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RESEARCH

Central Valley Spring-Run Chinook Salmon and Ocean Fisheries: Data Availability and Management Possibilities

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ABSTRACT

Central Valley spring-run Chinook Salmon (CVSC) are designated threatened by state and federal authorities. Although CVSC are caught in ocean fisheries, their harvest is not actively managed, because it is assumed that measures currently in place to protect endangered Sacramento River winter-run Chinook Salmon (SWRC) will also sufficiently protect CVSC. Recoveries of tags and genetically-identified CVSC suggest these fish have a more northerly distribution than SRWC. Further, escapement data and cohort reconstructions suggest that CVSC mature later than SRWC. Thus, regulations (time/area restrictions and minimum size limits) crafted to protect SRWC alone may not adequately protect CVSC; on the other hand, regulations to constrain impacts on Klamath River and California coastal Chinook Salmon populations may also reduce impacts on CVSC. Trends in CVSC escapement were deemed acceptable in recent status updates, but concerns remain because of the negative effects caused by recent drought and ocean conditions. Should more active management of CVSC be desired, current options are limited. The most promising approach is based on estimating age-specific ocean fishing mortality rates by using cohort reconstructions applied to tagged Chinook Salmon that originate from the Feather River Hatchery. At a minimum, ocean fishing mortality rates could be monitored and compared to proxy thresholds. If reference harvest rates were established, harvest models could be developed to predict how CVSC would be affected by fishing regulations, similar to the way fall-run Chinook Salmon fisheries are evaluated. Abundance forecasts would require improved juvenile production data (e.g., from genetic sampling of juvenile emigrants), since sibling-based forecasts commonly used for fall-run Chinook Salmon would not be available in time for pre-season planning. It is unclear if ocean fishing mortality rate estimates derived from hatchery proxies for natural-origin fish are truly representative, but existing data do not demonstrate obvious differences in ocean distribution or size-at-age fish. Substantial new investments in tagging or sampling would be needed to directly estimate ocean fishing mortality rates for natural-origin CVSC. Establishing specific harvest targets or limits for CVSC requires an improved understanding of production throughout their life cycle through juvenile production estimates and long-term information on spawner age structure.

KEY WORDS

Spring-run Chinook Salmon, *Oncorhynchus tshawytscha,* ocean fisheries, exploitation rates, indicator stock, threatened, endangered, cohort reconstruction, population management.

INTRODUCTION

Central Valley spring-run Chinook Salmon (*Oncorhynchus tshawytscha,* hereafter CVSC) have been listed as threatened under the California and United States Endangered Species acts (ESAs) since 1999 (CDFG 2001; NMFS 2011). This listing carries many implications for management and regulation of activities that may affect CVSC in freshwater, but we will not consider CVSC freshwater management further here. Instead, we focus on how the current management of ocean fisheries affects CVSC. We summarize current fishery management policies for CVSC and evaluate their justification, survey relevant data that could inform fisheries management, and discusses possible alternatives if more active management actions are desired, describing options based on both current and potential future data sources.

Extensive background on CVSC is available in the relevant status review documents (CDFG 1998; Myers et al. 1998; NMFS 2000, 2011, 2014; Johnson and Lindley 2016), and elsewhere (e.g., CDFG 2004). Briefly, CVSC were historically abundant in the upper watersheds throughout the Sacramento and San Joaquin basins (Yoshiyama et al. 1998), but much of that habitat is now blocked or degraded, and self-replacing populations of CVSC are currently restricted to a few tributaries (Mill, Butte, Deer, and Battle creeks) in the upper Sacramento River basin (Lindley et al. 2007). There are also numerous "dependent" populations in the upper Sacramento Basin, and some signs that fish exhibiting spring-run-like behavior may be re-colonizing the San Joaquin Basin (Johnson and Lindley 2016). Efforts are underway to re-introduce CVSC to the southern portion of their range via the San Joaquin River Restoration Project (SJRRP 2017), but we focus mostly on extant populations in the Sacramento River basin.

Nominally spring-run Chinook Salmon are produced at the Feather River Hatchery (FRH), although these fish are genetically introgressed with fall-run Chinook Salmon (Cramer and Demko 1996; Myers et al. 1998). Nevertheless, FRH spring-run Chinook Salmon are included in the federally-designated CVSC Evolutionarily Significant Unit (ESU; NMFS 2011) although FRH spring-run Chinook Salmon were not "considered to be essential for its recovery" (NMFS 2000). NMFS documents generally refer to genetic introgression from FRH fish as a threat to the ESU (Myers et al. 1998), although habitat loss and degradation is identified as the main threat (Myers et al. 1998). NMFS (2014) stated that the "principal strategy of salmonid conservation and recovery continues to be through the protection and restoration of the healthy ecosystems upon which they depend" while recognizing some role of "conservation hatcheries" for establishing new populations or allowing existing populations to recover, specifically pointing to winter-run Chinook Salmon produced at the Livingston Stone National Fish Hatchery (LSNFH) and the development of a hatchery to re-establish spring-run Chinook Salmon as part of the San Joaquin River Restoration Program (SJRRP). The SJRRP employs a conservation hatchery that currently sources broodstock from the FRH (SJRRP 2017), but goals for the project include phasing out the use of FRH broodstock and eventually eliminating the conservation hatchery once natural-area spawners are sufficiently productive. Thus, we focus primarily on the development of management tools that could contribute to the protection and recovery of natural-origin CVSC.

Fish (all spring-run, and a known fraction of fall-run Chinook Salmon) produced at the FRH are marked with an adipose fin clip and tagged with a coded-wire tag, a marking and tagging program similar to that which forms the basis of management of endangered SRWC (O'Farrell et al. 2012a, 2012b), and many other Pacific salmon stocks (PSC 2005, 2008). Recently, genotyping of all FRH broodstock using parentage-based tagging has also allowed identification of their recovered and genotyped offspring back to hatchery and brood year of origin (Clemento et al. 2014). Although it has been discontinued, a marking and tagging program trapped natural-origin spring-run Chinook Salmon juveniles leaving Butte Creek in 1996 and from 1998 to 2004 (Ward 2004). In addition, natural-origin CVSC (but not FRH spring-run Chinook Salmon, which because of extensive genetic introgression with fall-run Chinook Salmon are part of the "Central Valley Fall" genetic reporting group) can be identified through genetic stock identification (GSI) (Seeb et al. 2007; Clemento et al. 2014). However, GSI does not provide all of the supplemental information (e.g., brood year, release type) encoded in coded-wire tags. Carefully implemented, parentage-based tagging can provide the same information as coded-wire tags via genetic sampling, although parentage-based tagging is likely more practical for hatchery-origin than natural-origin fish (Satterthwaite et al. 2015a).

CVSC are contacted in commercial (Bellinger et al. 2015) and recreational (Satterthwaite et al. 2013, 2015b) fisheries off the coasts of California and Oregon, within the management purview of the Pacific Fishery Management Council (PFMC). The PFMC's current salmon Fishery Management Plan (FMP) does not call for any direct management of CVSC (PFMC 2016), although escapement is tracked and reported (e.g., PFMC 2017a) for tributaries with naturally spawning spring-run populations, as well as returns of nominal spring-run Chinook Salmon to the FRH (however, spring-run versus fall-run escapement is not currently distinguished for natural spawning grounds in the Feather River itself, with all natural area spawners reported as fall run).

The lack of management measures specific to CVSC is consistent with the biological opinion and incidental take permit (NMFS 2000), which reasoned that restrictions enacted to protect SRWC should sufficiently protect CVSC (NMFS 2000). In addition, the previous federal status review (Myers et al. 1998, p. 198) argued that the ocean spatial distribution of CVSC was similar to Sacramento River fall-run Chinook Salmon (SRFC) but CVSC were smaller, and so ocean fishing mortality rates on the two stocks were expected to be similar but lower for CVSC. Based on similar logic, the most recent 5-year federal status review update (Johnson and Lindley 2016) concluded that ocean fishing mortality rates for CVSC were probably lower than those for SRFC. They also noted that because maturing CVSC leave the ocean and return to rivers earlier within the year than SRFC, they would be less exposed to ocean fisheries if maturation schedules were similar.

Nevertheless, there has been interest in more active management of this threatened stock, and there may be a need to evaluate how fisheries affect the success of San Joaquin River spring-run Chinook Salmon restoration (SJRRP 2017). In 2002, an interagency workgroup was convened to review management options and available data at that time (Grover et al. 2004). The workgroup determined that active management based on cohort reconstruction (Hilborn and Walters 1992; O'Farrell et al. 2012b) facilitated by tagging of natural-origin fish was unlikely to be applicable to CVSC because of small sample sizes to date (brood years 1998–2000, with 2000 incomplete at that time) and the expectation (later proven correct) that the tagging project would be phased out (Grover et al. 2004). The workgroup was skeptical about the suitability of tagged FRH spring-run Chinook Salmon as an indicator for natural production in the ESU because of genetic introgression by fall-run Chinook Salmon (Grover et al. 2004). Butte Creek spring-run Chinook Salmon tagging did indeed terminate after Grover et al.'s (2004) report was released, and the completed project yielded ocean recoveries through 2007, which included some data beyond that which Grover et al. [2004] analyzed (Ward et al. 2004).

