An evaluation of the proposed increases in spatial stratification for California salmon fisheries

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Abstract

The merits of adding additional management lines to the existing California salmon management areas at Point Reyes and Point Sur were evaluated based on coded-wire tag (CWT) and genetic stock identification (GSI) data. Owing to the low levels of CWT recoveries for Sacramento River winter Chinook, and the implications for stock assessment precision, increased spatial stratification is not recommended for this stock. For Klamath River fall Chinook, the assessment precision costs to further stratifying CWT recovery data, and the limited support for differences in relative density north and south of Point Reyes also suggests that increased spatial stratification is not advisable. For Sacramento River fall Chinook, sufficient CWT recovery data exist to allow for increased spatial stratification. Yet, GSI data do not suggest consistent differences in relative density across the two proposed management lines. In summary, it is recommended that the existing San Francisco and Monterey management areas should remain in place with no additional management lines at Point Reyes or Point Sur.

Introduction

South of Cape Falcon, Oregon, salmon fishery management is spatially stratified by seven management areas: three in Oregon and four in California (for a map of California management areas, see Figure 1). At their April 2015 meeting, the Pacific Fishery Management Council (PFMC) requested an evaluation of potential modifications to fishery management area boundaries in California, including 1) the addition of a management line subdividing the California Klamath Management Zone (KC) into two management areas, 2) the addition of a management line at Point Reyes subdividing the San Francisco management area (SF) into two management areas, and 3) the addition of a management line at Point Sur splitting the Monterey management area (MO) into two management areas. If these existing management areas were to be modified as described above, the number of fishery management areas in California would increase from four to seven. The stocks, and stock assessments, that would be most affected by changes in management area boundaries are Sacramento River winter Chinook (SRWC), Klamath River fall Chinook (KRFC), and Sacramento River fall Chinook (SRFC). In this report, we address the request to evaluate Point Reyes and Point Sur as new management area boundaries with respect to these three stocks and their assessments. With regard to the request to evaluate a new management line within the KC area, there are currently insufficient data to perform that evaluation and a test fishery proposal is being developed to address this data deficiency.

Salmon fishery management is spatially stratified to enable effective weak stock management. Since there is some stability in the spatial distributions of many salmon stocks (Norris et al. 2000, Weitkamp 2010), spatial stratification of the ocean into management areas can allow for crafting fisheries that reduce fishing mortality on weak stocks. If there are strong biogeographic boundaries coinciding with management area boundaries, the effectiveness of weak stock management could be improved relative to a scenario where management boundaries are set based on other criteria (e.g., jurisdictional boundaries). Therefore, it makes sense to evaluate management areas to determine whether their boundaries are appropriate from an assessment and management perspective.

However, there can be costs to increasing stratification of finite data. Most salmon stock assessments, including those for SRWC, KRFC, and SRFC, rely on coded-wire tag (CWT) recovery data stratified at the level of month, management area, and fishery (e.g., commercial, recreational). For KRFC and SRWC, assessments are further stratified by age. Hankin et al. (2005) noted that there has been increasing pressure to perform more highly stratified assessments to support fishery management. The result of increased stratification is a reduction in stratum-specific CWT recoveries which leads to less precise stratum-specific fishing mortality rate estimates (Alexandersdottir et al. 2004, Hankin et al. 2005, PSC CWT Workgroup 2008). A decrease in exploitation rates over time has exacerbated this problem because it has led to fewer overall CWT recoveries for many stocks (Hankin et al. 2005). These trends undoubtedly have negative effects on the quality of salmon stock assessments.

Our general approach to the evaluation of Point Reyes and Point Sur as management lines was to first address the question of whether an increase in stratification by the addition of management area boundaries could be supported given the number of stock-specific CWT recoveries observed in recent years. We then evaluated genetic stock identification (GSI) data relevant to estimating the distribution of SRWC, KRFC, and SRFC about Point Reyes and Point Sur.

This report is organized as follows. We begin by providing a brief, general description of the use of CWT recovery data in the current stock assessments for SRWC, KRFC, and SRFC. We then review the effects of increased stratification of CWT recoveries on these stock assessments and describe the available GSI data. The benefits and consequences of proposed subdivision of the SF management area into two areas separated by Point Reyes and the MO management area into two areas separated by Point Sur are then evaluated individually for SRWC, KRFC, and SRFC using both CWT and GSI data. We conclude with recommendations regarding the use of Point Reyes and Point Sur as management area boundaries.

The use of CWTs in salmon stock assessments south of Cape Falcon

The stock assessments for SRWC, KRFC, and SRFC consist of both retrospective and prospective components. The retrospective components are various forms of run reconstruction from which abundance, harvest, and fishing mortality rates are estimated (among other quantities). Results from the retrospective portion of the assessments are used to evaluate whether Endangered Species Act (ESA) consultation standards are met, determine overfishing status, and evaluate compliance with annual catch limit requirements. The prospective components are generally referred to as harvest models and are used in the PFMC salmon management process to assess whether proposed fishing season structures result in expected compliance with individual stock management objectives. The retrospective and prospective components of the overall stock assessment are linked. Estimates from the retrospective portion of an assessment are used to parameterize the prospective, harvest model portion of an assessment.

The SRWC stock assessment is limited to the area south of Point Arena, California, which encompasses the two southernmost management areas: SF and MO. The proposed modifications of the current management areas would increase these two management areas to four areas, doubling the level of stratification for this assessment. The retrospective component of the assessment is a cohort reconstruction model (O'Farrell et al. 2012b) where age-specific abundance, contact rates, harvest rates, impact rates, and maturation rates are estimated from CWT recoveries of hatchery-origin fish. Contact rates *c* are the fraction of a cohort that encounter fishing gear, and these rates are an important component of the predicted impact rates used for fishery planning in the PFMC salmon management process. From the cohort reconstruction, contact rates are estimated for each age *a*, month *m*, management area *z*, and fishery sector *x*,

$$c_{a,m,z,x} = \frac{C_{a,m,z,x}}{N_{a,m}}, \qquad (1)$$

where *N* is the estimated abundance and *C* is the number of fish contacted by the fishing gear. Contacts are derived by expanding CWT recoveries by the sampling fraction, the mark rate, and the proportion of fish of legal size in the age/month/area/fishery stratum (O'Farrell et al. 2012b).

The Winter Run Harvest Model (WRHM; O'Farrell et al. 2012a) is the prospective component of the SRWC assessment. The WRHM uses age/month/area/fishery estimates of the contact rate coupled with estimated fishing effort *f*, to estimate average contact rates per unit effort β:

$$\beta_{a,m,z,x} = \frac{\bar{c}_{a,m,z,x}}{\bar{f}_{m,z,x}} \qquad (2)$$

where the $\bar{\ }$ indicates the arithmetic mean over years with paired *c* and *f* estimates in the stratum. Contact rates per unit effort are then multiplied by month/area/fishery forecasts of fishing effort, to produce a predicted, stratum-specific contact rate

$$\hat{c}_{a,m,z,x} = \beta_{a,m,z,x} \times \hat{f}_{m,z,x}, \qquad (3)$$

where $\hat{\ }$ indicates forecasted values. The predicted contact rates derived from equation 3 are the beginning of a string of computations within the WRHM that result in a prediction of the impact rate (O'Farrell et al. 2012a). As a result, the precision of stratum-specific contact rates estimated from the cohort reconstruction using CWT recoveries has a strong effect on the WRHM-derived predictions of the impact rate. Figure 2 displays SRWC age-3 contact rates plotted against fishing effort for the recreational fishery (a similar plot exists for the commercial sector but is not displayed). Each point represents a single year of paired contact rate and effort estimates. Uncertainty in contact rates affects the vertical position of the points in Figure 2, while uncertainty in fishing effort estimates affects the horizontal position of the points. In combination, uncertainty in these estimated quantities and year-specific process error has a strong effects on the contact rate per unit effort (β is the slope of the fitted line in Figure 2) used within the WRHM to make forecasts of the impact rate. The accuracy of effort forecasts will also affect the WRHM-derived predicted impact rates. Preseason forecasts of fishing effort are shared between all harvest models and the forecasting procedure is described in Mohr and O'Farrell (2014).

As with SRWC, the retrospective component of the KRFC assessment is a cohort reconstruction model (Goldwasser et al. 2001, Mohr 2006a). Age-specific abundance of the aggregate stock (hatchery- and natural-origin fish) is estimated from the KRFC cohort reconstruction model and these abundance estimates are used to forecast the abundance available for harvest in planned fisheries. Contact, harvest, and impact rates are estimated at the age/month/area/fishery level of stratification. The KRFC stock is more widely distributed relative to SRWC and the assessment extends to all management areas between Cape Falcon and Point Sur. Because the assessment does not continue south of Point Sur, the proposed management area boundary at Point Sur is not relevant to the KRFC assessment. The Klamath Ocean

Harvest Model (KOHM; Mohr 2006b) is the prospective component of the KRFC assessment. The KOHM uses age/month/area/fishery estimates of contact rates in a similar manner to the WRHM to predict harvest and impact rates based on proposed fishing season structures. As such, the precision of estimated contact rates has a strong effect on age-specific harvest and impact rates, as well as the predicted spawner escapement at age.

The retrospective assessment of SRFC is focused on estimation of the Sacramento Index (SI; O'Farrell et al. 2013). The SI is an aggregate-age index of adult ocean abundance for SRFC that is derived from CWT recoveries south of Cape Falcon. Estimates of adult ocean harvest, derived from expanded CWT recoveries and stratified by month/area/fishery, are divided by the SI to yield stratum-specific harvest rates. The Sacramento Harvest Model (SHM; Mohr and O'Farrell 2014) is the prospective component of the SRFC assessment. The SHM uses month/area/fishery estimates of harvest rates, coupled with fishing effort, to estimate a month/area/fishery average harvest rate per unit effort in a manner analogous to the estimation of contact rates per unit effort in the WRHM and KOHM. As with the WRHM and KOHM, the precision of stratum-specific harvest rates derived from CWT recoveries, and the accuracy of fishing effort forecasts, affects the SHM-derived predictions of SRFC harvest rates and escapement.

