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CALIFORNIA COASTAL CHINOOK SALMON FISHERY MANAGEMENT: FUTURE PROSPECTS

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U.S. DEPARTMENT OF COMMERCE
Penny S. Pritzker, Secretary of Commerce
National Oceanic and Atmospheric Administration
Dr. Kathryn D. Sullivan, Administrator
National Marine Fisheries Service
Eileen Sobeck, Assistant Administrator for Fisheries

Abstract

A joint National Marine Fisheries Service and California Department of Fish and Wildlife workshop with the title "California coastal Chinook salmon (CC-Chinook) fishery management: future prospects" convened in Santa Rosa, California, September 3-4, 2014. The goals of the workshop were to identify the level of information necessary to allow for development of an abundance-based fishery management (ABM) approach and evaluate the feasibility of collecting that level of information for the CC-Chinook salmon Evolutionarily Significant Unit (ESU). Workshop participants noted that the collection of sufficient data to enable ABM will be difficult to achieve in the CC-Chinook salmon ESU. The level of data needed for ABM is greater than the level of data currently collected, and is greater than the level of data that would be generated with full implementation of the California Coastal Monitoring Plan (CMP). There are substantial technical difficulties associated with spawner surveys in the ESU and new programs would need to be developed to obtain ocean harvest data. Looking toward the future, important steps include (1) addressing the technical challenges associated with implementation of the CMP and moving toward full implementation, (2) giving consideration to a pilot study aimed at assessing the feasibility of marking and tagging programs that would provide sufficient information for estimation of ocean harvest and enable cohort reconstruction assessments, and (3) identification of stable funding for this monitoring work.

Introduction

The California coastal Chinook (CC-Chinook) salmon Evolutionarily Significant Unit (ESU) is listed as threatened under the Endangered Species Act (ESA). The fishery management provisions intended to limit incidental take of fish from this ESU are in the form of a 16 percent cap on the predicted age-4 ocean harvest rate on Klamath River fall Chinook (KRFC) salmon (i.e., age-4 KRFC harvest cannot exceed 16 percent of the KRFC age-4 cohort abundance, in expectation). This consultation standard frequently constrains California and Oregon ocean salmon fisheries and there has been interest in exploring alternative fisheries management approaches, particularly those that allow for exploitation rates to vary with stock abundance (i.e., abundance-based management [ABM]). O'Farrell et al. (2012b) described the CC-Chinook salmon ESU status, ocean fishery consultation history, available ocean and freshwater data, and the feasibility for developing alternative fishery management strategies given the level of information available at of the time of publication. In brief, the conclusions of O'Farrell et al. (2012b) were that for CC-Chinook salmon sufficient freshwater monitoring data do not exist to estimate ESU-level escapement, sufficient ocean data do not exist to estimate ocean harvest, sufficient data do not exist to perform a stock assessment using cohort reconstruction methods (Hilborn and Walters, 1992; O'Farrell et al., 2012a), and few prospects exist for developing an ABM approach given the data available at that time.

Since the publication of O'Farrell et al. (2012b), there has been substantial attention given to CC-Chinook salmon status determination and fishery management, including a Pacific Fishery Management Council (PFMC)-organized workshop focused on the feasibility of alternative management strategies[1] (April 2013), a California Department of Fish and Wildlife (CDFW) presentation to the PFMC focused on freshwater monitoring[2] (March 2014), and the development of a CDFW white paper outlining current and proposed plans for future monitoring of the CC-Chinook salmon ESU (Lacy et al. 2014). Much of this attention was focused on the determination of whether sufficient data exist to change fishery management given current information, though Lacy et al. (2014) described future priorities.

In an effort to shift focus onto future fishery management priorities, a joint National Marine Fisheries Service (NMFS) and CDFW workshop titled "California coastal Chinook salmon fishery management: future prospects" was held September 3-4, 2014, in Santa Rosa, CA. The goals of this workshop were to identify the level of information necessary to allow for development of an ABM approach and evaluate the feasibility of collecting that level of information for CC-Chinook salmon. The first portion of the workshop was comprised of ten presentations describing aspects of fisheries management (Mohr, O'Farrell), CC-Chinook salmon size-at-age and ocean distribution (Satterthwaite), the ESA status review process (Spence), the California Coastal Monitoring Plan (CMP; Adams et al. 2011; presentation by Lacy), freshwater monitoring from the Eel River northward (Ricker), freshwater monitoring south of the Eel River (Gallagher, Larson), and ocean fishery monitoring (Kormos). The second portion of the workshop was dedicated to discussions about data needed for development and implementation of an ABM approach and the prospects for obtaining those data in the future.