Additional data on ocean harvest of natural-origin spring-run Chinook Salmon has become available through genetic analyses of samples collected from dockside sampling of 1998–2002 California recreational fisheries (Satterthwaite et al. 2015b), voluntary sampling by participants in California and Oregon commercial fisheries in 2010 (Bellinger et al. 2015), and ongoing West Coast Salmon GSI cooperative sampling of the commercial fishery (unpublished data). Collection of coded-wire tag data from comprehensive sampling of recreational and commercial ocean fisheries, freshwater fisheries, and freshwater spawning escapement has continued without interruption (aside from fishery closures). Analyses based on GSI have the advantage that, in theory, all natural-origin fish are 'tagged," but assignment errors are possible, and information on age and other release- or tagging-event-specific details are not available without supplemental analyses (e.g., using data from scales or otoliths). For the commercially-collected GSI data, catch locations of individual fish are available, but voluntary participation of samplers may call representativeness into question. Coded-wire tag data are collected in a consistent, representative sampling program and provide age and other release-specific information.

The availability of these new data—along with recent motivation to reassess abundance-based management options for California Coastal Chinook Salmon (CC-Chinook) (O'Farrell et al. 2012c, 2015) and SRWC (PFMC 2015)—suggest that this is a good time to

1. Re-examine the validity of assumptions made in past analyses,
2. Explore the currently available options to manage ocean fisheries for CVSC, and
3. Identify new data types or collection programs that could facilitate active management in the near future, if such active management were deemed desirable.

Suitability of Passive Management Approach and Underlying Assumptions

If measures designed to protect SRWC and other co-mingling stocks also protect CVSC (NMFS 2000), active management of CVSC may not be necessary. In this section, we explore the extent to which fishing regulations enacted for other stocks also may sufficiently protect CVSC.

SRWC protections center around restrictions on the possible season length and increased minimum size limits south of Point Arena (always in effect) and potentially additional restrictions on fisheries south of Point Arena driven by an abundance-based harvest control rule that places limits on the allowable anticipated ocean fishing mortality rate. The anticipated ocean fishing mortality rate is a function of forecasted fishing effort (based on the number of days open) and minimum size limits in effect each month for commercial and recreational fisheries in each of the two PFMC management areas south of Point Arena (O'Farrell et al. 2012a). Age-3 ocean fishing mortality rates are considered the most relevant measure of fishery effects on SRWC because of the stock's very high age-3 maturation rate (typically >0.9); (O'Farrell et al. 2012b; Winship et al. 2014).

Thus, the effectiveness of measures enacted for SRWC to protect CVSC depend partly on the stocks' similarity in spatial distribution, maturation schedules, and size-at-age; and the degree to which annual adjustments in maximum allowable ocean fishing mortality rates on SRWC mimic the appropriate annual adjustments in maximum allowable impacts on CVSC depend on covariation in production of the two stocks. Additionally, even if the two stocks were very similar in these respects, the effectiveness of the harvest control rule for SRWC in achieving conservation goals for SRWC is itself very important but beyond the scope of this analysis (see Winship et al. 2013 for an evaluation of the SRWC harvest control rule). Currently, there is great interest in making the SRWC management framework more prospective (based on a forecast of current abundance rather than past escapement; PFMC 2015). If doing so improves management of SRWC populations, then it should also improve management of CVSC populations if the two stocks are similar in productivity and exposure to the fishery.

In addition to evaluating the similarity between CVSC and SRWC as invoked by NMFS (2000), it is important to consider management measures enacted for other stocks that also may affect fishery impacts on CVSC. As noted previously, Myers et al. (1998) suggested that because of qualitatively "similar" spatial distribution and smaller size than SRFC, ocean fishing mortality rate should be lower for CVSC than SRFC, and so this merits comparison of CVSC with SRFC in factors that affect exposure to the fishery. In addition, forecast abundance of Klamath River fall-run Chinook (KRFC) Salmon and/or the consultation standard in effect for CC-Chinook—both of which tend to restrict fishing opportunity in northern California and southern Oregon (and to a lesser extent in central California and northern Oregon; O'Farrell et al. 2012c)—may be relevant, depending on how much the distribution of CVSC extends into northern California and Oregon.

Finally, Grover et al. (2004) suggest a practical approach to assessing the suitability of current fishery impacts on CVSC by simply examining trends in escapement and asking the question: Do the observed trends suggest that fishery effects are low enough—based on the current suite of habitat and environmental conditions—to continue the then-observed "recent trends in recovery"? Although Grover et al. (2004) did not establish strict quantitative criteria, and the influence of natural variability is difficult to disentangle from the effects of fishing and other anthropogenic effects, examining long-term trends may nevertheless be informative. However, a decline in abundance is not necessarily attributable to fishing pressure, nor does an increasing trend indicate that fishing is not slowing recovery.

Spatial Distribution

Although ocean research surveys have recovered small numbers of tagged or genetically-identified CVSC juveniles, the vast majority of information on the ocean spatial distribution of CVSC comes from fish recovered in commercial and recreational fisheries, specifically from fish samples that can be identified back to stock of origin through physical tags or genetic analysis. Thus, as with any fishery-dependent data source, care is needed when interpreting catch patterns as local abundance patterns. However, for management purposes, spatial patterns of interactions with the fishery may be of more interest than the true ocean distribution.

Existing literature on recoveries of CVSC comes from both coded-wire tags and GSI studies that vary in their spatio-temporal coverage and resolution, as well as how fishing effort and sampling error were accounted for. Many studies investigated ocean spatial distribution relative to ocean management areas used by the PFMC (Figure 1), although some studies sub-divide select management areas further. Satterthwaite et al. (2013) provides the most detailed examination of CVSC distributions based on recoveries of coded-wire tags from 4,058 FRH spring-run Chinook Salmon and 60 Butte Creek spring-run Chinook Salmon in the recreational fishery from 1978 to 2007. They used a hierarchical model to combine information across years while estimating month-specific patterns in relative density across space off the coast of California and Oregon, explicitly accounting for fishing effort, likely discards of sublegal-sized fish, and sampling error.

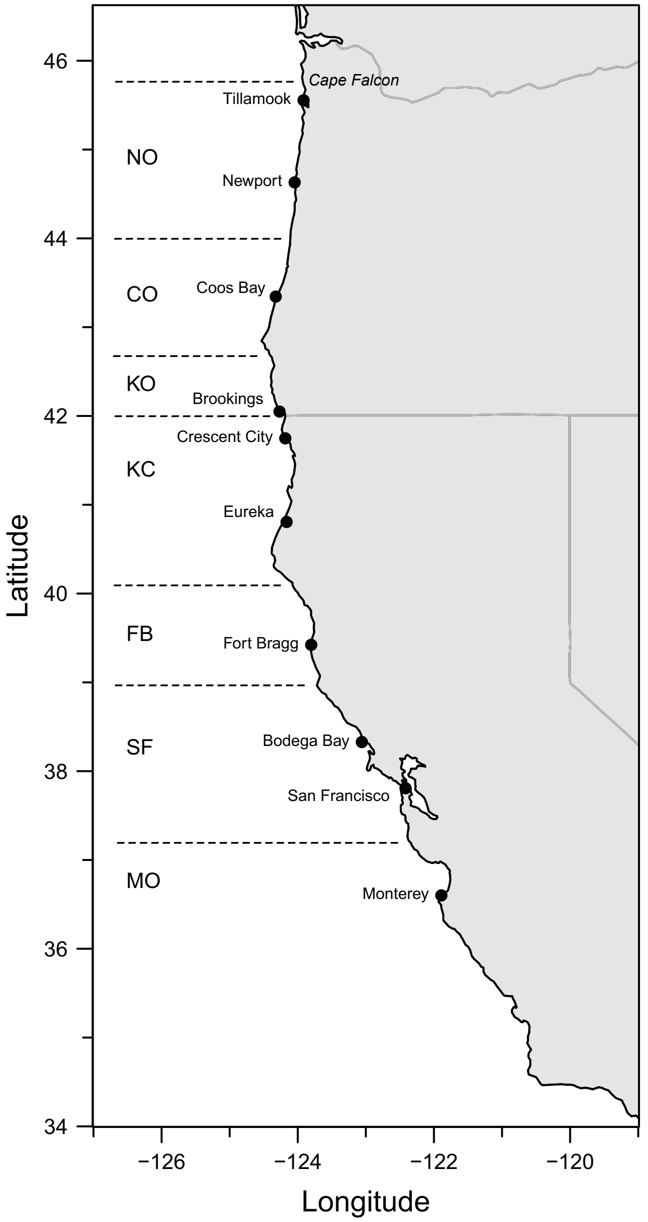

Figure 1 Ocean salmon management areas. Source: Adapted from PFMC (2014).