Effects of stratification on salmon stock assessment

Over time there has been increased stratification (by time, area, and fishing sector) of salmon stock assessments. This topic has been directly addressed in three reports: 1) Technical Review of the CWT System and Its Use for Chinook and Coho Salmon Management (Alexandersdottir et al. 2004), 2) Report of the Expert Panel on the Future of the Coded Wire Tag Recovery Program for Pacific Salmon (Hankin et al. 2005), and 3) An Action Plan in Response to Coded Wire Tag (CWT) Expert Panel Recommendations (PSC CWT Workgroup, 2008). We review the findings of these reports as they pertain to the use of CWT recoveries for stratified salmon assessments. These reports primarily refer to salmon fisheries managed under the Pacific Salmon Treaty, though the concepts discussed with regard to the use of CWTs for stock assessment are directly applicable to PFMC fisheries.

Of relevance are the estimators for the catch (or escapement) and the variance of catch (or escapement) in an individual stratum for a marked and tagged cohort. For an individual stratum where one assumes that the total harvest (all stocks combined) is estimated without error, the number of tagged fish of stock *s* harvested in stratum *i* is

$$H_{s,i} = \frac{T_{s,i}}{\lambda_i} \qquad (4)$$

where H is the estimated catch of tagged fish, T is the number of CWT recoveries, and λ is the fraction of the total (all stocks) harvest that is sampled. The sample variance of H_{si} is then

$$Var(H_{s,i}) = \frac{T_{s,i}}{\lambda_i^2}(1 - \lambda_i) \qquad (5)$$

(Bernard and Clark 1996, Alexandersdottir et al. 2004, PSC CWT Workgroup 2008). Both Alexandersdottir et al. (2004) and PSC CWT Workgroup (2008) represent the uncertainty in estimated catch and exploitation rates with the percent standard error (*PSE*), defined as

$$PSE_{s,i} = \frac{\sqrt{Var(H_{s,i})}}{H_{s,i}} \times 100. \qquad (6)$$

The sample variance and *PSE* of estimated catch from a tagged cohort have dependence on the number of CWT fish recovered in the sample and the sampling fraction. Figure 3 illustrates how estimated catch, catch variance, and the *PSE* vary with the number of tags recovered and the sampling rate. Increased CWT recoveries and higher sampling fractions both result in reduced *PSE* for catch estimates (Figure 3c). PSC CWT workgroup (2008) note that the maximum level of uncertainty deemed acceptable is a *PSE* of 0.30, which is the approximate value obtained when 10 CWTs are recovered under a 20 percent sampling rate (the target sampling rate in California and Oregon salmon fisheries) (Figure 3c).

The variance and *PSE* of catch for a tagged cohort under this most simple case where we assume that total catch (all stocks) in a stratum is known without error is reasonable for many commercial fisheries where catch values are determined through landing receipts and there is little uncertainty. In recreational fisheries where total catch is estimated through sampling, the uncertainty in the total catch estimate must be taken into account when estimating the variance and *PSE* (see Bernard and Clark 1996, Alexandersdottir et al. 2004, PSC CWT Workgroup 2008 for methods used to estimate the sample variance in this case). Including the uncertainty in total catch into the estimation of variance and *PSE* increases these quantities relative to the scenario described above and depicted in Figure 3.

Based on these general principles for estimating the variance of catch for a tagged cohort, Alexandersdottir et al. (2004) describe actions that can be taken to improve the precision of exploitation rates, including increasing the number of tagged fish released, increasing the sampling rate, or redefining fishery resolution. With regard to fishery resolution, the authors note that there are many low stratum-specific fishing mortality rates in the relatively highly stratified fisheries of the PSC management regime and these estimated mortality rates are informed by few CWT recoveries and thus have high *PSE*. If a higher level of precision is desired, strata can be aggregated to effectively increase the stratum specific fishing mortality rate (and CWT recoveries).

Hankin et al. (2005) note that inherent statistical uncertainties in catch estimation were exacerbated in the early 1990s by reduced survival and exploitation rates. Both reduced survival rates and reductions in fisheries resulted in fewer CWT recoveries which effectively increases uncertainty in CWT-based estimates of fishing mortality. At the same time, reduced CWT recoveries were being spread ever thinner by the increased spatial and temporal complexity of fisheries. Hankin et al. (2005) summarize by stating “This increasingly fine scale of resolution that seems required (or desired) by fishery managers can only come at the expense of greatly increased estimation uncertainties within individual fisheries” (Hankin et al. 2005, p. 9).

The PSC CWT Workgroup (2008) was tasked with addressing the recommendations of the Hankin et al. (2005) Expert Panel report. To this end, the workgroup recommended guidelines for improving estimates based on CWTs, including achieving ten observed tags within each sampling stratum to provide a 30% PSE for strata that represent a substantial proportion of the stock’s total exploitation rate (defined as ≥ 2.5 percent of the overall exploitation rate). To achieve this guideline, the PSC CWT Workgroup (2008) recommended evaluating both sampling rates and CWT group release size for indicator stocks. We evaluated the adequacy of CWT recoveries for SRWC, KRFC, and SRFC relative to the 10 tag recoveries per stratum guideline.

To provide some perspective on the level of stratification for the estimation of fishing mortality rates in PFMC fisheries south of Cape Falcon, we examined the number of strata for which CWT-based estimates of fishing mortality will be required for 2015 fisheries impacting SRFC, KRFC, and SRWC. For the commercial fishery south of Cape Falcon, there were a total of 33 month/management area strata (17 in OR and 16 in CA). For the recreational fishery south of Cape Falcon, there were a total of 47 month/management area strata (21 in OR and 26 in CA). For the aggregate-age SRFC assessment, 80 month/area/fishery estimates of fishing mortality will be made postseason for the 2015 fishery. For the age-structured KRFC assessment, where there are two primary age classes for which fishing mortality rates are estimated, the 2015 fisheries result in 160 age/month/area/fishery strata. For SRWC, the assessment is confined to the two current management areas south of Point Arena with one primary age class, resulting in a total of 23 month/area/fishery estimates of fishing mortality for 2015 fisheries.

Genetic stock identification

Recent GSI sampling in California and Oregon has been performed by the West Coast GSI Collaboration, and a focus of this program has been the linking of tissue samples with the precise location of fish encounters (Satterthwaite et al. 2014, Bellinger et al. 2015). This fine scale spatial information is not available for CWT data which are linked to a port of landing. In some cases, CWT recoveries linked to the port of landing may have been from fish harvested far from the port of landing, possibly in another fishery management area, which can confound estimation of fine scale stock distributions. The incidence of “cross-porting” is more pronounced in the commercial fishery relative to the recreational fishery.

While GSI data have some advantages over CWT data for addressing spatial questions, there are limitations to these data that have prevented GSI information from being used directly in salmon stock assessment on the U.S. west coast. Of relevance to this analysis are mismatches between the resolution of genetic reporting groups and stock definitions used in PFMC fishery management as well as the lack of inherent age information from GSI data. We will not dwell on such issues here since they have been discussed at length in a variety of sources (e.g., O’Farrell et al. 2012c, Satterthwaite et al. 2014, Satterthwaite et al. 2015, Bellinger et al. 2015). We instead will review and evaluate new GSI information as it pertains to stock-specific catch per unit effort (CPUE) in regions north and south of the proposed new management area boundaries.

Information pertinent to the use of Point Reyes as a management boundary can be found in Satterthwaite et al. (2014, 2015) and Bellinger et al. (2015). Satterthwaite et al. (2014) made inferences regarding spatial distributions of Klamath Chinook and California Coastal Chinook based on GSI data collected from the commercial fishery in 2010 and 2011 (the Klamath Chinook reporting group is primarily comprised of KRFC, though it is inclusive of Klamath River spring Chinook). Estimates of CPUE suggested that Klamath Chinook had similar or higher density in the SF-N area relative to SF-S, where results varied among years and months. Using the same GSI data as Satterthwaite et al. (2014) from 2010 but applying different methods, Bellinger et al. (2015) described qualitatively similar results with regard to Klamath CPUE north and south of Point Reyes. There was no coherent pattern in Central Valley (CV) fall Chinook CPUE between the SF-N and SF-S areas (the CV fall Chinook GSI reporting group includes SRFC, as well as other stocks such as San Joaquin fall Chinook, Sacramento River late fall Chinook, and Feather River Hatchery spring Chinook). Using dockside-collected genetic data from the recreational fishery in California for years 1998-2002, Satterthwaite et al. (2015) tested the hypothesis that there is a change in stock-specific CPUE at Point Reyes. With regard to Klamath Chinook, results were mixed with evidence of a higher local density in SF-S (relative to SF-N) in May, though the converse was found for July and September. With regard to SRWC, there was evidence for a higher local density in the SF-S region relative to SF-N, though Satterthwaite et al. (2015) caution that it is difficult to quantify differences in local density for this population owing to the very low sample size. Central Valley fall Chinook showed little evidence of CPUE differences across Point Reyes, with the exception of the month of May, where there was evidence for higher CPUE in SF-S.

Limited information pertinent to the use of Point Sur as a management boundary can be found in Bellinger et al. (2015). Catch per unit effort for SRWC was estimated to be marginally higher in MO-S relative to MO-N in the months of August and September (there appear to be no SRWC samples from May-July). Central Valley fall Chinook appear to have similar or higher CPUE in MO-N relative to MO-S.