This report documents the findings of the workshop and is organized as follows. We first provide brief summaries of each presentation given at the workshop. We then outline the minimum level of data needed for ABM as currently practiced for several stocks managed by the PFMC. Given these data needs, the technical and funding impediments to collecting sufficient data are described. Finally, we conclude with a discussion of the prospects and timelines associated with moving toward an ABM approach for CC-Chinook salmon.

[1] http://www.pcouncil.org/wp-content/uploads/SAS_STT_JOINT_MTG_AGENDA_APR2013BB.pdf
[2] http://www.pcouncil.org/wp-content/uploads/F9b_SUP_CDFW_PPT_MAR2014BB.pdf

Presentation summaries

Michael Mohr (NMFS) led off the presentations by providing context to the fishery management issues surrounding CC-Chinook salmon and set forth the goals of the workshop. Mohr noted that the CC-Chinook salmon consultation standard constrains California and Oregon fisheries, particularly when other stocks are abundant, creating frustration on the part of fishing groups. Additionally, there has been a perceived lack of progress toward improved data and fishery management. Mohr then noted that the intent of the workshop was to foster a better understanding of the current CC-Chinook salmon status and data, identify the obstacles to augmenting CC-Chinook salmon ocean and river data, and further evaluate the potential for developing a new fishery management strategy.

Following Mohr's introduction, Michael O'Farrell (NMFS) described the current fishery management setting for CC-Chinook salmon and provided examples of ABM used for other Pacific salmon stocks. Much of the first portion of the presentation was focused on summarizing the findings of O'Farrell et al. (2012b), including the ESA status, current NMFS ESA fishery consultation standard, and the reasons why an ABM approach is currently not feasible for the ESU. The second part of the presentation displayed examples of how ABM is used for a variety of stocks that differ with respect to data richness. KRFC, Sacramento River fall Chinook (SRFC) salmon, Lower Columbia River (LCR) Tule Chinook salmon, many Pacific Salmon Treaty stocks (stocks managed jointly by the United States and Canada), and several coho stocks are managed using control rules which specify the relationship between the maximum allowable exploitation rate and a measure of abundance. The different ABM approaches used for many of these stocks reflects life history differences and variation in data availability. The LCR natural Tule Chinook salmon fishery management context was examined in some detail. In comparison to CC-Chinook salmon, the data available for LCR Tule Chinook salmon are sufficient to enable abundance forecasts and postseason estimates of exploitation rates. These capabilities largely come from the availability of coded-wire tag (CWT) recovery data from hatchery indicator stocks, a data source that does not exist for CC-Chinook salmon.

Will Satterthwaite (NMFS) presented a comparison of size-at-age and ocean spatial distributions for CC-Chinook salmon and Klamath Chinook salmon derived from genetic stock identification (GSI) data (Satterthwaite et al. 2014; Satterthwaite et al. In review). This work was in part motivated by the current CC-Chinook salmon consultation standard that specifies a 16 percent cap on the KRFC age-4 ocean harvest rate. Data collected from the commercial fishery in 2010 suggested that CC-Chinook salmon and Klamath Chinook salmon size-at-age was similar through July, but CC-Chinook salmon tended to be larger than Klamath fish in August and September. Catch per unit effort (CPUE) of CC-Chinook salmon and Klamath Chinook salmon were estimated using data collected from the commercial fishery in both 2010 and 2011; comparisons of CPUE estimates indicate that distributions of these stocks were similar early in the year but diverged later in the year in some management areas (particularly Fort Bragg and the California Klamath Management Zone). This divergence in late summer/early fall may reflect migration of these stocks toward their natal streams (Satterthwaite et al. 2014). Based on GSI data that were collected dockside from the California recreational fishery from 1998-2002, CPUE was significantly higher for Klamath Chinook salmon than CC-Chinook salmon in all months and areas but very low sample sizes of CC-Chinook salmon prohibited making strong inference about differences in spatial distributions (Satterthwaite et al. In review).