FRH spring-run Chinook Salmon appear to have non-zero contact rates (credible intervals clearly above zero) throughout California (areas labeled MO through KC, Figure 1) year-round, peaking in northern California (KC) in July and September,

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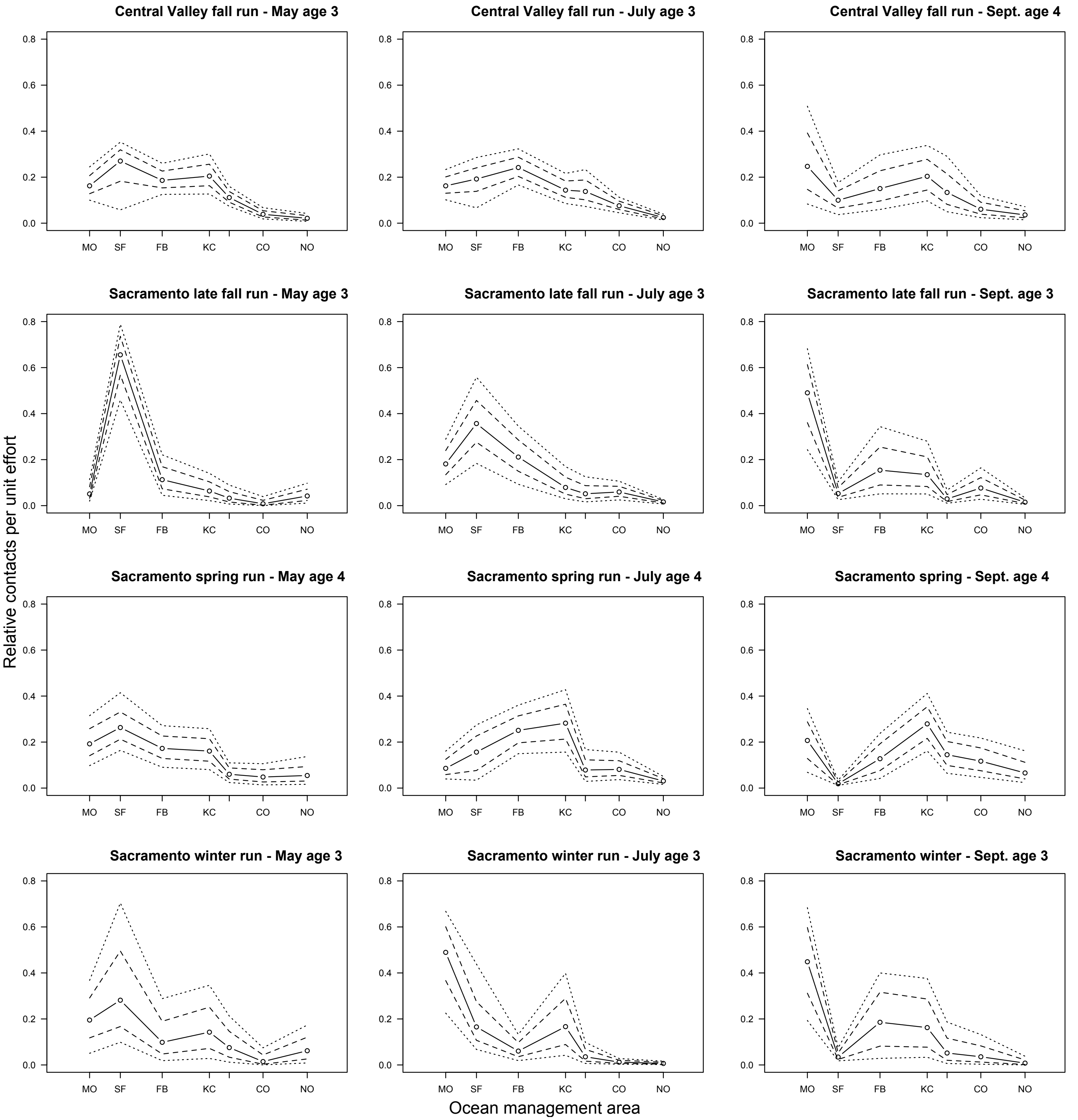

Figure 2 Relative contacts per unit effort estimated for each management area, for fish starting the year at age-3 from Central Valley fall-run Chinook Salmon and Sacramento River spring-run and winter-run Chinook Salmon in May, July, and September, modified from Satterthwaite et al. (2013). Management areas are arranged along the x-axis in order of increasing latitude of their major ports. The label for the KO area between KC and CO is omitted for legibility. Points are posterior medians; broken lines represent 68% and 95% credible intervals. Sacramento River spring-run Chinook Salmon results reflect all tags combined, whether they originate from the FRH or naturally from Butte Creek, but patterns are driven primarily by FRH tags, which were more numerous.

and extending into Oregon in the fall (Figure 2). This contrasts with SRWC, where clearly non-zero contact rates are restricted to the southernmost areas (labeled MO and SF, see Figure 1). Note that although it is difficult to rule out non-zero contact rates for SRWC in areas FB and KC (Figure 1), despite very limited tag recoveries, this largely reflects how the model treats strata with limited fishing effort and a substantial portion of fish estimated to be of sub-legal size and so not available for sampling. Estimates for the other runs are also affected by fishing effort and size limits, but size limits influence the other runs less because the fish are larger at a given age (Satterthwaite et al. 2017). Because contact rates for the other stocks are higher in the core of their ranges, inflation of possible contact rates in areas with less effort (fishing effort and/or sampling) is less apparent. Additionally, the Satterthwaite et al. (2013) model does not share information across months or between adjacent areas; thus, the consistent rarity of SRWC tag recoveries in northern areas year-round increases confidence that catchable SRWC are restricted to the south relative to FRH spring-run Chinook Salmon, as do GSI data described later. In addition, FRH spring-run Chinook Salmon appear to be distributed somewhat to the north of CV fall-run Chinook Salmon later in the year (i.e., in July and September).

GSI data from recreational and commercial fisheries show broadly similar patterns. Satterthwaite et al. (2015) used GSI recoveries from the California recreational fishery in 1998–2002 to provide the most detailed information available on natural-origin CVSC distribution, even though the number of CVSC recoveries was low overall (34 fish were assigned to CVSC with highest probability) and thus limited the strength of inferences made. Results obtained for natural-origin CVSC via GSI were consistent with the FRH coded-wire tag results. CVSC were recovered sporadically throughout the sampled range (contrasting with SRWC recoveries restricted to south of Point Arena), potentially with higher catch per unit effort (CPUE) in the south in April and May, and higher CPUE in the north in June through September. Patterns were less clear in an analysis of the commercial fishery using GSI reported by Bellinger et al. (2015) based on 88 fish genetically identified as CVSC in 2010, but that study consistently found CVSC in northern California (FB and KC areas, Figure 1) during July through September, while not detecting SRWC in northern areas. In an earlier published report on natural-origin CVSC distribution, Grover et al. (2004) found coded-wire tagged fish from Butte Creek concentrated south of Point Arena, but not to the same extent as SRWC. It is important to note that Grover et al. (2004) did not consider fishing effort or stratify recoveries by month.

To provide a more detailed look at the CVSC ocean distribution as estimated from coded-wire tag recoveries of Butte Creek spring-run Chinook Salmon, we fit the models described in Satterthwaite et al. (2013) to 2000–2007 recreational fishery recoveries, and compared this against the same models fit to data for FRH spring-run Chinook Salmon recovered in the same years. Our analysis accounted for the effects of fishing effort, sampling rate, proportion of sublegal-sized fish (assuming the same size-at-age for both stocks; see below for support), and monthly variation, while we assumed the same proportional distribution through space across years. Our analysis was restricted to recreational fisheries for consistency with Satterthwaite et al. (2013), and because recreational fishers take shorter trips and land fish near where they are caught whereas commercial fishers may not, and the lower minimum size limits for recreational fishers mean less extrapolation is necessary to account for sublegal-sized fish. We were limited in the number of months with adequate data to fit the model to Butte Creek spring-run Chinook Salmon, but in those 2 months the two stocks appeared similarly distributed, with peak contacts per unit effort in the northernmost California ocean management area (Figure 3).