We obtained GSI data collected at sea by California commercial salmon fishermen from 2010-2014 as part of the West Coast GSI Collaboration (data provided to the senior author by Carlos Garza and Anthony Clemento, National Marine Fisheries Service, Santa Cruz, CA). Details regarding the collection of genetic samples are provided in Satterthwaite et al. (2014) and Bellinger et al. (2015). We computed stock-specific CPUE for Klamath Chinook, CV fall Chinook, and SRWC for the areas north and south of Point Reyes and Point Sur, when applicable to the particular stock. Stock-specific CPUE was computed using the method of Bellinger et al. (2015),

$$CPUE_{s,i} = p_{s,i} \times \frac{H_i}{f_i}, \qquad (7)$$

where total CPUE (or in the case of non-retention sampling, contacts per unit effort) was partitioned into stock-specific CPUE based on the proportion of genotyped samples with assignment to stock *s* (p_s). Fishing effort *f* was the number of vessel days fished in stratum *i* by participating fishermen in the West Coast GSI project. A vessel day was defined as eight hours of fishing, which is consistent with the definition of fishing effort used in Satterthwaite et al. (2014). In 2010, commercial salmon fisheries in California were heavily constrained and many samples were collected under a scientific collection permit in times and areas otherwise closed to fishing. For the estimates of CPUE reported here, samples obtained in open or closed fishing strata were considered together and not analyzed separately (Bellinger et al. 2015). All GSI data collected in California after 2010 were derived from sampling in open fisheries.

SRWC

Table 1 displays SRWC CWT recoveries from 2000-2014 for all ages combined, corresponding to the years where hatchery production occurred at Livingston Stone National Fish Hatchery. The CWT recoveries in Table 1 are stratified by year/month/area/and fishery. In general, the SRWC stock assessment suffers from low numbers of CWT recoveries. In 10 of 13 years, there are greater than 10 CWT recoveries for the entire stock (across all ages, months, management areas, and fisheries), indicating that there appears to be minimally sufficient CWT recoveries to estimate a total impact rate in most years. However, there are few instances of 10 CWT recoveries within individual strata.

We assessed the month/area/fishery strata that are responsible for ≥ 2.5 percent of the age-3 impact rate to identify strata with substantial contributions to the overall fishing mortality (PSC CWT Workgroup 2008) by examining the distribution of predicted impact rates from the WRHM for 2015 fisheries. This is reasonable since the 2015 fisheries featured substantial fishing opportunity spread over time and space. For the commercial fishery, the bulk of the impact rate results from June and July fisheries in SF and MO. For the recreational fishery, the bulk of the impact rate results from May through August in SF and April through August in MO.

Because SRWC have one dominant age class that is harvested in the fishery, the PSC CWT Workgroup (2008) CWT recovery guideline is 10 per stratum in eight of ten years. For all commercial fisheries in June and July since 2000, the minimum guideline for CWT recoveries has only been achieved twice (SF June 2004 and MO July 2004) (Table 1). If the spatial component of the SRWC assessment were to be further stratified by the addition of management boundaries at Point Reyes and Point Sur, the stratum-specific CWT guideline would only be achieved once in the commercial fishery (in SF-S, June 2004) (Table 1). In the recreational fishery, more strata meet the CWT recovery guideline relative to the commercial fishery. However, in 117 strata for the recreational fishery since 2000 (SF and MO combined) only 16 have met the CWT recovery guideline. This number decreases to 14 strata (of a possible 234) if the SF and MO management areas were subdivided into four areas.

There are several reasons for the low number of SRWC recoveries. While the hatchery-origin component of SRWC is marked and tagged at a 100 percent rate, the release sizes are relatively low, ranging from 31,000 to 252,000 (mean = 169,000). These release levels fall below the guideline of at least 200,000 Chinook used for PSC indicator stocks (CWT Workgroup 2008). Hatchery-origin fish are released in the upper Sacramento River and likely incur high mortality rates during outmigration to the ocean. The length at age for SRWC is relatively small compared to other Chinook stocks (Satterthwaite et al. 2012), and a substantial proportion of a cohort can be smaller than the minimum size limit (O'Farrell et al. 2012b), resulting in a low rate of fish retained as harvest (and then potentially sampled) per encounter. The small size of SRWC relative to minimum size limits is particularly problematic for the recovery of CWTs in the commercial fishery where minimum size limits are large relative to the recreational fishery. Finally, sampling for CWTs in the MO-S area was sparse prior to 2008 in the late-summer and fall months (Tables 1 and 3) owing to the low proportion (<1 percent) of total California harvest landed in there during those months.

Catch per unit effort estimated from 2010 GSI data suggest a higher relative density in MO-S relative to MO-N in some months (Figure 4; Bellinger et al. 2015). Evaluation of CPUE for years since 2010 is difficult because little GSI sampling effort was expended in MO-S and MO-N. With regard to a Point Reyes management area boundary, there is some evidence for persistently higher CPUE in SF-S relative to SF-N, though this inference suffers from some instances of low sample effort in SF-S (Figure 4). Comparisons of CPUE across both Point Reyes and Point Sur are hampered by relatively few winter Chinook genetic assignments.

In summary, increasing the spatial stratification for SRWC would reduce precision of stratum-specific impact rate estimates and reduce accuracy of WRHM-derived forecasts of impact rates. The current SRWC assessment is currently over-stratified, given the number of CWT recoveries in ocean fisheries, and the doubling of fishery management areas south of Point Arena would exacerbate this problem. While there is limited GSI information suggesting differences in local density across Point Reyes and Point Sur, the data poor nature of the SRWC stock assessment cannot accommodate further stratification. As a result, we do not recommend increased spatial subdivision by splitting the existing management areas at Point Reyes or Point Sur.

KRFC

Table 2 displays KRFC CWT recoveries from 1980-2014 for the SF management area, with SF-N and SF-S denoting the SF management area north and south of Point Reyes, respectively. The proposal to add a management area boundary at Point Sur is not relevant to the KRFC stock assessment.

We assessed the month/area/fishery strata that are responsible for greater than or equal to 2.5 percent of the aggregate age impact rate to determine strata with substantial contributions to the overall fishing mortality rate. This was assessed using the predicted impact rate from the KOHM for 2015 fisheries. This is reasonable since the 2015 fisheries featured substantial fishing opportunity spread over time and space. For the SF area, strata that resulted in at least 2.5 percent of the impact rate include the months of June and July for the commercial fishery. No month/area combinations for the recreational fishery had substantial contributions to the impact rate. Commercial fisheries further north (e.g., Fort Bragg and central Oregon) accounted for the bulk of the KRFC impact rate.

Because KRFC have two dominant age classes in the fishery, the PSC CWT Workgroup (2008) CWT recovery guideline is 20 per stratum in eight of 10 years. For the SF management area, there were 62 open fisheries in the months of June and July. The duration and spatial extent of these open fisheries varied across years. Nonetheless, of these 62 strata, 29 had at least 20 KRFC CWT recoveries (47 percent), which falls below the 80 percent guideline. If the SF management area were to be split at Point Reyes, the SF-N area would have had at least 20 CWT recoveries in 18 of 50 strata (36 percent) and the SF-S area would have had at least 20 CWT recoveries in 15 of 62 strata (24 percent). Beginning with brood year 2008, marking and tagging levels at Iron Gate Hatchery were increased to a 25% rate which matched the levels of marking and tagging that had been occurring at Trinity River Hatchery since brood year 2000 (brood year 2010 was an exception where Iron Gate Hatchery marked and tagged at less than a 25 percent rate). If we restrict our examination of tag recoveries to the June-July commercial fishery since 2011 to correspond with CWT recoveries corresponding to this contemporary level of marking and tagging, the SF area would have at least 20 CWT recoveries in 5 of 8 strata (63 percent), whereas both the SF-N and SF-S areas would have had at least 20 CWT recoveries in 3 of 8 strata (38 percent).

Genetic stock identification-based estimates of CPUE for Klamath Chinook suggest that relative densities are similar or higher in SF-N relative to SF-S (Figure 5), which is consistent with other published results (Satterthwaite et al. 2014, 2015, Bellinger et al. 2015). There appear to be some interannual differences in relative density, as the pattern of higher density in SF-N is not apparent in 2012 whereas larger, more persistent differences are evident in 2010 and 2011. Low levels of sampling effort in 2013 and 2014 preclude making strong inferences in relative density in those years (Figure 5). Overall, the available GSI data suggest moderately higher relative density in SF-N when compared to SF-S, but the variability in these estimates across years does not suggest a strong and persistent pattern.

From 1991 through 2001 in the SF management area, additional management lines at Point Reyes and Point San Pedro were used to structure commercial salmon fisheries. As part of the process of developing a new version of the KOHM in the early 2000s, the value of the Point Reyes and Point San Pedro management lines was investigated through an analysis of CWT recovery data. Based on this analysis, the use of these sub-areas within SF could not be justified (M. Mohr, *personal communication*). Since 2002, Point Reyes and Point San Pedro have not been used as management lines except for the October Fall Area Target Zone fishery.

In summary, further subdivision of the SF management area would result in reduced number of strata with adequate CWT recoveries which will have precision implications for the assessment. The available GSI-based estimates of CPUE suggest differences in relative density north and south of Point Reyes, but these differences are variable across months and years. Because current levels of CWT recoveries are below guideline levels, and in the absence of overwhelming evidence that Point Reyes serves as a persistent and strong biogeographical boundary for Klamath Chinook, we do not recommend increased spatial subdivision by splitting the existing SF management area at Point Reyes.

SRFC

Table 3 displays SRFC CWT recoveries for the commercial fishery from 1980-2014 and Table 4 displays this information for the recreational fishery. As with the previous tables, SF-N and SF-S denote the SF management area north and south of Point Reyes, respectively, and MO-N and MO-S denote the MO management area north and south of Point Sur, respectively.

For SRFC we assessed the month/area/fishery strata that were responsible for at least 2.5 percent of the impact rate predicted from the SHM for 2015 fisheries. For the commercial fishery, the month and area strata resulting in substantial contributions to the impact rate include May through September in SF and May through June in MO. For the recreational fishery, substantial contributions to the impact rate result from June through August fisheries in SF and April fisheries in MO.

The current SRFC assessment is an aggregate-age assessment, and therefore the PSC CWT Workgroup (2008) CWT recovery guideline is 10 per stratum in eight of 10 years. This guideline is clearly achieved (and surpassed) in both SF and MO commercial fishery strata that have substantial contributions to the overall impact rate. For recreational fisheries in SF, the CWT recovery guideline is surpassed as well. For the recreational fishery in MO, the guideline of at least 10 CWT recoveries in 80 percent of April fisheries is nearly achieved; at least 10 CWT recoveries occur in 25 of 35 years with open fisheries (76 percent).