In a temporary shift away from the ocean fishery focus of the first several presentations, Brian Spence (NMFS) gave an overview of the NMFS ESA 5-year status review process. At least once every five years, a Biological Review Team (BRT) and/or the Southwest Fisheries Science Center (SWFSC) evaluates the current status and extinction risk of the CC-Chinook salmon ESU, and the NMFS West Coast Regional Office (WCRO) reconsiders its ESA-listing determination for the ESU. Extinction risk is assessed using biological viability criteria, which includes abundance, productivity, spatial structure, and diversity components, both at the ESU and independent population level (Viable Salmonid Population [VSP] concept, McElhany et al. 2000). For the 2011 biological review (Williams et al. 2011), the prior status of CC-Chinook salmon was reaffirmed: the ESU was at risk of becoming endangered in the foreseeable future. All status reviews conducted to date have been completed with very limited data (mostly index counts) which were inadequate to evaluate population-level viability criteria. It is anticipated that data available for the 2016 biological review, while still limited, will be improved with the inclusion of some CMP spatially balanced adult escapement data as well as data from a few life-cycle monitoring stations (LCMs).

Michael Lacy (CDFW) provided an overview of the CMP and CDFW priorities for monitoring CC-Chinook salmon. The CMP was designed to provide data informing the various biological viability criteria associated with the VSP concept for California's coastal salmonid populations (Adams et al. 2011). However, Lacy pointed out that the CMP was not designed specifically for fishery management purposes. The current CDFW monitoring priority goals for CC-Chinook salmon are to (1) establish CC-Chinook salmon status and trend at the ESU and smaller scales and (2) develop sufficient monitoring to obtain information to effectively manage ocean fisheries. The first goal would be accomplished by an expansion of the degree of implementation of the CMP (Lacy et al. 2014). Expanded CMP sampling effort would be focused on the major Chinook salmon contributors in the ESU (i.e., Redwood Creek, Eel River, Mattole River, Russian River; Figure 1). However, many difficulties remain, including: accessing large areas repeatedly over the spawning season; application of LCM redd-to-fish relationships at large scales; acquiring access to private land; logistical issues; and stable funding. Addressing the second goal (fisheries management-focused) would require additional monitoring beyond what is outlined in the CMP.

Seth Ricker's (CDFW) presentation was focused on the technical and statistical details of implementing the CMP, primarily in the Eel River. Ricker outlined how the General Randomized Tessellation-Stratified (GRTS) sampling design of the CMP (Adams et al. 2011) would include observations of live fish, carcasses (marked and observed through time), and redds (marked and observed through time) over a spatially balanced sample of stream reaches. A goal is to revisit each sampled site every 14 days, but the time between visits can vary owing to environmental factors (e.g., flow, turbidity). The probability of observing a redd depends on the probability of its being detected (given it is currently present) and the probability of it "surviving" over time (i.e., the probability that a redd formed sometime prior to the survey remained intact at the time of the survey). For coho spawner surveys, the detection rate of redds is high but the detection rate may differ considerably in "Chinook space" (i.e., the core Chinook salmon spawning areas), which tends to be mainstem and larger tributary reaches. For the Eel River, Chinook salmon-focused sampling schemes are currently in development. Chinook salmon-focused, CMP-type sampling occurred on the South Fork Eel River in 2013/2014, though it was acknowledged that the drought conditions that characterized this spawning year were unusual, making it difficult to assess whether this level of escapement sampling could be performed in non-drought years. Under more typical conditions, discharge and turbidity would be much higher, posing technical difficulties for redd surveys and carcass collection in Chinook space.

Moving south in the CC-Chinook salmon ESU, Sean Gallagher (CDFW) gave a presentation on implementing the CMP in Mendocino County streams. Gallagher noted that many of these streams were previously thought to not support Chinook salmon populations. For example, the Noyo River was not originally designated as a Chinook salmon stream, however smolt traps and spawning surveys began counting Chinook salmon smolts and redds in 2000. Currently, Chinook salmon escapement is estimated for the Ten Mile River, Noyo River, Big River, Albion River, Navarro River, and Garcia River, but there is considerable uncertainty in the number of estimated redds/number of spawning adults because most of the sampling is not occurring in Chinook salmon space (it is focused on coho space). The number of

GRTS-sampled reaches needs to be increased (to at least 50% of the Chinook salmon reaches) to improve upon the precision of the population level abundances (McDonald 2003).