Taken together, these results suggest that CVSC are clearly distributed more to the north than SRWC, and may be distributed somewhat to the north of SRFC, especially late in the fishing season. Thus, measures taken to protect SRWC south of Point Arena, when viewed in isolation, may not similarly protect CVSC. At the same time, the more northerly distribution of CVSC means that measures in place to meet the CC-Chinook consultation standard, which typically constrains fishing effort most strongly in northern California and southern Oregon (O'Farrell et al. 2012c), may serve to reduce the fishery impacts on CVSC as well, such that the combined constraints

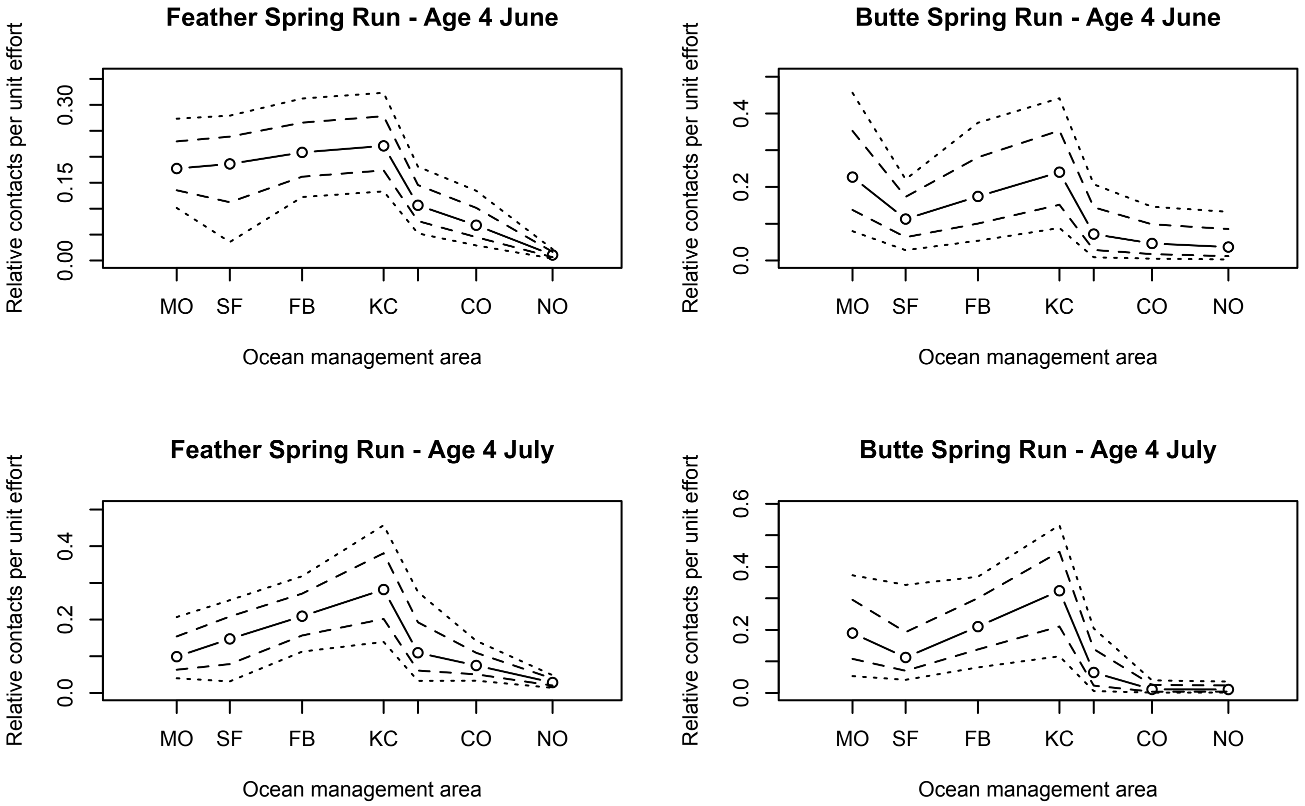

Figure 3 Relative contacts per unit effort for tagged Butte Creek versus Feather River Hatchery spring-run Chinook Salmon by month–area stratum. Note that the y-axis is scaled differently for each stock, and the magnitude of values should not be compared between stocks. Only strata with sufficient data to make estimates for Butte Creek are shown. Circles are posterior medians; broken lines represent 68% and 95% credible intervals.

that result from measures taken for SRWC and CC-Chinook may protect CVSC throughout its range. Although not always more constraining than the CC-Chinook consultation standard, limits on allowable expected ocean fishing mortality rates for KRFC (most relevant in years of low forecasted KRFC abundance) may further reduce the effects of fishing in northern California and southern Oregon. KRFC abundance forecasts constrained the fishery more than the CC-Chinook consultation standard in 10 out of 17 years during 2001–2017.

Maturation Schedule

The literature is mixed on the spawner age composition and maturation schedule of CVSC. In a comparison of the four Central Valley Chinook Salmon run timings, Fisher (1994) reported a high proportion of age-3 spawners (87%) for CVSC, second only to SRWC. Reports for natural-origin fish from Butte Creek (Ward et al. 2003, 2004; McReynolds et al. 2005, 2006, 2007; Garman and McReynolds 2008, 2009) indicated predominantly age-3 spawners in 2001, 2002, 2004, 2005, and 2007 but predominantly age-4 spawners in 2003 and 2006. (However Grover and Kormos [2009] reported, based on scale reading, that 78% of Butte Creek spring-run spawners in 2006 were age-3.) This variability in age structure is likely confounded with variation in cohort strength (although several reports refer to correcting for the number of fish marked each year, but the correction is not described in detail) and in ocean fishing mortality. Cohort reconstructions can remove some of these confounding effects, but care must be taken when vital rates are estimated from only a small number of tag recoveries (PSC 2005). Additionally, cohort reconstructions performed for CVSC have varied slightly in their assumptions about natural mortality rates for adults in the ocean, how they account for the assumed mortality of fish that are hooked but not retained in the harvest, and whether they use monthly or annual time-steps. With these caveats in mind, Grover et al. (2004) reported age-3 maturation rates of 40% and 28% based on cohort reconstructions for natural-origin Butte Creek spring-run Chinook Salmon from brood years 1998 and 1999, respectively. These rates, while uncertain, are within the range reported for FRH spring-run Chinook Salmon. Palmer–Zwahlen et al. (2006) estimated FRH spring-run age-3 maturation rates of 39% for brood year 1998 and 28% for brood year 1999, while Cramer and Demko (1996) estimated age-3 female maturation rates of 15% to 30% for brood years 1975–1977 (when fish were released relatively late in December or January) and 63% to 72% for 1984–1986 (when fish were released earlier in March or April). Faster maturation of earlier releases has also been observed in other populations (e.g., Hankin and Logan 2010), and it is reasonable to hypothesize that earlier-emigrating natural-origin fish would tend to mature earlier as well. Natural-origin CVSC emigrate over an extended period (Fisher 1994), and emigration may be later on average in the Deer and Mill creek populations where body growth is slower (Cramer and Demko 1996).

In contrast with CVSC, SRWC escapement is dominated by age-3 fish (91% in Fisher 1994), and cohort reconstructions estimate age-3 maturation rates of 85% to 100% with a mean of 95% for winter-run Chinook Salmon produced by the LSNFH (O'Farrell et al. 2012b). These values are all outside (above) the range of estimates reported for CVSC. SRFC escapement typically consists of appreciable numbers of age-2, age-3, and age-4 fish, with age-3 fish most common (Fisher 1994; Myers et al. 1998 and references therein). Although historical sampling for coded-wire tags has not been conducive to basin-wide cohort reconstructions of SRFC (Bergman et al. 2012), results from small-scale coded-wire tag studies estimated that age-3 maturation rates for FRH fall-run Chinook Salmon ranged from 46% to 78% for brood year 1998, and from 30% to 60% for brood year 1999 (Palmer–Zwahlen et al. 2006).

Thus, although the maturation schedule of CVSC remains somewhat uncertain, these fish seem likely to mature later than SRWC. As a result, the cumulative exposure of CVSC to the fishery may be greater, and effects on age-4 (and possibly older fish) may make up a larger fraction of the total fishery effects on CVSC than on SRWC. It is less clear how CVSC maturation schedules compare to those of SRFC, and so maturation schedules for both run timings, particularly for natural-origin fish, warrant further investigation.

Size at Age

As with spatial distribution, the largest data source for estimating size-at-age of CVSC recovered in the ocean comes from FRH spring-run Chinook Salmon coded-wire tag recoveries. In addition, there are sufficient Butte Creek spring-run Chinook Salmon coded-wire tag recoveries to allow estimation of size-at-age for some months. Since GSI sample sizes were low and not all fish sampled for GSI were also aged, we were unable to make estimations of size-at-age

Table 1 Mean length-at-age of FRH spring-run Chinook Salmon estimated in this paper compared to mean lengths of SR winter-run Chinook estimated by O'Farrell et al. (2012b). Fish are measured by total length in inches.