It is noteworthy that since the widespread fishery closures spanning 2008-2010, there have been high numbers of SRFC CWT recoveries. In 2006, hatcheries in the Sacramento Basin instituted a “constant fractional marking” policy, where 25% of SRFC hatchery production is marked with an adipose fin clip and tagged with a CWT. This represented a large increase in the marking and tagging fraction for this stock and this is reflected in the number of CWT recoveries since 2010. If this program continues, the high level of tag recoveries from recent years would be expected to continue (under similar levels of abundance and fishing opportunity).

Genetic stock identification information suggests little difference in relative density of Central Valley fall Chinook between SF-N and SF-S, but some evidence for increased relative density in MO-N compared to MO-S (Figure 6). These results are consistent with those presented in Bellinger et al. (2015).

The level of CWT recoveries for SRFC experienced since 2011 indicates that increased spatial stratification could be accommodated in the commercial fishery while still meeting CWT recovery guidelines. In the recreational fishery it appears that sufficient CWT recoveries would result if the SF management area were subdivided. For the MO management area, subdivision at Point Sur would likely result in some years with low levels of CWT recoveries in MO-S, though this would be expected given the variable nature of fisheries in that area and may not be problematic if recreational fisheries in the MO-S area do not make a substantial contribution to the impact rate (i.e., ≥ 2.5 percent of the overall impact rate for the stock). However, the GSI-based estimates of relative density do not make a compelling case for further subdivision of the existing salmon management areas.

Discussion

For this assessment of Point Reyes and Point Sur as potential new management area boundaries, the first priority was to evaluate whether there are sufficient CWT recoveries to support further spatial stratification. We found that the low level of CWT recoveries for SRWC cannot support further stratification and rather there should be consideration given to reducing stratification or employing other tactics to increase CWT recoveries (e.g., increased sampling). The KRFC assessment is less data poor than the SRWC assessment, but the number of CWT recoveries still falls below guideline levels. As a result, we conclude that additional stratification is not advisable. Finally, the SRFC assessment is relatively data rich and the level of CWT recoveries could allow for further stratification.

Our second priority was to estimate stock-specific CPUE from GSI data to determine whether the relative density differed across the proposed management lines for stocks with sufficient CWT data to support additional stratification. While the KRFC stock falls short of CWT recovery goals, we were interested in evaluating whether there were substantial and persistent differences in relative density between the SF-N and SF-S. The GSI data lend some support for increased density of Klamath Chinook in SF-N relative to SF-S though this result was not consistent across all months and years, reflecting the results in Satterthwaite et al. (2014, 2015) and Bellinger et al. (2015). In short, these results were not compelling enough to suggest that the potential benefits of a new management line at Point Reyes would outweigh the costs of decreased assessment precision that would result from greater spatial stratification. For SRFC, relative densities of Central Valley Chinook were similar across Point Reyes, suggesting that a new management line would not necessarily improve assessment or management of this stock.

The consideration of Point Sur as a management area boundary was primarily motivated by conservation concerns for SRWC. The GSI data suggest potentially higher density of SRWC in MO-S relative to MO-N, but it is difficult to draw strong inferences from the CPUE estimates owing to low levels of sampling effort in this region and the rarity of SRWC-assigned fish. If we assume that there is substantially higher density of SRWC in MO-S relative to MO-N, the nature of salmon fisheries in the MO-S area suggests that those fisheries may not result in high levels of SRWC mortality. The MO-S area lies at the southern end of the ocean distribution of Chinook salmon and fishing effort and catch in this area is a small fraction of the fishing effort in the region from Pigeon Point to the U.S.-Mexico border. For the commercial fishery, on average (2000-2014) only 15 percent of the MO area effort and 13 percent of the MO catch occurs in MO-S. For the recreational fishery, eight percent of the MO area effort and five percent of the MO catch occurs in MO-S. As a result, while there may be a higher contribution rate of SRWC to the catch in MO-S relative to MO-N, this does not necessarily result in a high overall fishing mortality resulting from fisheries in MO-S.

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Table 1. Sacramento River winter Chinook coded-wire tag (CWT) recoveries stratified by year, month, area, and sector. Dark shading indicates strata where at least 10 CWTs were recovered. Light shading indicates when at least 10 CWT recoveries occurred given the status quo spatial stratification (e.g., the sum of SF-N and SF-S CWT recoveries is greater than or equal to 10). Stippled cells indicate strata with little or no fishing (and sampling) effort. Blank cells represent strata where fisheries were completely closed.

SF-N commercial

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
2000				0	0	0			0
2001			0	1	0	0			1
2002		0	3	0	1	0			4
2003		0	1	0	0	0			1
2004		3	0	0	0	0			3
2005				2	0	2			4
2006				0	0	0			0
2007		0		0	0	0			0
2008									0
2009									0
2010				0					0
2011		0	0	0	1	0			1
2012		0	0	1	0	0			1
2013		0	0	0	1	0			1
2014		0	0	0	0	1			1

SF-N recreational

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
2000	0	0	0	0	0	0	0	0	0
2001	0	0	1	0	0	0	0	0	1
2002	0	0	0	1	0	0	0	0	1
2003	0	0	0	0	0	0	0	0	0
2004	0	0	0	3	1	0	0	0	4
2005	0	0	0	0	0	0	0	0	0
2006	0	0	0	1	0	0	0	0	1
2007	0	0	0	0	0	0	0	0	0
2008									0
2009									0
2010	0	0	0	0	0	0			0
2011	0	0	1	1	0	0	0		2
2012	0	0	0	2	0	0	0	0	2
2013	0	0	0	1	0	0	0	0	1
2014	0	0	0	0	1	0	0	0	1

SF-S commercial

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
2000		0	0	0	0	0			0
2001		0	0	1	0	0	0		1
2002		0	1	1	0	0	0		2
2003		0	0	0	0	0	0		0
2004		0	14	2	0	0	0		16
2005				5	2	1	0		8
2006				0	0	0	0		0
2007		0		0	0	0	0		0
2008									0
2009									0
2010				0					0
2011		0	0	0	0	0	0		0
2012		0	0	0	0	0	0		0
2013		0	0	0	0	0	2		2
2014		0	0	0	1	0	0		1

SF-S recreational

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
2000	1	0	2	1	1	0	2	0	7
2001	0	0	0	3	2	0	0	0	5
2002	0	2	1	3	1	0	0	0	7
2003	0	4	4	1	0	0	0	0	9
2004	1	34	28	28	8	0	1	4	104
2005	13	10	15	11	4	1	0	3	57
2006	0	0	1	2	0	0	0	0	3
2007	0	1	0	0	0	0	0	0	1
2008									0
2009									0
2010	0	0	0	1	0	0			1
2011	0	0	0	2	7	2	1		12
2012	0	0	1	0	0	0	0	0	1
2013	0	2	0	1	0	0	2	0	5
2014	0	0	1	3	6	2	1	0	13

MO-N commercial

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
2000		0	1	0	0				1
2001		0	0	0	0				0
2002		0	0	2	0	0			2
2003		0	0	0	0	0			0
2004		1	3	9	1	0			14
2005		2		2	1	1			6
2006		0		0	0	0			0
2007		0		0	0	0			0
2008									0
2009									0
2010				0					0
2011		2	2	0	2	0			6
2012		0	0	0	0	0			0
2013		0	1	3	2	0			6
2014		0	0	4	1				5

MO-N recreational

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
2000	0	0	8	12	1	1	0		22
2001	1	1	0	3	0	0			5
2002	0	3	1	2	1	0			7
2003	0	0	0	2	0	0			2
2004	2	4	8	30	4	1	0		49
2005	8	12	9	5	0	0			34
2006	1	0	1	1	0	0			3
2007	0	0	1	1	0	0	0		2
2008									0
2009									0
2010	0	0	0	0	0	0			0
2011	1	0	1	15	15	0			32
2012	0	0	0	2	0	0	0		2
2013	0	0	0	11	7	0	0		18
2014	2	0	0	2	1	0	0		5

MO-S commercial

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
2000		0	3	0	0				3
2001		1	0	0	0	0			1
2002		0	0	0	0	0			0
2003		0	0	0	0	0			0
2004		0	0	1	0	0			1
2005		0	6	1	3	0			10
2006		1	0	0	0	0			1
2007		0	0	0	0	0			0
2008									0
2009									0
2010				0					0
2011		1	2	0	0				3
2012		0	0	0	5	1			6
2013		0	1	0	0	0			1
2014		0	0	0	0				0

MO-S recreational

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
2000	0	0	0	0	0	0	0		0
2001	1	0	0	0	0	0			1
2002	0	0	2	0	0	0			2
2003	0	0	0	0	0	0			0
2004	3	6	0	2	0	0	0		11
2005	7	2	18	3	0	0			30
2006	1	0	0	0	0	0			1
2007	0	1	0	1	0	0	0		2
2008									0
2009									0
2010	0	0	0	0	0	0			0
2011	1	0	8	0	4	0			13
2012	0	0	0	0	1	0	0		1
2013	0	0	1	0	0	0	0		1
2014	0	3	0	0	0	0	0		3

Table 2. Klamath River fall Chinook coded-wire tag (CWT) recoveries stratified by year, month, area, and fishery. Dark shading indicates strata where at least 20 CWTs were recovered. Light shading indicates when at least 20 CWT recoveries occurred given the status quo spatial stratification (e.g., the sum of SF-N and SF-S CWT recoveries is greater than or equal to 20). Blank cells represent strata where fisheries were completely closed.