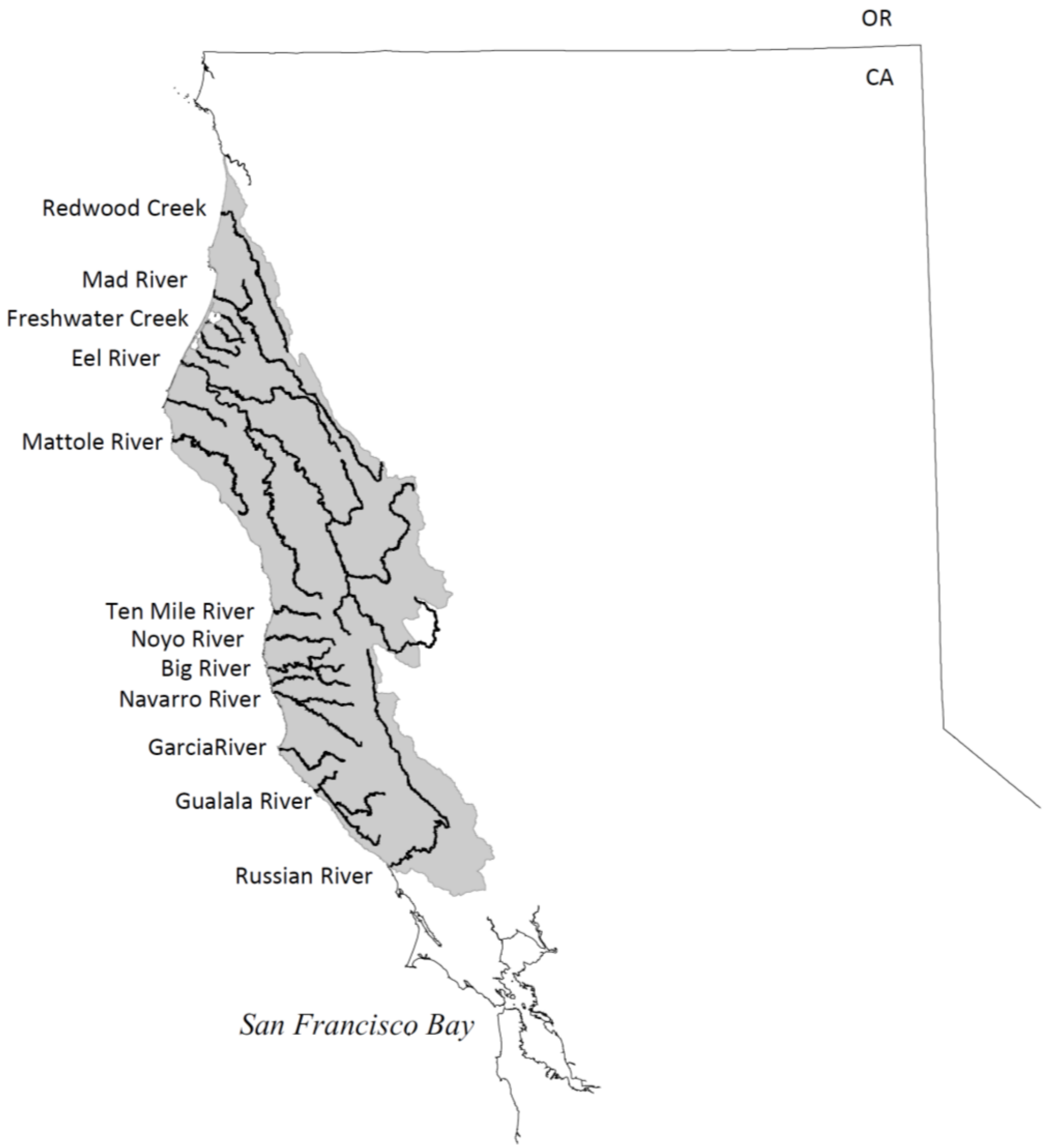

Figure 1. Map of the California Coastal Chinook salmon ESU and major watersheds.