Age			Mean length (TL)	
Spring	**Winter**	**Month**	**Spring**	**Winter**
2	3	Mar	—	20.8
2	3	Apr	—	21.9
3	3	May	—	22.9
3	3	Jun	20.5	24.0
3	3	Jul	21.7	25.1
3	3	Aug	22.1	26.2
3	3	Sep	23.9	27.3
3	3	Oct	25.6	28.4
3	4	Mar	29.2	29.0
3	4	Apr	29.9	29.9
4	4	May	30.2	30.9
4	4	Jun	30.1	31.9
4	4	Jul	30.4	32.9
4	4	Aug	30.3	33.8
4	4	Sep	30.5	34.8
4	4	Oct	31.3	35.8

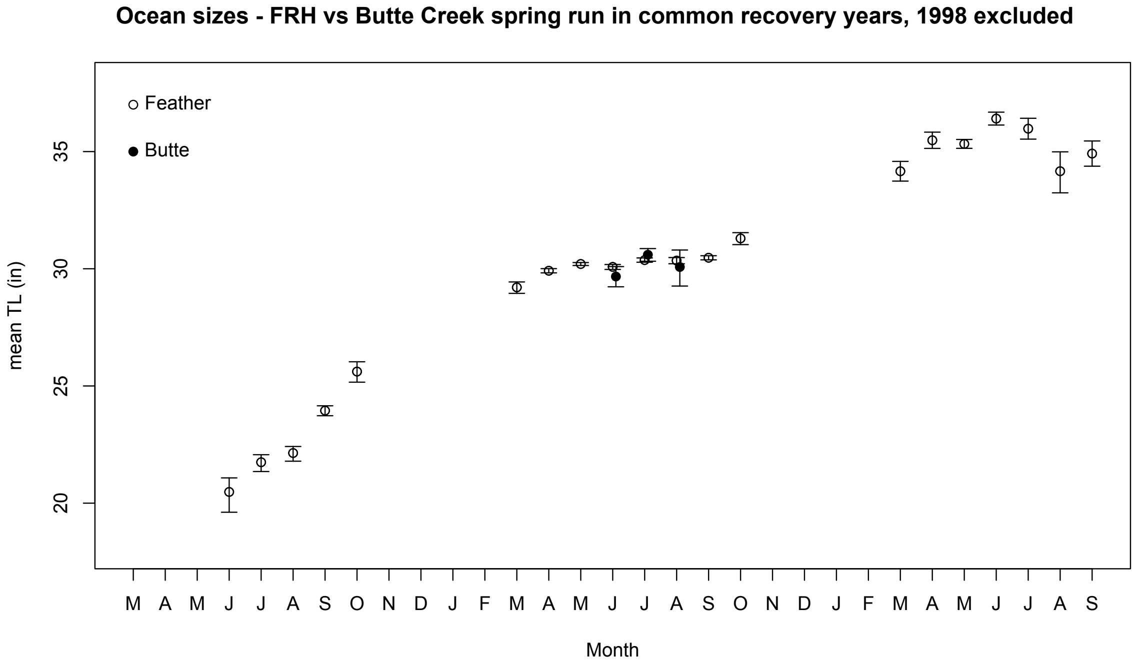

Figure 4 Estimated monthly mean (across years) length (+/- 1 SE) of spring-run Chinook Salmon from Feather River Hatchery (FRH, open circles) and the Butte Creek natural-origin tagging program (filled circles) recovered in recreational ocean fisheries, 2000–2007. Only month–stock combinations with adequate tag recoveries in a given month are plotted.

from natural-origin CVSC recovered in the GSI data sets.

We estimated monthly mean size using maximum likelihood methods that assumed truncated normal distributions (Satterthwaite et al. 2012) that we applied separately to coded-wire tag recoveries in the recreational ocean fishery from both Butte Creek spring-run Chinook Salmon and FRH spring-run Chinook Salmon. Our analysis was restricted to recovery years 2000–2007, the years for which recoveries from both stocks were available. We excluded data from 1998, which had a few recoveries from a pilot tagging study performed earlier on Butte Creek, since 1998 was discontinuous with the other years and SRFC were anomalously small in 1998 (Satterthwaite et al. 2012).

The two components of CVSC appear highly similar in size-at-age for those month–age strata with sufficient data to estimate a length for Butte Creek spring-run Chinook Salmon (Figure 4). CVSC are generally shorter at a given "age" (defined later) than SWRC (O'Farrell et al. 2012a), except during March and April, when the largest fish from winter-run cohorts have likely matured and left the ocean, while maturing spring-run remain in the ocean (Table 1). Under the management convention for SRWC (O'Farrell et al. 2012a), winter-run Chinook Salmon in the ocean advance in age on March 1, when all maturing fish are assumed to have returned to the river, so here we assumed a May 1 birth date for spring-run Chinook Salmon (and as in Grover et al. 2004). Within each calendar year, ages are calculated as recovery year minus brood year before the birth date, and recovery year minus brood year +1 after the birth date.

These size-at-age values for CVSC are smaller than those for SRFC (Satterthwaite et al. 2012), although a direct comparison of size-at-age is complicated by the difference in birth dates; for example, in June an age-3 fall-run fish comes from a brood year 1 year earlier than an age-3 spring-run fish. As a result of the small size of age-3 CVSC, increases in size limits like those enacted to reduce ocean fishing mortality rates for SRWC (which are also smaller at a given age than CVSC) would reduce impacts on age-3 CVSC as well. However, to the extent that CVSC are distributed more to the north, minimum size limits in effect south of Point Arena may be less protective of most CVSC. In addition, differences in maturation schedules may reduce the importance of age-3 impacts relative to age-4 impacts, which are less affected by size limits.

Covariation in Juvenile Production

Reliable juvenile production estimates for natural-origin CVSC populations are not available from most systems. Juvenile passage is counted biweekly at Red Buff Diversion Dam, but run assignment is based on length-at-date and subject to error, particularly because of the similar sizes of natural-origin CVSC and unmarked Coleman Hatchery fall-run Chinook Salmon. Production of CVSC could be better assessed by using GSI methods, which would better distinguish emigrating juveniles. Although rotary-screw traps have operated in Butte, Mill, and Deer creeks, their continued operation is uncertain, and there are no trap efficiency estimates to scale these samples to estimate population abundance. Thus, it is not possible to empirically estimate the covariation in winter-run, fall-run, and spring-run juvenile Chinook Salmon production.

In the absence of quantitative comparisons of long time-series of well-supported juvenile production estimates, we can consider the expected correlation given differences in their life history and ecology. Although prolonged (i.e., multi-year) droughts are likely to have similarly adverse effects on multiple runs, these runs vary in their timing and location of spawning, incubation, emergence, rearing, and downstream migration. Thus, there is ample opportunity for contrasting responses to spatio-temporal environmental variation or specific water management actions, such that close covariation in juvenile production cannot be assumed.

Covariation in Adult Escapement

To explore the degree of covariation in CVSC production with nearby stocks that might serve as proxies, we calculated the correlation of CVSC escapement with escapement of SRWC, CV fall-run Chinook Salmon (including escapement to the Mokelumne River and San Joaquin Basin along with SRFC), SR late-fall-run Chinook Salmon, and KRFC (Table 2). For the analyses presented here, we obtained Central Valley escapements from Grandtab (*http://www.calfish.org/ProgramsData/Species/CDFWAnadromousResourceAssessment.aspx*), maintained by the California Department of Fish and Wildlife and last updated on April 7, 2017. We obtained KRFC escapements from the PFMC Salmon Document Library: Historical Data of Ocean Salmon Fisheries "Blue Book" (*http://www.pcouncil.org/salmon/background/document-library/historical-data-of-ocean-salmon-fisheries/*) accessed August 3, 2017. The reliability of these data varies. For CVSC, counts at the FRH are considered very reliable, and Butte Creek estimates since 2001 are based on mark–recapture estimates using the super-population format of the Cormack Jolly Seber model (Bergman et al. 2012). Through the years, methodologies have varied for estimating CVSC populations on other streams, with snorkel surveys used on Butte Creek before 2001. Butte Creek makes up the majority of CVSC

Table 2 Correlation of escapement (or total returns) among California Chinook Salmon stocks: Central Valley spring-run Chinook (CVSC) with or without Feather River Chinook (FRC), Sacramento River winter-run Chinook (SRWC), Sacramento River late-fall-run Chinook (SRLFC), Central Valley fall-run Chinook (CVFC), and Klamath River fall-run Chinook (KRFC).

