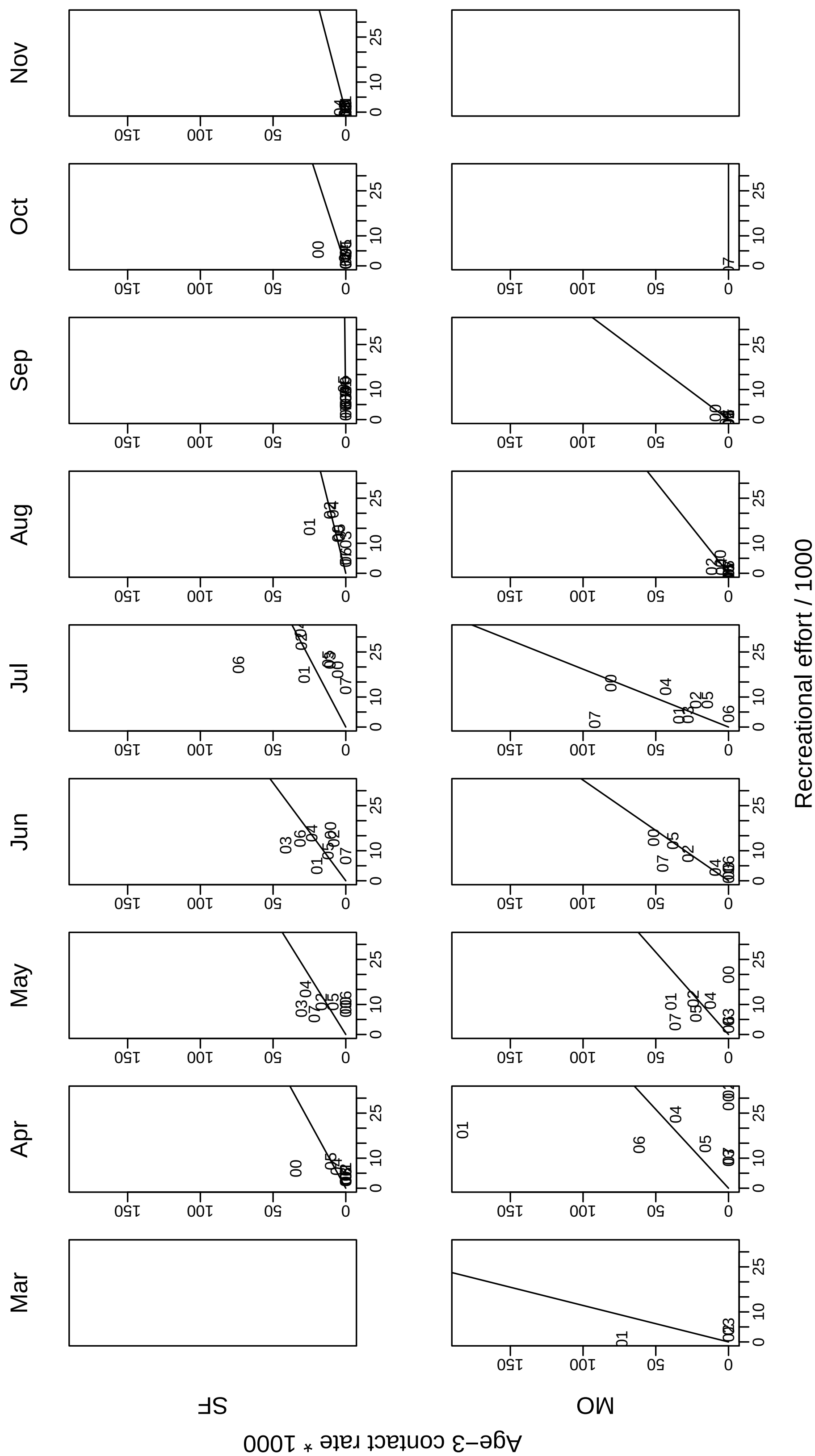


**Figure 3.** Recreational sector age-3 contact rates, plotted as a function of fishing effort, by month and management area. Numbers in the plot are the last two digits of the calendar year for the contact rate and effort estimates.

## 4.2 Fishing effort

Fishing effort is forecast for each month/area/sector external to the WRHM. Effort forecasts are necessary inputs for the Klamath Ocean Harvest Model (KOHM) and Sacramento Harvest Model (SHM), as well as the WRHM, hence they are shared across models. Fishing effort forecast methods for both days-open fisheries and quota fisheries are documented in Mohr (2006a,b).

As described in Mohr (2006a), quota fishery effort is forecast in a different manner than days-open fishery effort. Effort expected in a quota fishery is determined by the size of the mixed-stock quota and the stock contribution rate of abundant target stocks (e.g., Klamath and Sacramento River fall Chinook). For quota fisheries occurring between September ($y$) and February ($y+1$), the stock contribution rate of these target stocks is not known at the time of the PFMC preseason salmon management process because the ocean abundance of these fall run stocks has not yet been forecast (O'Farrell 2009). As a result, it is currently not possible to forecast effort in quota fisheries for these months. Note, however, that quota fisheries in the SF and MO area during this period have been extremely rare.