Eric Larson (CDFW) continued to discuss Chinook salmon monitoring south of the Eel River with a focus on the Russian River. The California Fisheries Restoration Grant Program (FRGP) provides most of the funding for monitoring the Russian River, but this funding is primarily intended for coho salmon. The Sonoma County Water Agency offers some funding specifically for Chinook salmon. Existing Chinook salmon monitoring includes dual-frequency identification sonar (DIDSON) units and video cameras on both the mainstem Russian River at Mirabel Dam (an inflatable dam that allows for enumerating fish passage when inflated) and Dry Creek (a major tributary to the Russian River). Annual spawning surveys are also performed on the mainstem Russian River upstream of Mirabel Dam and on Dry Creek. Chinook salmon smolt abundances are estimated at rotary screw traps downstream of Mirabel dam. In most years, the peak of the Chinook salmon spawning run is captured by the video counts at Mirabel Dam, but the dam is deflated and counting ends when flows are elevated. At the current time, Mirabel Dam is being renovated and the modifications are intended to improve fish passage through ladders that should be functional at all flow levels. Video cameras will be permanently mounted in the ladders and operated throughout the year. It is anticipated that these changes will result in a monitoring method for estimating the number of returning adult salmonids that will not be affected by dam removal during seasonal high flows. The entire Chinook salmon spawning season could be monitored on Dry Creek, however the spawning population there is estimated to be less than half of the total Russian River spawner escapement. High winter discharge on the Russian River, and the high turbidity associated with high discharge events, can complicate redd surveys toward the end of the Chinook salmon spawning run.

Brett Kormos (CDFW) provided an overview of ocean fisheries monitoring objectives, sampling design, and collection of GSI data. The objectives of ocean fishery monitoring are to estimate salmon harvest, fishing effort, and contribution rates of specific salmon stocks (using CWT recoveries) for each management area by half month periods for all California ocean salmon fisheries. Random stratified sampling is performed but the sampling unit differs among fishing sectors (e.g., private skiffs, commercial passenger fishing vessels [CPFV], and commercial vessels). The target sampling fraction is at least 20% of landings for all sectors. For 2013 California ocean salmon fisheries, nearly 6,000 CWTs were recovered from the recreational fishery and approximately 17,000 CWTs from the commercial fishery. Estimated statewide stock proportion estimates in the commercial fishery ranged from a low of 0.3% for Klamath River spring Chinook salmon to a high of 81% for SRFC. For the recreational fishery, stock proportion estimates ranged from a low of 0.3% for Oregon and Washington stocks to a high of 82% for SRFC. Tissue sampling for genetic stock identification (at-sea and dockside), which can provide some information about CC-Chinook salmon catch, has been limited in terms of spatial and temporal coverage and does not have dependable funding. Obtaining precise estimates of catch proportions for all stocks of concern (e.g., CC-Chinook salmon) in all strata would require sampling the catch at very high rates.

Minimum level of data needed for abundance-based management

Salmon stocks managed under ABM vary in their levels of data richness. Some stocks have sufficient data to perform cohort reconstructions (e.g., KRFC), which provide estimates of age-specific stock abundance and exploitation rates and other metrics used for salmon management. Other, less data-rich stocks, such as SRFC, rely on an aggregate age abundance index and approximations to the exploitation rate (e.g., catch / [catch+escapement]). Regardless of the assessment methods used, the minimum requirements for implementing an ABM approach include (1) the ability to produce reliable estimates of abundance, and (2) the ability to estimate exploitation rates for the managed stock or its indicator.

Currently, neither of these minimum requirements for ABM are met for CC-Chinook salmon. To address the question of what data would be necessary to move CC-Chinook salmon toward a state where ABM would be feasible, the workshop participants discussed potential data collection priorities that would enable estimation of abundance and fishing mortality rates using cohort reconstruction methods. These included (1) estimation of age-specific escapement in the Eel and Russian rivers (or subpopulations within each of those systems) and (2) implementation of a marking and tagging program in each of these systems.

The workshop participants felt that two indicator populations might be appropriate for CC-Chinook salmon owing to the large geographic range of the ESU and the likely low levels of production from streams between the Mattole and Russian rivers. Furthermore, there is substantial genetic differentiation between Russian River Chinook salmon and Eel River Chinook salmon (and potentially other populations in the ESU). Because of the potential for different productivity, life-history characteristics, and ocean distributions, a northern and southern indicator population may be the minimum geographic coverage necessary. The Eel and Russian rivers were the most discussed watersheds because they are likely the largest Chinook salmon contributors to the ESU, though Redwood Creek was also discussed as a potential indicator population.