	CVSC (no FRC)	SRWC	SRLFC	CVFC	KRFC (esc.)	KRFC (returns)
CVSC (all)	0.97	0.29	0.44	0.57	0.40	0.45
CVSC (no FRC)		0.37	0.43	0.50	0.35	0.40
SRWC			0.17	0.22	-0.03	-0.03
SRLFC				0.40	-0.002	0.02
CVFC					0.42	0.45
KRFC (esc.)						0.95

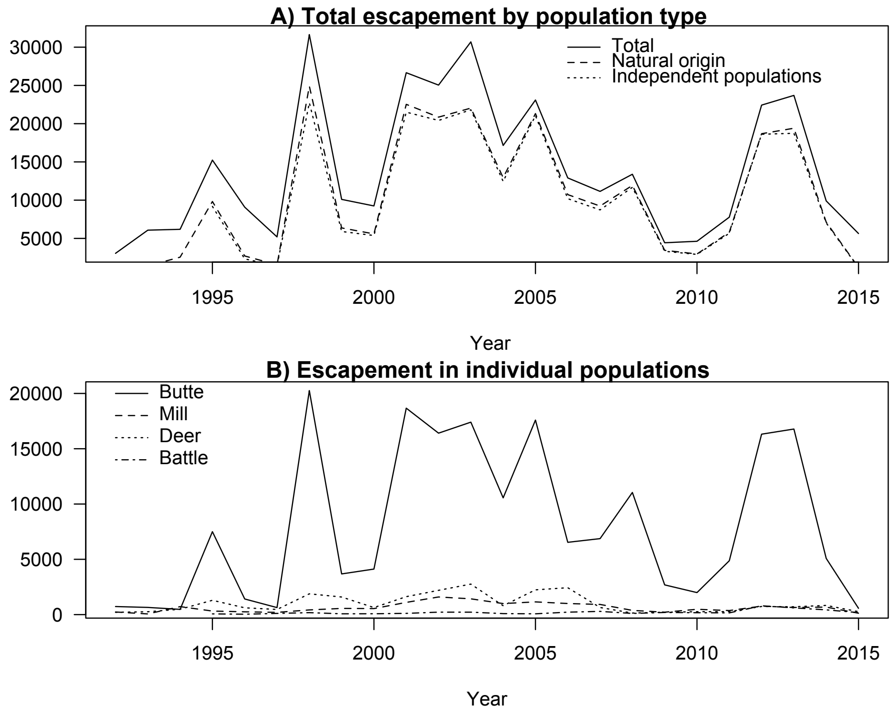

Figure 5 Trends in adult Central Valley spring-run Chinook Salmon escapement. In (**A**), the solid line includes all populations, the heavily dashed line excludes hatchery-origin fish, and the lightly dashed line is the sum of escapements to the four independent populations (Battle, Deer, Butte, and Mill creeks). In (**B**), each of the four independent populations are shown. (Butte Creek escapement estimates before 2001 are from snorkel surveys.)

escapement in most years (Figure 5), although the number of FRH spring-run Chinook Salmon spawning in natural areas are not estimated separately from FRH fall-run Chinook Salmon. Escapement estimates for SRFC and KRFC have also varied in quality, but all are deemed sufficient for use in management.

We considered measures of CVSC with and without inclusion of FRH spring-run Chinook Salmon. Because there is a substantial river fishery for KRFC, we looked at both spawner escapement and river returns (includes river harvest) for these fish. Escapement is of course an imperfect surrogate for production, confounded by differences in age structure and partially shared effects of ocean harvest.

The exclusion of FRH spring-run fish had little effect on how well correlated CVSC escapement was to other stocks, given the high correlation between total CVSC escapement with or without FRH fish ($r=0.97$). This likely reflects the modest proportion of FRH spring-run spawners in total CVSC escapement (26% of the arithmetic mean total escapement 1992–2016) rather than high correlation to natural-origin spring-run Chinook Salmon escapement ($r=0.34$ between FRH and Butte Creek spring-run escapement). Generally, CVSC escapement correlated moderately positively with escapement of other runs (with a high of 0.57 for CV fall-run Chinook Salmon and a low of 0.29 for SRWC). With the exception of the correlation with SRWC, all of these correlations were statistically significant (2-tailed $p<0.05$) even after correcting the degrees of freedom for temporal autocorrelation (Pyper and Peterman 1998). If a 1-tailed test was used because of the *a priori* expectation of a positive correlation (Carlson and Satterthwaite 2011), resulting from shared environmental conditions, the correlation between CVSC and SRWC escapement was statistically significant as well. Although these correlations are statistically significant, none are likely strong enough to serve as the basis for identifying a suitable indicator stock. O'Farrell et al. (2012c) deemed a correlation coefficient of 0.50 between escapement of CC-Chinook to the Russian River and SRFC insufficient to support inference of likely Russian River cohort strength on the basis of SRFC forecasts, and none of the correlations found between escapements of CVSC and any

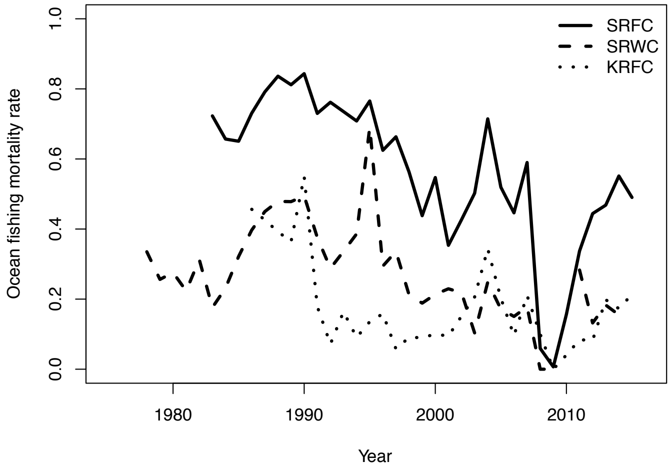

Figure 6 Annual ocean fishing mortality rate estimates for Sacramento River fall-run Chinook (SRFC), Sacramento River winter-run Chinook (SRWC), and Klamath River fall-run Chinook (KRFC). The plotted metrics are age-4 ocean fishing mortality rate for KRFC, age-3 ocean fishing mortality rate for SRWC, and SI ocean harvest rate index (H_0/SI) for SRFC, where H_0 is the estimated ocean harvest of SRFC adults and SI is the sum of SRFC escapement and harvest. The calculation of these quantities is described in PFMC (2017b).

other stock are substantially higher than this. Thus, active management of the other stocks, even if it successfully tracks changes in their productivity, may not respond to productivity changes in CVSC.

Trends in Adult Escapement

Trends in composite adult CVSC escapement, along with select populations, are shown in Figure 5. Williams et al. (2016) discuss recent CVSC escapement trends through 2014 (Figure 5). They estimated that all four "independent" populations (Battle, Deer, Mill, and Butte creeks) have increased since the 2010 assessment, but the majority of "dependent" populations have decreased. Point estimates of trends over the last 10 years available at the time of Williams et al. (2016) were positive for Battle, Butte, and Deer creeks (although 95% confidence intervals included negative values for Butte and Deer creeks) but negative for Mill Creek (although the 95% confidence interval included positive values). However, escapements were lower in 2015–2016 (Figure 5).

Trends in Ocean Fishing Mortality Rates

Although CVSC fishing mortality rates are not currently estimated, trends in these rates for co-mingling stocks allows for some inference about how changes in fishing may also affect CVSC. Figure 6 displays estimated ocean fishing mortality rates for SRFC, SRWC, and KRFC. Ocean fishing mortality rates (which include both landed and non-landed mortalities, e.g. including an estimate of the mortality associated with sublegal-sized fish that are released back into the ocean) have generally decreased since the late 1980s for each of these three stocks, partially as a result of a complete closure of ocean fisheries off California and most of Oregon for 2008–2009. Given the decreasing ocean fishing mortality rates on all three stocks, it is likely that ocean fishing mortality rates on CVSC also decreased over this same time-period, although the magnitude of this change is unknown. Given their respective ocean spatial distributions, CVSC ocean fishing mortality rates are likely most similar to SRFC, but since the stocks are not identical in their distributions, the degree to which their ocean fishing mortality rates covary is unknown.

Prospects for Alternative Management Approaches

This section explores the options to more actively manage CVSC populations by describing the approaches used for active management of other stocks encountered in ocean fisheries off the coast of California. We also describe management approaches which have been proposed but not adopted for other stocks.

Stock–Recruit Relationship Estimation

Currently, sufficient data to estimate a stock–recruit relationship for CVSC do not exist. Should such data become available in the future, the likely goal of estimating a stock–recruit relationship would not be to estimate the fishing level corresponding to maximum sustained yield, since harvesting at maximum sustained yield is rarely a management target for listed (i.e., threatened or endangered) stocks. However, a stock–recruit relationship would allow for inference about population productivity, and could serve as an input for an analysis of relative risk associated with different harvest control rules (c.f. Winship et al. 2013).

Forecasting

For some other California stocks, the ocean abundance before the beginning of the annual fishing season is predicted based on sibling relationships (i.e., the abundance of age-*a* KRFC is forecast based on the previous year's escapement of age *a*-1) or something approximating a sibling relationship. (The composite SRFC adult [age 3+] abundance index is forecast based on information that includes the previous year's jack [age 2] escapement.) For other stocks, escapement or river mouth returns (rather than pre-fishery abundance) is forecast in a similar manner, conditioned (either explicitly or implicitly) on the assumption that harvest rates do not vary significantly across years, so that escapement and pre-fishery ocean abundance covary closely.