## 4.3 Proportion legal size

Determination of $p_{tzx}$ requires a specified minimum size limit ($l^*_{tzx}$), and the mean ($\mu_t$) and standard deviation ($\sigma_t$) of the length distribution of age-3 SRWC in the ocean for month $t$. Minimum size limits are specified for nearly all ocean fisheries, and are a standard input to the WRHM. The model used to estimate monthly size-at-age is described in O'Farrell et al. (2011, Appendix A). Size-at-age in month $t$ is assumed to be normally distributed so that given $l^*_{tzx}$, $\mu_t$, and $\sigma_t$,

$$p_{tzx} = P\{l \geq l^*_{tzx} | \mu_t, \sigma_t\} = 1 - \Phi(l^*_{tzx} | \mu_t, \sigma_t), \tag{11}$$

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

## 4.4 Release mortality rate

Based on the Salmon Technical Team (STT) review of hook and release mortality rates (STT 2000), we employ the conventional rate values of $s_{tz(\text{com})} = 0.26$ for the commercial sector, and $s_{tz(\text{rec})} = 0.14$ for the recreational sector when the method of fishing is exclusively trolling.

However, for the recreational sector, if the method of fishing known as "mooching" is used in addition to trolling in a particular month/area, then $s_{tz(\text{rec})}$ is formulated as a weighted average of the troll release mortality rate (0.14) and the elevated mooch release mortality rate (0.422) (Grover et al. 2002). Mooching is a fishing technique that consists of drifting whole bait, encourages swallowing of the bait, and results in a high proportion of these fish being gut-hooked (hence the high release mortality rate). Mooching is popular in the SF and MO areas, but its use varies by month/area. Denoting by $\bar{\rho}_{tz}$ the 5-year average of the month- and area-specific proportion of the recreational catch taken by mooching, the $s_{tz(\text{rec})}$ forecast for the SF and MO areas is derived as

$$s_{tz(\text{rec})} = (\bar{\rho}_{tz} \times 0.422) + ((1 - \bar{\rho}_{tz}) \times 0.14). \tag{12}$$

Grover et al. (2002) presents details pertaining to the parameterization of this relationship.

## 4.5 Dropoff mortality rate

Fish that contact fishing gear yet are not brought to the boat may experience dropoff mortality. This source of mortality could result from a variety of causes, such as predation events or wounds inflicted by the fishing gear. Following STT (2000), we employ the conventional rate value of $d = 0.05$.

## 4.6 Natural mortality rate

The natural mortality annual rate is assumed to be 20 percent, and this corresponds to a monthly rate value of $v = 0.0184$. This is consistent with values used in the assessment of other Pacific salmon (e.g., Goldwasser et al. 2001; Mohr 2006a).

# 5 Discussion

We have formulated a harvest model capable of forecasting the annual age-3 impact rate for SRWC, given a proposed set of ocean salmon fishery management measures. This model will be used as a tool to meet, in expectation, maximum allowable age-3 impact rates specified by the SRWC consultation standard. The PFMC will have the customary fishery management controls of time/area/sector closures, spring/summer quotas, and minimum size limits available to meet the SRWC objectives.

Key inputs to the WRHM such as fishing effort and contact rates are based on relationships that utilize new information as it becomes available. Cohort reconstructions will be performed annually, providing new data that will be incorporated into the WRHM each year. This process allows the model to integrate changes in effort or exploitation patterns should they occur.

Contact rate forecasts are a very important component of the WRHM. For the commercial sector, examination of contact rate and effort relationships illustrate the relative rarity of coded-wire tagged age-3 SRWC harvest. In part, this can be explained by the low abundance of SRWC relative to target stocks such as Sacramento River fall Chinook. In addition, for the spring and summer months, a large proportion of age-3 SRWC are smaller than typical commercial minimum size limits (O'Farrell et al. 2011, table A-2) and therefore landed catch is low. These factors contribute to the many instances of zero contact rates, with occasional nonzero estimates for most month and area strata. This pattern is not evident for recreational fisheries, where age-3 SRWC become largely vulnerable to retention in the spring, and nearly all are vulnerable in the summer, given typical recreational sector size limits. As a result, fewer zero contact rate estimates exist, and patterns in contact rates per unit effort are more clearly evident for the recreational sector.

Since 2004, recreational fisheries south of Point Arena have been required to open no earlier than the first Saturday in April, yet these fisheries traditionally opened in mid-February. Sufficient data do not exist to allow for robust contact rate estimation in February and March. Resumption of these early fisheries would result in highly uncertain forecasts of age-3 impact rates for those months because $\beta_{tzx}$ would need to be assumed rather than directly estimated. Because of SRWC river return timing, it is likely that $\beta_{tzx}$ is high in February and March (see Figure 11 in O'Farrell et al. 2011). This potential problem also exists for the commercial sector if fisheries prior to May 1 are proposed, and for both sectors if fisheries are proposed for late-fall or winter, when contact rate estimates are sparse or nonexistent.

The WRHM shares many structural similarities to existing PFMC harvest models for Chinook salmon, and to the KOHM in particular. Like the KOHM, the WRHM is an age-structured model, though it only accounts for one age class. It is linked to a cohort reconstruction model with the same structure, which is updated annually. A size-at-age model is incorporated into both the KOHM and WRHM to allow for forecasting of release mortality incurred by sublegal size fish. Contact rates per unit effort are forecast in the same manner. Finally, many of the same conventions for $s$, $d$, and $v$ are shared across models. In contrast to the existing harvest models, the WRHM does not account for river fisheries as SRWC are rarely harvested in the Sacramento River. Most importantly, neither preseason ocean abundance forecasts nor spawner escapement forecasts are made by the WRHM. As such, the WRHM can be considered a simplified harvest model in the same family as the KOHM and SHM.

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