SF-N commercial

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
1980		1		23	0	1			25
1981		3	2	30	6	1			42
1982	5	11	18	5	2	1			42
1983	0	11	1	2	0	0			14
1984		3	0	15	1	0			19
1985		7	20	4	1	2			34
1986		34	132	92	17	0			275
1987		44	75	31	16	0			166
1988		22	72	65	0	0			159
1989		11	21	7	4	0			43
1990		4	5	4	0	0			13
1991		5	7	8	14	0			34
1992					2	1			3
1993		6		5	26	0			37
1994					9	1			10
1995				7	1	1			9
1996			0		0	0			0
1997				0	1	0			1
1998				0	0	0			0
1999				4	0	0			4
2000				11	8	0			19
2001			7	36	5	0			48
2002		3	6	16	0	0			25
2003		8	147	58	74	5			292
2004		19	6	65	3	1			94
2005				12	6	1			19
2006				3	2	0			5
2007		11		46	10	2			69
2008									0
2009									0
2010				1					1
2011		3	0	10	0	0			13
2012		23	15	120	5	0			163
2013		36	58	19	0	0			113
2014		47	20	6	0	0			73

SF-N recreational

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
1980	0	0	0	0	0	0	0		0
1981	0	0	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	0	0
1984	0	0	0	0	1	0	0	0	1
1985	0	0	0	0	0	0	0	0	0
1986	0	1	0	0	0	0	0	0	1
1987	0	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0	0	0
1990	0	0	0	1	0	0	0	0	1
1991	0	0	0	2	0	0	0	0	2
1992	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0		0
1994	0	0	0	1	0	0	0		1
1995	0	0	1	0	0	0	0		1
1996	0	0	0	0	0	0	0		0
1997	0	0	0	0	0	0	0	0	0
1998	0	0	0	0	0	0	0	0	0
1999	0	0	0	2	0	0	0		2
2000	2	2	4	0	0	0	0	0	8
2001	0	0	0	3	0	0	0	0	3
2002	1	0	0	0	0	0	0	0	1
2003	1	1	1	1	4	0	0	0	8
2004	2	1	1	0	0	0	0	0	4
2005	1	0	2	0	0	0	0	0	3
2006	0	2	0	4	0	0	0	0	6
2007	0	0	0	3	0	0	0	0	3
2008									0
2009									0
2010	0	0	2	1	0	0			3
2011	0	0	1	0	0	0	0		1
2012	1	4	2	2	0	0	0	0	9
2013	0	1	0	6	0	0	0	0	7
2014	0	0	1	0	0	0	0	0	1

SF-S commercial

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
1980			0	2	0	0			2
1981		3	0	2	0	0			5
1982	0	0	4	3	1	0			8
1983	0	1	0	2	0	0			3
1984		0	2	0	0	0			2
1985		8	5	0	0	0			13
1986		3	16	92	7	0			118
1987		3	19	4	6	0			32
1988		6	10	5	0	0			21
1989		1	1	1	0	0			3
1990		0	2	0	0	0			2
1991		1	2	2	0	0			5
1992		0	0	0	0	0			0
1993		2	0	0	1	0			3
1994		0	12	10	0	0			22
1995		16	27	11	0	0			54
1996		6	86	28	1	0			121
1997		7	1	4	0	0			12
1998		0	0	0	0	0			0
1999	0	2	2	2	0	0			6
2000		31	59	9	0	1			100
2001		5	0	28	0	1	0		34
2002		8	9	18	0	0	0		35
2003		9	94	84	17	2	2		208
2004		38	157	57	0	0	0		252
2005				35	1	0	0		36
2006				4	0	0	0		4
2007		10		28	0	0	0		38
2008									0
2009									0
2010				0					0
2011		1	0	0	0	0	0		1
2012		29	16	31	2	0	0		78
2013		84	110	5	0	0	0		199
2014		14	31	1	0	0	0		46

SF-S recreational

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
1980	2	1	3	3	0	0	0		9
1981	1	0	1	0	1	0	0	0	3
1982	0	1	0	2	4	0	0	0	7
1983	0	2	0	0	0	0	0	0	2
1984	0	0	0	0	0	0	0	0	0
1985	0	0	2	0	0	0	0	0	2
1986	3	2	5	2	0	0	0	0	12
1987	3	1	2	0	1	0	0	0	7
1988	0	3	0	0	0	0	0	0	3
1989	2	0	0	0	0	1	0	0	3
1990	1	0	0	0	0	1	0	0	2
1991	0	0	2	0	0	0	0	0	2
1992	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0		0
1994	0	0	0	1	0	0	0		1
1995	1	0	2	1	0	0	0		4
1996	3	3	5	2	0	0	0		13
1997	1	1	0	1	0	0	0	0	3
1998	0	0	0	2	1	0	0	0	3
1999	0	0	0	1	0	0	0		1
2000	2	5	3	0	0	0	0	0	10
2001	1	0	0	0	0	0	0	0	1
2002	0	1	0	0	0	0	0	0	1
2003	0	2	1	4	0	0	0	0	7
2004	3	3	4	0	0	0	0	0	10
2005	0	1	7	1	1	0	0	0	10
2006	0	0	0	0	0	0	0	0	0
2007	0	2	0	2	0	0	0	0	4
2008									0
2009									0
2010	0	0	0	0	0	0			0
2011	0	0	0	0	0	0	0		0
2012	5	8	18	8	0	0	0	0	39
2013	6	10	18	5	0	0	0	0	39
2014	0	0	0	0	0	0	0	0	0

Table 3. Sacramento River fall Chinook coded-wire tag (CWT) recoveries stratified by year, month, and area, for the commercial fishery. Dark shading indicates strata where at least 10 CWTs were recovered. Light shading indicates when at least 10 CWT recoveries occurred given the status quo spatial stratification (e.g., the sum of SF-N and SF-S CWT recoveries is greater than or equal to 10). Stippled cells indicate strata with little or no fishing (and sampling) effort. Blank cells represent strata where fisheries were completely closed.

SF-N commercial

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
1980		108		211	36	5			360
1981		27	20	187	85	18			337
1982	97	164	144	58	47	6			516
1983	0	32	13	44	21	0			110
1984		4	5	88	115	4			216
1985		53	80	51	28	23			235
1986		64	94	57	19	5			239
1987		183	73	64	18	1			339
1988		142	170	284	97	67			760
1989		70	104	17	21	0			212
1990		68	63	57	32	0			220
1991		101	72	68	89	3			333
1992		1			76	27			104
1993		56		17	17	2			92
1994					17	14			31
1995				28	17	15			60
1996			0		15	0			15
1997				36	105	5			146
1998				70	78	23			171
1999				271	82	0			353
2000				31	44	10			85
2001			56	277	26	5			364
2002		98	135	145	16	1			395
2003		311	483	163	214	30			1201
2004		195	8	201	66	20			490
2005				69	50	12			131
2006				41	58	17			116
2007		7		25	6	1			39
2008									0
2009									0
2010				28					28
2011		119	65	408	59	2			653
2012		577	348	1679	332	34			2970
2013		469	869	1036	152	172			2698
2014		834	558	463	452	219			2526

MO-N commercial

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
1980		102		190	38	1			331
1981		51	0	77	19	0			147
1982	100	111	76	109	20	11			427
1983	0	161	85	72	3	0			321
1984		105	84	25	0	0			214
1985		38	18	7	0	0			63
1986		172	83	94	18	1			368
1987		49	25	66	5	0			145
1988		63	230	123	46	0			462
1989		102	34	43	17	2			198
1990		125	151	72	7	0			355
1991		107	65	63	6	0			241
1992		23	6	7	0	0			36
1993		62	11	12	2	0			87
1994		39	19	23	0	0			81
1995		348	140	208	6	0			702
1996		760	344	225	1	0			1330
1997		948	370	539		0			1857
1998		776	224	67	0	0			1067
1999		432	909	101	1	6			1449
2000		376	182	41	2				601
2001		345	37	18	0				400
2002		146	164	171	2	0			483
2003		246	250	96	0	0			592
2004		298	361	167	3	0			829
2005		362		52	3	0			417
2006		54		0	3	0			57
2007		15		0	0	0			15
2008									0
2009									0
2010				123					123
2011		236	90	17	20	1			364
2012		1264	588	1086	61	0			2999
2013		682	525	199	29	9			1444
2014		325	103	164	15				607

SF-S commercial

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
1980		99		110	9	11			229
1981		84	3	12	2	0			101
1982	6	43	33	29	4	6			121
1983	0	88	18	37	7	0			150
1984		2	12	6	4	0			24
1985		30	17	13	1	0			61
1986		45	26	51	18	1			141
1987		13	43	32	4	10			102
1988		104	40	32	10	2			188
1989		45	17	4	0	0			66
1990		23	57	22	2	0			104
1991		95	76	23	8	0			202
1992		14	2	3	10	16			45
1993		33	9	17	11	1			71
1994		132	115	71	4	0			322
1995		628	98	30	15	2			773
1996		281	315	96	13	7			712
1997		1236	52	444	49	14			1795
1998		238	321	785	58	30			1432
1999	164	229	652	208	30	1			1284
2000		153	114	69	14	4			354
2001		399	10	235	16	12	0		672
2002		304	385	280	47	11	3		1030
2003		321	389	128	152	24	21		1035
2004		304	1033	224	21	17	12		1611
2005				188	33	21	0		242
2006				14	19	3	0		36
2007		35		14	3	1	0		53
2008									0
2009									0
2010				20					20
2011		266	17	92	49	71	10		505
2012		980	284	597	308	155	99		2423
2013		1649	1534	241	166	96	38		3724
2014		626	315	198	873	435	134		2581

MO-S commercial

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
1980		0		18	0	0			18
1981		0	0	4	0	0			4
1982	0	0	0	0	0	0			0
1983	0	1	0	0	0	0			1
1984		3	1	0	0	0			4
1985		0	0	0	0	0			0
1986		39	14	10	0	0			63
1987		47	7	6	0	0			60
1988		1	15	12	0	0			28
1989		6	1	0	2	0			9
1990		31	1	0	0	0			32
1991		19	48	10	0	0			77
1992		25	7	3	0	0			35
1993		46	23	4	0	1			74
1994		19	1	0	0	1			21
1995		223	52	23	12	0			310
1996		36	11	14	0	0			61
1997	469	97	33	45		1			645
1998		545	93	30	1	0			669
1999	0	16	1	0	0	0			17
2000		43	96	0	0				139
2001		30	0	0	0	0			30
2002		1	5	8	0	0			14
2003		0	0	0	0	0			0
2004		19	20	2	0	0			41
2005		27	21	4	1	0			53
2006		1	0	0	0	0			1
2007		0	0	0	0	0			0
2008									0
2009									0
2010				0					0
2011		12	18	0	0				30
2012		263	117	107	30	1			518
2013		90	57	0	1	0			148
2014		9	13	0	0				22

Table 4. Sacramento River fall Chinook coded-wire tag (CWT) recoveries stratified by year, month, and area, for the recreational fishery. Dark shading indicates strata where at least 10 CWTs were recovered. Light shading indicates when at least 10 CWT recoveries occurred given the status quo spatial stratification (e.g., the sum of SF-N and SF-S CWT recoveries is greater than or equal to 10). Stippled cells indicate strata with little or no fishing (and sampling) effort. Blank cells represent strata where fisheries were completely closed.