If adequate data on age-specific escapement were available, CVSC escapement could be forecasted as well. This could be extended to a forecast of preseason ocean abundance if age-specific fishing mortality rate estimates were available as well (see discussion of cohort reconstructions later). To make use of these forecasts, a harvest control rule would need to be developed that appropriately translated forecasted abundance into a maximum allowable fishing mortality rate. But even if such a harvest control rule were developed, the timing of spring-run Chinook Salmon escapement presents challenges similar to that encountered for SRWC for incorporating such information into the annual PFMC season planning process (O'Farrell et al. 2016). The PFMC process relies on forecasts made and reviewed in March, with the final salmon fishery seasons adopted by May 1. The most recent escapement estimates available for making forecasts in March are from the previous year, providing information on fish that still remain in the ocean after spring-run Chinook Salmon have returned in the spring of the previous year. The maturing members of the cohort still in the ocean at that time would begin to return in March or April of the current year, and thus the majority of these fish would not be exposed to the ocean fishery by the time regulations relevant to that cohort could be in place. Even if management could accommodate a schedule change, sibling-based ocean abundance forecasts could probably not be made much earlier because of the time lag involved (i.e., because escapement is estimated from post-spawning carcass surveys).

Thus, any ocean abundance forecasting approach for CVSC would likely need to be based on indices of juvenile production and/or environmental covariates. Currently, data on natural juvenile production are very limited. Although rotary-screw traps have been operated in Butte, Mill, and Deer creeks, trap efficiency is not estimated, and continued operation is uncertain. Estimates of CVSC production made from trapping operations further downstream are complicated by poor performance of the size-at-date model used to apportion juveniles by run (Harvey et al. 2014; reviewed in Johnson et al. 2017). Use of GSI instead would provide more accurate stock apportionment. Thus, a carefully designed and implemented genetic sampling program for juveniles in Sacramento River and Chipps Island trawls would help to assess the abundance of CVSC juveniles entering and leaving the Delta, and entering the ocean (Johnson et al. 2017). Trap efficiency would need to be estimated at each sampling site for juvenile production to be able to be inferred, as recommended for SRWC (Johnson et al. 2017).

Cohort Reconstruction Based on CWT Recovery Data

Sufficient data likely exist for cohort reconstructions and harvest models to estimate fishing mortality and maturation rates for FRH spring-run Chinook Salmon, similar to those currently estimated for SRWC (O'Farrell et al. 2012a, 2012b). Although the Winter-run Harvest Model is updated continuously with yearly data, the first published description (O'Farrell et al. 2012b) was based on 464 coded-wire tag recoveries from the commercial and recreational ocean fisheries in the years 2000–2009. During that same period, there were 8,788 ocean recoveries of coded-wire tagged FRH spring-run Chinook Salmon. In contrast with the availability of coded-wire tagged FRH spring-run Chinook Salmon, the coded-wire tag program for natural-origin Butte Creek spring-run Chinook Salmon has been discontinued, and even when tagging occurred the tag recoveries were insufficient for reliable cohort reconstruction. (Coded-wire tag recoveries for Butte Creek spring-run Chinook Salmon were approximately one-fifth as numerous as SRWC [Grover et al. 2004]).

Ideally, cohort reconstructions would be performed for natural-origin fish, but, as noted, there is no ongoing tagging program for natural-origin fish, and the tag recovery rates for Butte Creek fish were inadequate when the tagging program was operating, so any cohort reconstruction (at least in the short term) would need to be based on FRH spring-run Chinook Salmon. Salmon managers are considerably concerned about the suitability of tagged hatchery-origin fish as a proxy for natural-origin stocks (e.g., see Finding 5 in Hankin et al. 2005). Grover et al. (2004) were "generally skeptical of the use of Feather River Hatchery spring-run chinook as a surrogate for naturally spawning spring chinook populations" and cautioned that "use of Feather River Hatchery spring-run chinook [coded-wire tag] data set, which is large, should be conditioned on a demonstration that the stock exhibits similarities with naturally spawning spring-run chinook populations with respect to ocean distribution and run timing." Here, it is worth noting that, starting with brood year 2004, hatchery protocols were changed to decrease the genetic introgression of fall-run with spring-run FRH Chinook Salmon. Thus, FRH fish may serve as better surrogates of natural-origin CVSC in the future, as effects of fall-run introgression are reduced.

As a result of limited tag recoveries, the power of our comparison is necessarily low; however, we found no evidence for differences in mean size-at-age or spatial distribution (two major factors in exposure to the fishery) between Butte Creek natural-origin and FRH-origin spring-run Chinook Salmon for the few months that had enough adequate data to compare. However, our literature search does suggest different maturation schedules (and thus cumulative fishery exposure) for the two sub-stocks, with apparent earlier maturation (at younger ages) of natural-origin CVSC. This is largely consistent with other studies that have found generally similar spatial distributions of natural-origin stocks and their hatchery indicators (e.g., Weitkamp and Neely 2002; Weitkamp 2010; Satterthwaite et al. 2014) but some researchers have expressed concern about the equivalency of maturation rates (Sharma and Quinn 2012). In addition, our comparison of the spatial distributions of FRH versus natural-origin CVSC was limited to only a few months of the year, excluding the period of peak spring-run Chinook Salmon returns to freshwater.

Nevertheless, despite these caveats, fishing mortality rates derived from cohort reconstructions performed on FRH spring-run Chinook Salmon may provide some useful information on how fisheries affect natural-origin CVSC—effects otherwise unquantifiable in most years. Although differences in maturation schedules would affect how fisheries cumulatively impact fish over their complete life cycle, these differences would not affect the age-specific ocean fishing mortality rates estimated by cohort reconstructions. Differential time of return within years could lead to differences, and Cramer and Demko (1996) suggest that FRH spring-run Chinook Salmon return later in the year than natural-origin spring-run (June and July for FRH spring-run Chinook Salmon versus mid-April to mid-June for natural-origin CVSC). An earlier return timing could mean that natural-origin CVSC ocean fishing mortality rates may be lower than those of FRH spring-run Chinook Salmon because CVSC are exposed to the fishery for less time, and, thus, FRH spring-run Chinook Salmon ocean fishing mortality rates might serve as a conservative proxy for ocean fishing mortality rates on natural-origin CVSC. However, the basis for concluding that FRH spring-run Chinook Salmon return later is not clear, since returning adult spring-run Chinook Salmon are externally tagged at the FRH beginning in April or May in most years (CDWR 2017). Thus, although caution is warranted in assuming equivalence between the ocean fishing mortality rates of FRH spring-run Chinook Salmon and natural-origin CVSC, we found no direct evidence that age-specific ocean fishing mortality rates would differ, and so ocean fishing mortality estimates for FRH spring-run Chinook Salmon could inform CVSC management.

The SJRRP (2017) calls for marking and tagging all fish produced at the San Joaquin facility. Such fish could be included in cohort reconstructions and fishing mortality rate calculations as well, assuming adequate escapement sampling and coded-wire tag recoveries. With adequate sample sizes, San Joaquin River spring-run Chinook Salmon could be compared to FRH spring-run Chinook Salmon to partially evaluate the suitability of FRH as a proxy for the CVSC complex (assuming that natural-origin spring-run Chinook Salmon occurring in the San Joaquin and Sacramento basins are similar in their life histories). Although coded-wire tags recovered from the San Joaquin River could simply be pooled with coded-wire tags from the FRH, a separate analysis of each tag type would ideally be based on a release of 200,000 or more tagged juveniles per year, given typical survival rates for downstream migrants, with larger releases needed if the survival rate is unusually low (O'Farrell et al. 2015). SJRRP operations might also tag, but not mark, natural-origin juveniles handled during trap and haul operations. Because these fish would not have adipose fin clips, they would not be recovered during routine sampling of ocean fisheries unless electronic tag-detection methods were used. Using electronic tag detection to identify such fish in ocean harvest sampling would be worthwhile only if sufficient recoveries were anticipated to reliably estimate fishing mortality rates.