Improved escapement data from the Eel and Russian rivers will allow for the ability to track trends in abundance, the ability to assess whether CC-Chinook salmon population abundance covaries with other populations outside the ESU, and ultimately will improve ESA status determinations. When coupled with the estimation of age structure (likely from scales) and the recovery of a sufficient number of CWTs (assuming a marking/tagging program is implemented), the minimum freshwater data requirements for ABM could be met.

Implementation of a marking/tagging program(s), if performed at a sufficient magnitude, could allow for the estimation of ocean harvest from these populations and potentially the ability to perform cohort reconstruction assessments. Use of the adipose fin clip as the “mark” and a CWT as the “tag” would allow for CWT recoveries from ocean fishery sampling programs in California and Oregon as they are currently operated. There is some uncertainty about what would constitute a minimum level of juvenile out-migrant tagging for credible cohort reconstructions. However, workshop participants discussed a tagging level of 200,000 juveniles annually for each indicator population, which would approximate the annual level of tagged production of Sacramento River winter Chinook salmon at Livingston Stone National Fish Hatchery and several indicator stocks along the west coast of the U.S. and Canada (PSC CWT Workgroup 2008). It is likely that the marking and tagging of CC-Chinook salmon would be performed on natural-origin fish as there are currently no hatcheries in the ESU that produce Chinook salmon and it is highly unlikely that hatchery Chinook salmon production would resume. It is unknown whether the annual target of 200,000 wild juveniles per indicator population could actually be met. Extensive attention would need to be given to the location of juvenile marking and tagging and the location of escapement sampling and CWT recoveries from returning fish. It may be feasible to mark and tag a sufficient number of out-migrating juveniles in certain “representative” portions of the Eel and Russian watersheds. If returning adults stray at low levels, spawner surveys and the recovery of marked carcasses could be concentrated in these portions of the watersheds. However, to be considered representative, these subpopulations would need to serve effectively as an indicator of the abundance and productivity of the other portions of the watershed and the other CC-Chinook salmon streams in the region. Additional discussion focused on the implementation of a marking and tagging program in the CC-Chinook salmon ESU is presented in the next section and Appendix A.

Technical issues for implementing abundance-based management

A substantial amount of discussion at the workshop was focused on technical issues associated with obtaining escapement estimates and implementing marking and tagging programs for CC-Chinook salmon. A framework for the estimation of population- and ESU-level escapement exists currently with the CMP. Furthermore, LCMs are one component of the CMP framework that could potentially facilitate trapping, marking, and tagging out-migrating juveniles. However, implementation of the CMP in Chinook space within the CC-Chinook salmon ESU is rife with practical challenges and including marking and tagging programs on top of CMP implementation for Chinook salmon adds further complications.

The Eel River is the largest river in the CC-Chinook salmon ESU and is therefore a priority area for basin-wide escapement estimation. The CMP escapement estimation framework is based partly on spatially-balanced redd surveys, where redd counts are calibrated by adult to redd ratios determined with the aid of LCM data. For the most part, CMP-style surveys and escapement estimation have been focused on coho salmon, with spatially balanced spawning surveys in Eel River Chinook space occurring only on the South Fork during the 2013-2014 run. The difficulties of estimating escapement are particularly acute in a watershed as large as the Eel. The geographic scale, rugged terrain, and extensive private land ownership present logistical and accessibility challenges (though not insurmountable) to repeatedly performing spawner surveys within a spawning season. The Eel River frequently features prolonged periods of high and turbid flows during the Chinook salmon spawning period. As a result of these conditions, the number of days between repeat surveys frequently exceeds the 14 day target. When surveys are conducted, these flow conditions can complicate the observation of redds and carcasses. High flow events increase the likelihood that redds are created and washed out between surveys. Low visibility and wide reaches can prevent redds from being detected. Few carcasses are currently observed, likely due to a combination of difficult terrain, large flushing events, and high levels of scavenging. There are currently no suitable LCMs in operation on the Eel River to calibrate redd counts to escapement. The redd to escapement relationship differs widely among reaches in other rivers where LCMs have been deployed, with some of this variation perhaps due to different detection probabilities or weir bias. It is likely not possible to implement multiple LCMs within the Eel River owing to the typical flow conditions.