SF-N recreational

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
1980	1	0	9	8	1	0	0		19
1981	0	1	1	12	6	3	0	0	23
1982	1	0	16	16	1	0	0	0	34
1983	0	0	7	1	0	0	0	0	8
1984	0	0	0	1	0	0	0	0	1
1985	0	0	5	10	2	2	0	0	19
1986	0	3	8	3	2	0	0	0	16
1987	0	0	0	0	0	0	0	0	0
1988	0	0	9	26	4	0	0	0	39
1989	0	0	0	0	0	0	0	0	0
1990	4	0	17	14	10	2	5	0	52
1991	0	0	8	17	0	0	0	0	25
1992	0	0	0	16	6	1	0	0	23
1993	0	1	0	12	2	2	0		17
1994	3	4	6	17	2	1	0		33
1995	0	2	5	25	9	1	0		42
1996	3	2	0	16	3	1	0		25
1997	0	9	3	51	4	0	0	0	67
1998	7	18	31	62	33	14	0	0	165
1999	4	0	7	154	10	0	0		175
2000	1	2	24	22	4	4	0	0	57
2001	0	6	8	50	15	4	0	0	83
2002	8	12	20	115	25	1	0	0	181
2003	14	18	55	82	21	2	0	0	192
2004	25	12	10	29	8	0	0	0	84
2005	3	2	4	12	7	2	1	0	31
2006	7	14	15	22	0	0	0	0	58
2007	0	0	3	1	0	0	0	0	4
2008									0
2009									0
2010	29	7	8	68	24	3			139
2011	12	10	9	98	112	42	0		283
2012	73	62	132	230	14	12	3	0	526
2013	17	3	83	365	31	6	0	0	505
2014	50	29	21	153	143	15	9	0	420

MO-N recreational

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
1980	16	0	26	2	0	0	0		44
1981	6	1	1	2	0	0	3	0	13
1982	6	4	1	4	2	1	0	0	18
1983	0	3	1	3	0	0	0	0	7
1984	14	1	4	2	2	0	0	0	23
1985	0	0	0	2	2	0	0	0	4
1986	35	4	23	25	13	0	0	0	100
1987	6	1	5	17	3	2	0	0	34
1988	4	3	5	1	1	0	0	0	14
1989	93	0	2	8	5	0	0	0	108
1990	34	0	13	20	4	0	4	5	80
1991	43	0	10	26	0	0	1	0	80
1992	11	2	8	9	1	0	0	0	31
1993	30	0	1	4	0	0	1		36
1994	18	2	9	4	2	2	4		41
1995	62	21	43	156	29	0	0		311
1996	140	48	18	71	14				291
1997	132	40	182	137	14	1	0		506
1998	73	55	97	86	9	0			320
1999	4	5	18	14	3	0			44
2000	134	46	40	45	27	12	0		304
2001	152	39	1	10	0	0			202
2002	228	29	25	43	6	0			331
2003	89	30	11	44	0	0			174
2004	319	53	12	61	8	0	0		453
2005	35	6	27	14	0	0			82
2006	26	1	2	2	0	0			31
2007	6	1	1	1	0	0	0		9
2008									0
2009									0
2010	149	59	0	9	2	0			219
2011	166	7	26	283	118	40			640
2012	579	124	203	289	18	4	1		1218
2013	187	45	24	108	18	2	0		384
2014	573	45	54	48	19	4	1		744

SF-S recreational

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
1980	45	30	108	44	36	11	8		282
1981	19	38	78	183	135	109	62	23	647
1982	24	45	40	95	161	119	107	40	631
1983	30	102	51	79	19	25	8	0	314
1984	8	18	57	54	44	22	3	0	206
1985	37	53	73	72	80	36	14	2	367
1986	55	58	67	161	116	31	10	1	499
1987	60	34	45	111	112	22	12	2	398
1988	70	79	166	129	76	17	23	1	561
1989	25	10	51	79	64	51	22	8	310
1990	16	10	17	40	43	20	6	4	156
1991	28	17	30	57	3	3	0	0	138
1992	1	14	16	40	24	8	7	0	110
1993	10	17	18	52	14	4	1		116
1994	13	9	72	115	58	32	13		312
1995	57	57	98	255	106	106	11		690
1996	142	58	67	79	23	2	0		371
1997	70	103	103	360	205	8	6	0	855
1998	76	43	131	225	204	14	2	0	695
1999	75	18	99	113	56	9	3		373
2000	6	15	61	60	57	9	19	21	248
2001	43	57	9	96	59	11	7	1	283
2002	21	117	149	263	132	44	4	1	731
2003	135	233	127	269	85	41	15	0	905
2004	63	149	161	200	95	40	17	1	726
2005	31	48	41	86	24	18	3	0	251
2006	6	43	59	40	2	3	0	0	153
2007	3	9	6	3	2	1	0	3	27
2008									0
2009									0
2010	10	42	17	22	108	12			211
2011	31	27	24	216	523	391	54		1266
2012	274	285	556	520	239	86	49	3	2012
2013	398	410	396	363	304	69	46	5	1991
2014	84	149	30	256	883	461	93	3	1959

MO-S recreational

	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
1980	0	0	0	0	0	0	0		0
1981	0	0	0	0	0	0	0	0	0
1982	0	0	0	0	0	0	0	0	0
1983	0	0	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	0	0	0
1985	0	0	0	0	0	0	0	0	0
1986	0	1	0	0	0	0	0	0	1
1987	0	0	0	0	0	0	0	0	0
1988	0	0	0	0	0	0	0	0	0
1989	0	0	0	0	0	0	0	0	0
1990	0	0	0	0	0	0	0	0	0
1991	2	0	0	0	0	0	0	0	2
1992	0	0	0	0	0	0	0	0	0
1993	0	0	0	0	0	0	0		0
1994	0	0	0	0	1	0	0		1
1995	26	29	26	36	0	0	0		117
1996	2	1	1	0	0				4
1997	42	2	17	0	0	0	0		61
1998	28	58	19	2	1	1			109
1999	0	1	0	0	0	0			1
2000	10	3	3	0	0	0	0		16
2001	2	0	0	0	0	0			2
2002	13	3	4	0	0	0			20
2003	0	0	0	0	0	0			0
2004	23	4	0	0	0	0	0		27
2005	0	3	2	0	0	0			5
2006	3	0	0	0	0	0			3
2007	0	0	1	0	0	0	0		1
2008									0
2009									0
2010	2	0	0	0	0	0			2
2011	1	0	9	1	0	0			11
2012	33	56	4	0	0	1	2		96
2013	6	3	19	7	0	0	0		35
2014	28	3	4	4	0	0	0		39

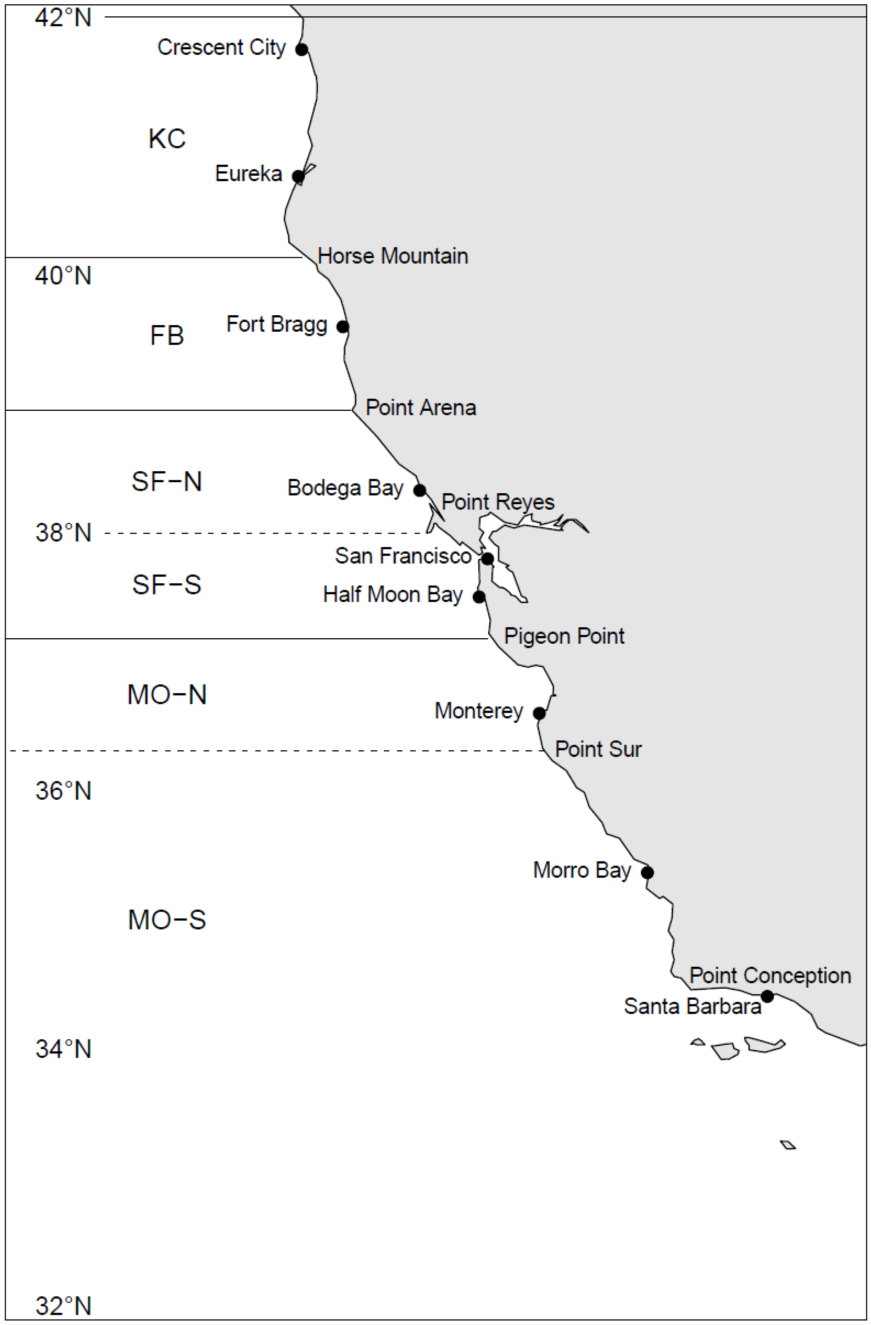

Figure 1. Map of California ocean salmon fishery management areas. The current SF management area is the area between Point Arena and Pigeon Point (comprised of SF-N and SF-S). The current MO management area is the area south of Pigeon Point (comprised of MO-N and MO-S). Proposed new management lines considered in this report are denoted by dashed lines.