Cohort Reconstruction Based on Alternative Tagging Technologies

As noted in exploring options for active management of CC-Chinook (O'Farrell et al. 2012c, 2015), cohort reconstructions require, at a minimum, stock- and age-specific estimates of harvest (from all relevant strata) and escapement. At present, only coded-wire tag recoveries can provide the required data from all relevant strata. If GSI data were collected coastwide from representative harvest sampling and were accompanied by reliable age estimates (i.e., from validated scale or otolith readings), GSI could potentially provide the required information about ocean harvest, although the low proportion of natural-origin CVSC expected in the catch (Bellinger et al. 2015; Satterthwaite et al. 2015b) means that very large sample sizes would be required to accurately estimate stock-specific catches (Allen–Moran et al. 2013). In addition, GSI classifies FRH spring-run Chinook Salmon as part of the CV fall-run Chinook Salmon reporting group (Clemento et al. 2014), and therefore GSI cannot provide harvest estimates for the entire ESU. If escapement were reliably estimated for all tributaries to which spawning CVSC return and if the escapement estimates were age-specific, with minimal aging error, cohort reconstructions could be attempted for natural-origin fish based on harvest estimates derived for the spring-run genetic reporting group. (FRH spring-run Chinook Salmon would be excluded from these calculations, because spring-run versus fall-run are not distinguished in Feather River escapement surveys, and Feather River fish would not be genetically identified as CVSC in the harvest.) Further, if the Butte Creek population could be consistently distinguished from the rest of the genetic reporting group, cohort reconstructions could be performed for the Butte Creek population without intensive sampling of the escapement to other streams. Cohort reconstruction would be possible to the point when fish were recruited to the fishery (i.e., age-2), allowing fishing mortality and maturation rates to be calculated, but, without known juvenile production, early ocean and river survival (i.e., survival from the time that the juvenile production estimate refers to through ocean age-2) could not be calculated.

If all relevant strata of the ocean fishery, in-river fishery, and escapement were comprehensively and representatively genetically sampled, parentage-based tagging could be used analogously to coded-wire tagging to reconstruct cohorts. However, genetic sampling is not currently carried out at the required scale, and the prospects of this happening in the near future are doubtful. A parentage-based tagging system is not cost-competitive with a coded-wire tag-based tagging and sampling system for natural-origin stocks if the number of tags deployed needs to be accurately estimated (Satterthwaite et al. 2015a). However, as with the GSI scenario, some aspects of cohort reconstruction (e.g., estimation of fishing mortality rates, but not juvenile survival or initial cohort strength) are possible, even if the number of tags deployed is unknown.

Even in the absence of comprehensive ocean sampling, genetic techniques might improve our understanding of juvenile production, as described at the end of the "Forecasting" section.

Management Uses of Ocean Fishing Mortality Rate Estimates

At a minimum, ocean fishing mortality rates derived from cohort reconstructions for CVSC could be used to verify assumptions that ocean fishing mortality rates for CVSC fall between those that apply to SRFC and SRWC (if FRH tagged spring-run Chinook Salmon were relied upon, this would be conditioned on the assumption that ocean fishing mortality rates for natural-origin CVSC are similar to FRH spring-run Chinook Salmon), and to evaluate the correlation among CVSC, SRFC, and SRWC ocean fishing mortality rates. Similarly, routine calculation of CVSC ocean fishing mortality rates could test the SJRRP's assumption that ocean fishing mortality rates for spring-run Chinook Salmon are approximately 50% (SJRRP 2017). The observed range of fishing mortality rates could be examined against trends in escapement over the same time-period, but care would need to be taken not to confound the effects of harvest with changes in environmental drivers and habitat conditions.

Ideally, fishing mortality rates from cohort reconstructions would be coupled with either studies that identify a maximum allowable fishing mortality rate based on a detailed understanding of CVSC productivity, or with a harvest control rule that adjusts the allowable fishing mortality rate in response to changing stock status and productivity. Developing a harvest control rule could require a management strategy evaluation (c.f. Winship et al. 2013) and thus a clear understanding of the natural population dynamics for CVSC (c.f. Winship et al. 2014). Alternatively, a threshold fishing mortality rate could be set, such that fishing mortality rates that consistently exceeded the threshold triggered further actions to limit and/or better understand how fisheries affect CVSC. Ideally, threshold levels would be informed by CVSC-specific population modeling, although proxies based on levels used in other systems might be adopted as interim measures.

Approaches That Ignore Age Structure

If aging of catch and/or escapement is prohibitively expensive or otherwise impractical, it could still be possible to derive some index of fishing mortality of CVSC based on composite harvest (as might be estimated from comprehensive coastwide GSI sampling) and total escapement. Although many authors have argued for the importance of considering age structure and cohort effects in fishery management (e.g., Botsford et al. 2011), such an index might provide a coarse metric that allows major shifts in fishing effects to be detected. Current SRFC management distinguishes "jacks" (age 2) from "adults" (ages 3 and older) but does not distinguish among adult age classes. More detailed information on the age structure and maturation schedule of natural-origin CVSC would be needed to evaluate the advisability of such coarse approaches.

Harvest-Only Strategies

Conceivably, total harvest of natural-origin CVSC could be estimated from a coastwide GSI sampling program. Although current Pacific salmon management does not include any approaches based on harvest-data only, the PFMC does use "data-poor" catch-only techniques to assess some groundfish stocks (MacCall 2009; Dick and MacCall 2011). However, the data-limited approaches the PFMC uses are far better suited for long-lived, iteroparous species than they are for short-lived, semelparous species with environmentally-forced recruitment (NOAA Fisheries 2015). A comprehensive survey of other data-limited approaches (e.g., Carruthers et al. 2014; Carruthers and Hordyk 2016) and their suitability for reflecting Chinook Salmon life histories might reveal options more suited to CVSC.

Escapement-Only Strategies

As outlined by Grover et al. (2004), the set of fishery management measures in place for SRFC, SRWC, CC-Chinook, and KRFC combined might be assumed to adequately protect CVSC unless escapement trajectories are inconsistent with continued recovery. However, such an approach is prone to the confounding effects of variation in environmental and habitat conditions. Ongoing habitat restoration efforts might allow Chinook Salmon populations to remain stable or even increase in the face of over-exploitation, or droughts or other catastrophes might cause declines even in the absence of fishing pressure.

What the appropriate temporal scale is to evaluate trends in escapement remains an open question, as does how rapidly harvest rates should be adjusted in response to temporary changes in the environment (let alone how temporary changes should be distinguished from lasting changes in the environment). In addition, simply knowing that harvest rates on CVSC should be adjusted does not clearly indicate the most effective or efficient way to bring out the desired changes.

CONCLUSIONS

Currently, we lack estimates of ocean fishing mortality rates on CVSC. We also lack sufficient analysis of CVSC population dynamics to identify what levels of fishing mortality are consistent with persistence, recovery, or restoration of CVSC populations. Without understanding more clearly both what fishing mortality rates are, and what their consequences are for population dynamics, we are unable to rigorously evaluate the compatibility of current fisheries management with conservation and restoration goals, nor properly rank the importance of fishery effects versus other anthropogenic effects when prioritizing CVSC conservation and recovery efforts. Further, there is no mechanism in place to adjust allowable fishery impacts in response to changes in CVSC productivity. It is also possible that a better understanding of CVSC fishing mortality rates and population dynamics would reveal that CVSC could sustain higher fishing mortality rates than they currently experience, such that reduced constraints on the fishery would be acceptable from a CVSC conservation perspective. However, under the current management framework, this would not result in an immediate change to less restrictive fishing regulations since the fishery is primarily constrained by measures in effect for SRWC, CC-Chinook, KRFC, and SRFC.

In the near term, it appears that the best approach for determining whether a change in CVSC fishery management is warranted would be to look for trends in escapement as compared to concurrent fishing mortality rates on stocks for which these rates can be calculated, while considering concurrent trends in the environment and habitat conditions, and whether such trends are likely to be maintained into the future. This will be, at best, a qualitative exercise depending on expert judgment until well-supported life-cycle models for CVSC are developed and implemented.

There could also be benefit in performing routine cohort reconstructions for FRH spring-run Chinook Salmon to evaluate whether ocean fishing mortality rates on that subset of CVSC are higher than the fishing mortality deemed suitable for other stocks with similar status, or inconsistent with assumptions contained in the Biological Opinion (NMFS 2000), or the assumptions that guide the SJRRP's consideration of fishery effects. Even without specific management triggers, a time-series of estimated ocean fishing mortality rates could be useful in retrospective analyses of population dynamics, should a negative trend emerge.

Should more active fishery management be desired, the most appropriate guidance on how to restructure fishing regulations to modify effects on CVSC in accordance with limits defined by a harvest control rule would likely come from a harvest model based on coded-wire tag recoveries, similar to the current Winter-Run Harvest Model (O'Farrell et al. 2012a), Klamath Ocean Harvest Model (Mohr 2006), and Sacramento Harvest Model (Mohr and O'Farrell 2014). Such a model's parameters would need to be based on coded-wire tag recoveries of FRH spring-run Chinook Salmon, which are the only tag recoveries currently available in sufficient numbers. Potential differences between natural-origin and hatchery-origin CVSC would need to considered. Differences in maturation schedules would not be problematic for evaluating age-specific ocean fishing mortality rates. However, differences in spatial distribution—which affect the amount of overlap with fishing activity in different times and management areas—could be more relevant, as could differences in within-year migration timing. Because the available data are insufficient to conclusively rule out such differences, further research into the comparability of natural- and hatchery-origin CVSC would be very valuable.

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