While the Russian River is smaller and more accessible than the Eel River, and therefore generally easier to survey, current practices do not allow for accurate escapement estimation. Two DIDSONs and an underwater video camera enumerate returning Chinook salmon at Mirabel Dam (mainstem Russian River), but turbidity prevents accurate counts when the dam is deflated during high flows. For most years, this represents an incomplete, but minimum, count of the number of returning adults. For example, the dam could be deflated as early as September, while the peak spawning period is typically in December and fish enter as late as February. Moreover, the location of the video weir does not capture an unknown number of downstream spawners. Annual, one-time spawner surveys are performed on the mainstem Russian River upstream of Mirabel dam, but do not provide accurate redd counts over the entire spawning season.

It was noted at the workshop that many Chinook salmon-focused escapement surveys encounter similar difficulties and yet are able to reliably estimate spawner escapement. A more directed focus on Chinook salmon escapement estimation in the challenging systems of the CC-Chinook salmon ESU may reveal techniques that can partially overcome the technical difficulties identified here. Yet, for the most part, the focus on coho salmon and steelhead have not allowed for directly confronting many of these issues. Alternatives to the CMP escapement estimation methods that may be worthy of further consideration include increased use of DIDSON units, with the development of new methods to segregate observations by species, and the potential use of genetic mark-recapture methods where spawners and the resulting out-migrating juveniles are tissue sampled and the number of "recaptured" parent genotypes in the juveniles leads to an estimate of escapement (Rawding et al. 2014).

Successfully implementing a marking and tagging program in the Eel and Russian basins has a variety of technical obstacles that would need to be resolved. There was substantial discussion about potential issues with capturing, marking, and tagging a sufficient number of out-migrating juveniles. A major impediment is the lack of hatchery Chinook salmon production in the ESU, and the very low likelihood of any new hatchery supplementation of Chinook salmon in this ESU. The vast majority of juvenile salmon marking and tagging on the west coast occurs in a hatchery setting where there is ample access to large numbers of juveniles in a confined area. The relatively few examples of marking and tagging programs for natural-origin fish that we are aware of have been small in scale and mostly insufficient for cohort reconstruction or other fishery assessments. LCMs can allow for downstream migrant trapping which may be useful for capturing natural-origin fish. However, there are logistical issues with using LCMs for this purpose. All current LCMs are located on small streams or tributaries where it may not be possible to capture, mark, and tag sufficient numbers of fish. It is unlikely that an LCM could be placed at a downstream location on the Eel or Russian rivers because large flow events would likely destroy the structure. It was also unknown whether annually marking and tagging large numbers of natural-origin ESA-listed juveniles would be permitted by NMFS and CDFW.

For a marking and tagging program to be successful, a sufficient number of tags need to be recovered in ocean and river sampling programs. In particular, the recovery of tags from river carcasses in Chinook salmon-focused sampling programs is likely to be difficult in the CC-Chinook salmon ESU. In ESUs with hatchery production, the sampling of marked/tagged fish that return to the source hatchery can allow for substantial numbers of tag recoveries. In the case of CC-Chinook salmon, river tag recoveries will need to exclusively come from sampling carcasses in natural spawning areas. While there has yet to be an emphasis on carcass sampling for Chinook salmon in the ESU, it was noted at the workshop that few carcasses are observed in the Eel River. The attributes of this system that make escapement sampling difficult (e.g., access, flashy flow conditions, turbidity) also make carcass recovery difficult. However, until a more concerted effort to sample Chinook salmon carcasses is initiated, the magnitude of this problem is unknown.

In an attempt to identify the number of CWT recoveries that might be expected under alternative release sizes and escapement sampling rates, we performed a series of calculations using information borrowed from the KRFC stock (Appendix A). These calculations suggested that there may be the potential for sufficient CWT recoveries for cohort reconstruction purposes if at least 200,000 marked/tagged fish are released, and escapement is sampled at a rate of 0.05 or greater. These results are of course dependent on the set of parameters that was chosen to approximate CC-Chinook salmon survival, maturation, and exploitation rates. However, we currently do not know whether these proxy values are suitable for characterizing CC-Chinook salmon and therefore the results are speculative and highly uncertain. Because of this uncertainty, and uncertainty regarding the feasibility of implementing a marking and tagging program, a pilot study focused on answering these questions would be useful. A pilot study that attempts to capture, mark, tag, and release 200,000 CC-Chinook salmon would greatly improve our understanding of the feasibility of implementing an effective CWT program for CC-Chinook salmon. Insight would be gained on the practicality of both releasing and recovering sufficient CWT fish. The results of such a study would enable an evaluation of whether cohort reconstruction can be used to estimate exploitation and maturation rates for CC-Chinook salmon, and at what level of stratification such a cohort reconstruction could be performed.