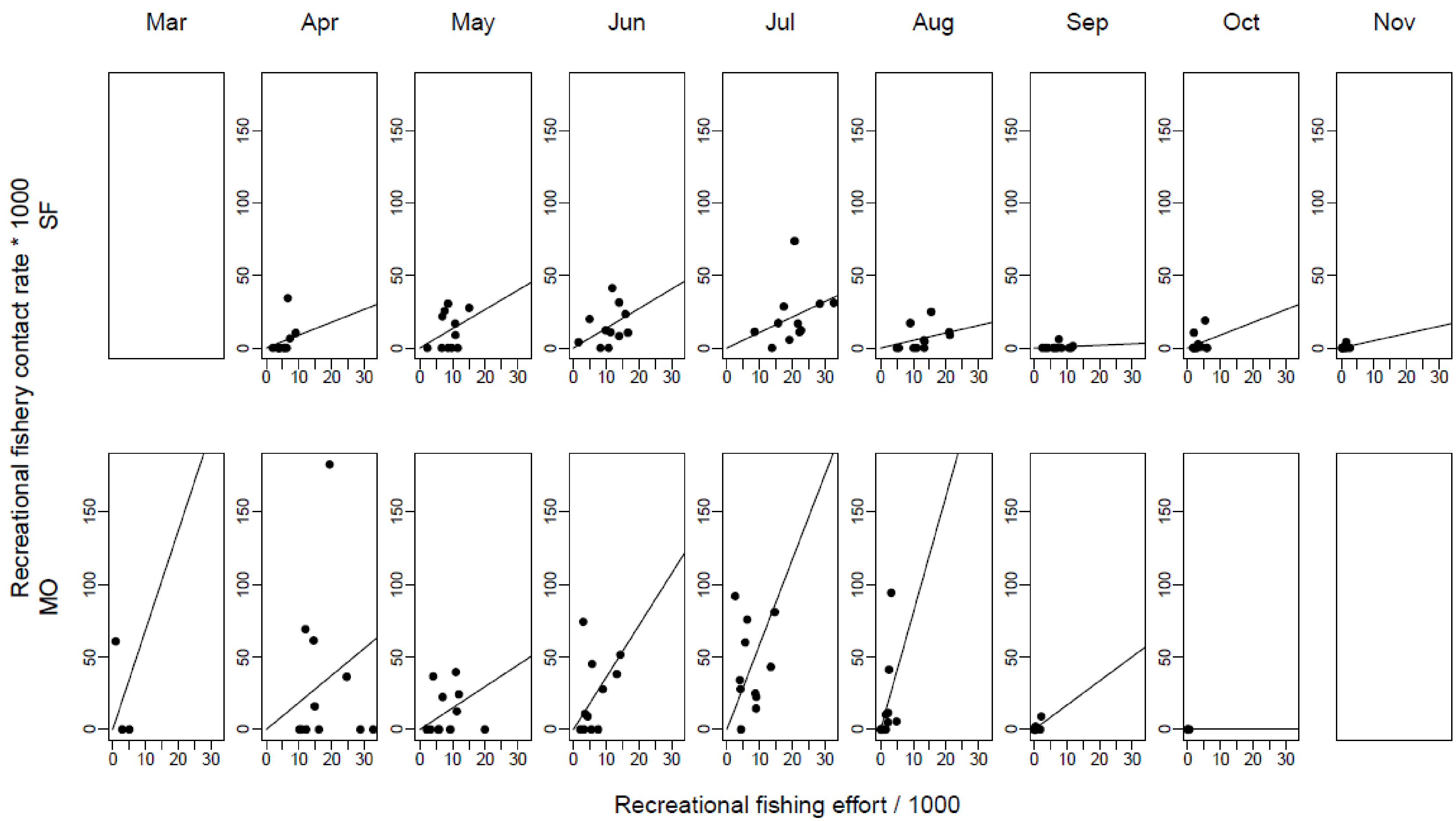

Figure 2. Sacramento River winter Chinook contact rates plotted as a function of fishing effort for the recreational fishery. Lines are fitted zero-intercept linear regressions.

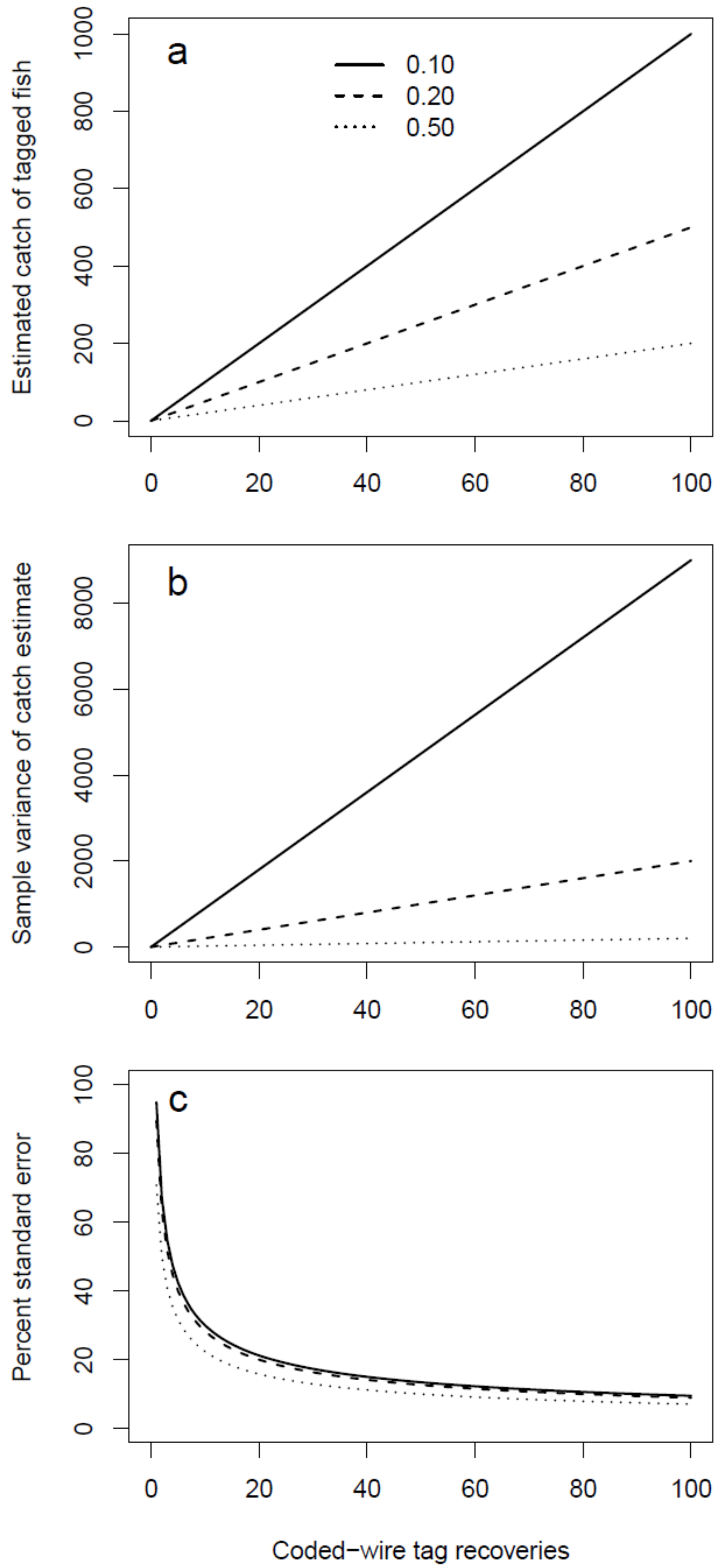

Figure 3. Estimated catch of tagged fish (a), catch variance (b), and the percent standard error (c) plotted as a function of the number of coded wire tag recoveries. Line types denote the catch sampling rate.

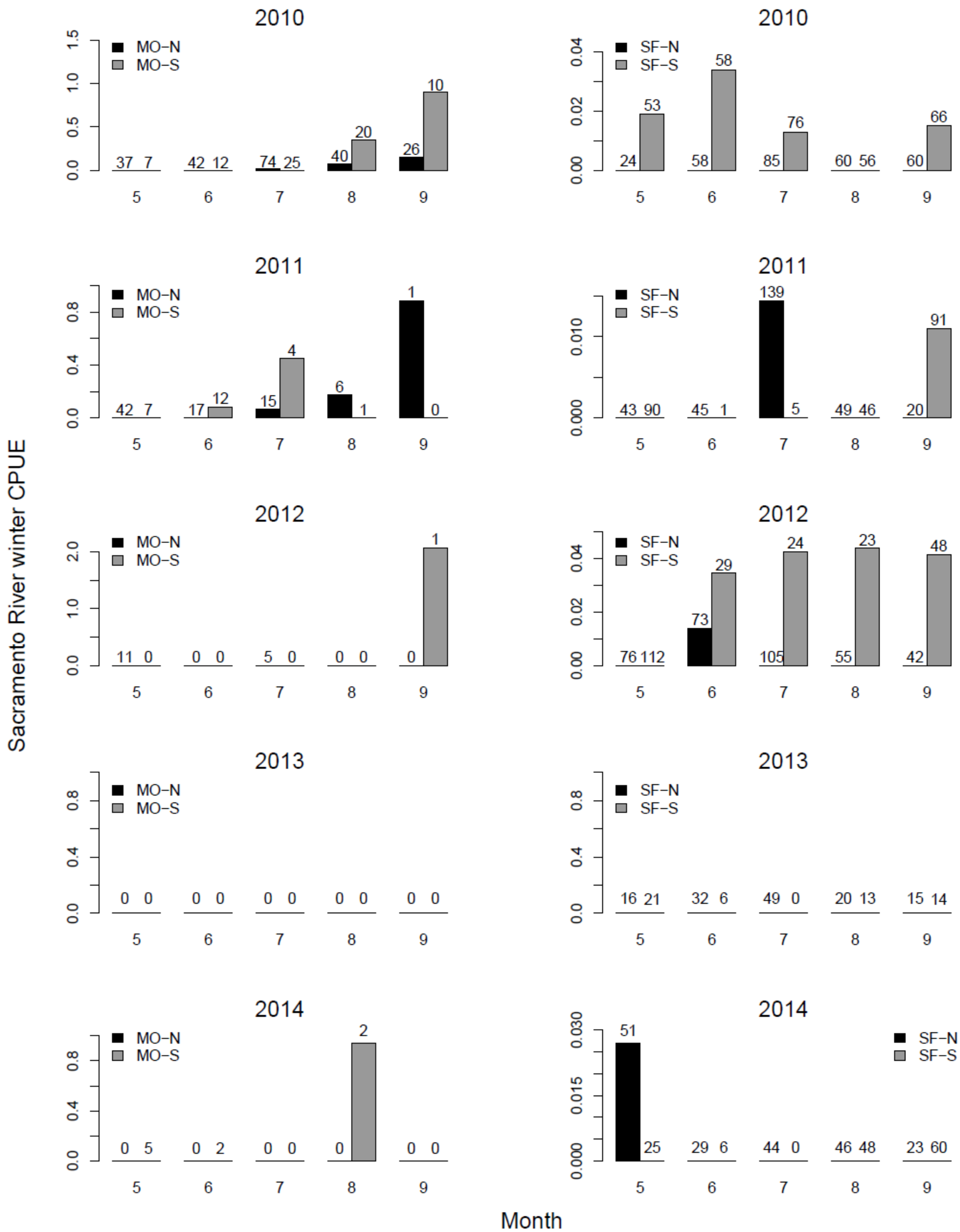

Figure 4. Catch per unit effort for Sacramento River winter Chinook derived from genetic stock identification data. Numbers above the bars indicate the fishing effort for that stratum in units of vessel days.

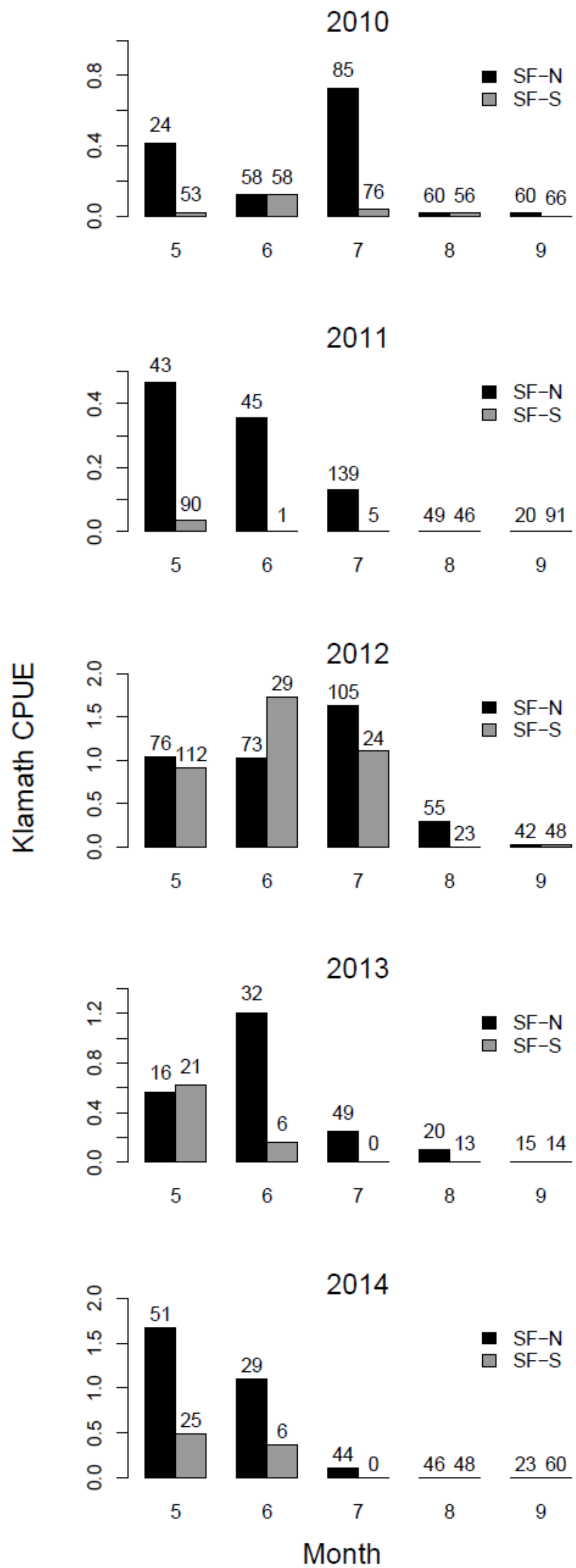

Figure 5. Catch per unit effort for Klamath Chinook derived from genetic stock identification data. Numbers above the bars indicate the fishing effort for that stratum in units of vessel days.

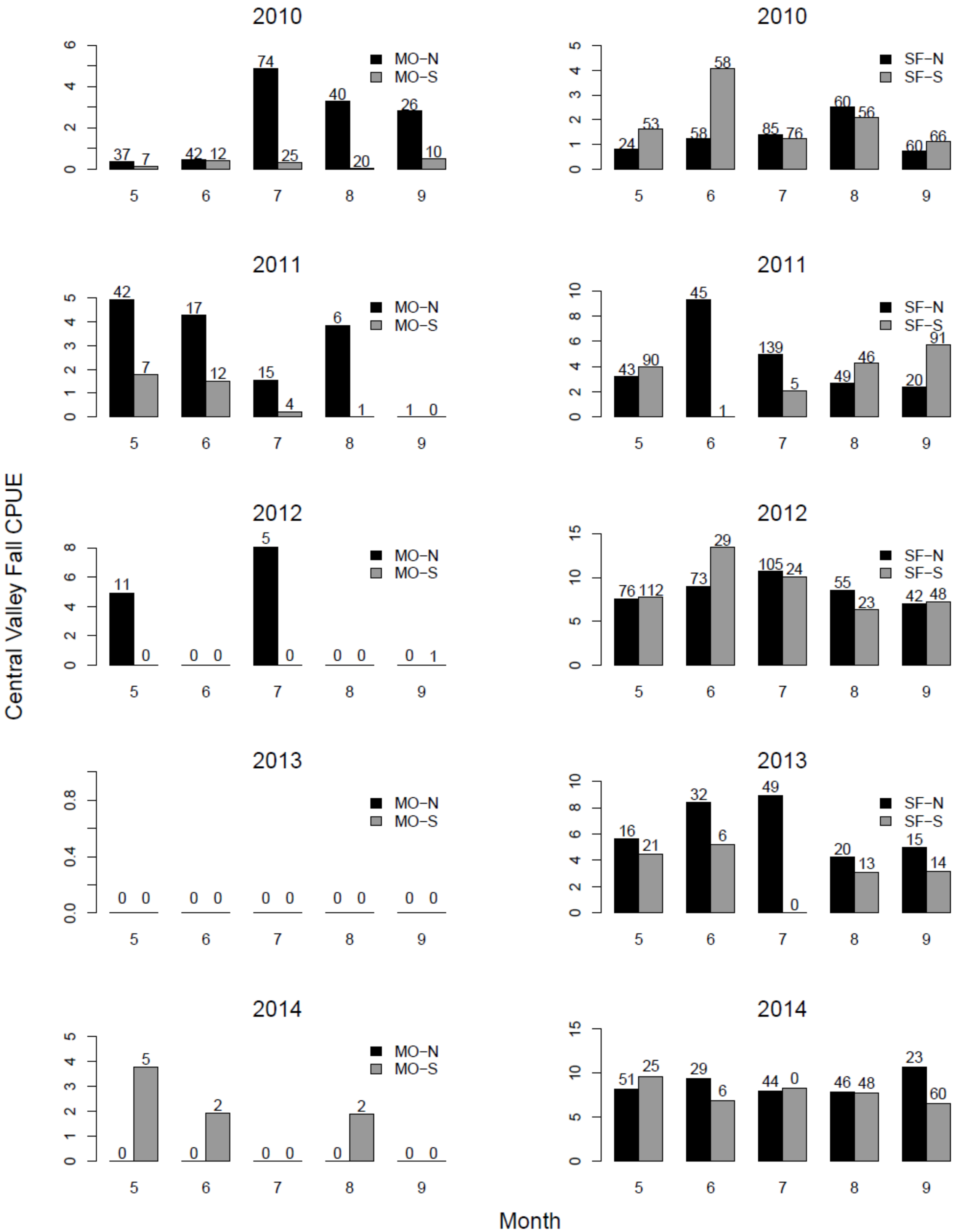

Figure 6. Catch per unit effort for Central Valley fall Chinook derived from genetic stock identification data. Numbers above the bars indicate the fishing effort for that stratum in units of vessel days.