A minimally stratified cohort reconstruction could have two strata (ocean fisheries and escapement), and would allow for estimation of the overall, age-specific exploitation and maturation rates for a population. This minimally stratified cohort reconstruction would require relatively low numbers of CWT recoveries- on the order of 20-30 per stratum (Appendix A). More highly stratified cohort reconstructions allow for exploitation rates to be estimated for individual time/area/age/fishery strata. Highly stratified cohort reconstructions of this sort are currently performed for KRFC and SRWC, and the time/area/age/fishery estimates of exploitation rate are used to parameterize harvest models (e.g., the Klamath Ocean Harvest Model [KOHM] and the Winter Run Harvest Model [WRHM]) that are used in the PFMC salmon fishery planning process. Such cohort reconstructions would need more CWT recoveries than the minimally-stratified version described above. Unlike the minimally stratified cohort reconstruction, a more highly stratified model like those used for KRFC and SRWC could allow for directly managing CC-Chinook salmon using CC-Chinook salmon data and methods similar to those currently employed for other stocks.

Funding issues for implementing abundance-based management

Immediate and long term funding of the CMP has yet to be secured, let alone the additional resources that would be necessary to implement ABM. At present, the main funding source for the CMP is 1-3 year grants through the FRGP, which is primarily comprised of federal funds (Pacific coast salmon recovery funds, bond, and drought related funds) with some state matching funds. Additional funding partners include water resource agencies, timber companies, and other private industries. Most of these funds are directed toward coho and steelhead habitat restoration, rather than long-term monitoring of all three salmonid species, thus hindering implementation of the CMP for Chinook salmon, or the expansion of Chinook salmon monitoring beyond the CMP framework for fishery management purposes. The lack of centralized oversight of CMP implementation makes it difficult to secure funding, and forces biologists in different regions to compete with each other for the limited funds.

Conclusions

The collection of sufficient data to enable ABM will not be an easy task in the CC-Chinook salmon ESU. The level of data needed for ABM far surpasses the level of data currently collected for the ESU, and is greater than the level of data expected to be generated with full implementation of the CMP. The workshop participants identified substantial technical difficulties associated with monitoring CC-Chinook salmon for fishery management purposes. These issues may or may not be surmountable, but a concerted effort would need to be made to address them head on. Expanding Chinook salmon monitoring will remain difficult without more stable funding dedicated to such work.

A major advancement in our understanding of CC-Chinook salmon would result from full implementation of the CMP in Chinook space. Data generated using the CMP framework would provide better status and trend information, more informed ESA status reviews, and enable an evaluation of whether neighboring populations (such as KRFC) could possibly serve as a proxy stock in an ABM approach. Workshop participants expressed an eagerness to implement the CMP in Chinook space and work through the inherent technical issues. While stable funding does not currently exist for the CMP, the State of California is supportive of CMP implementation.

It will be substantially more difficult to implement a Chinook salmon marking and tagging program within the CC-Chinook salmon ESU. Funding for such a program would be considerably above and beyond what is necessary for full implementation of the CMP. However, if a successful marking and tagging program were paired with escapement estimation, ABM could be possible. Calculations made in Appendix A suggest that a substantial marking and tagging program would be required to obtain sufficient CWT recoveries to implement ABM in the manner that it is currently practiced for other California Chinook salmon stocks, and a pilot study would go a long way toward understanding what levels of CWT releases and recovery are feasible. If new marking, tagging, and monitoring programs were initiated, and carried out on an annual basis, approximately 10 years of data collection would likely be needed before an ABM approach for CC-Chinook salmon could be implemented. This time frame is similar to the period of time between initiation of a Sacramento River winter Chinook salmon marking and tagging program and the implementation for an ABM approach for that population. Given the need for preliminary studies to address logistical and practical issues associated with implementation of a marking and tagging program for Chinook salmon in coastal northern California, the time frame for implementing an ABM approach could be more protracted than 10 years.

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APPENDIX A

Introduction

Exploitation rates, maturation rates, and other metrics used in salmon fishery management are often estimated using cohort reconstruction methods applied to coded-wire tag (CWT) recovery data (e.g., Goldwasser et al. 2001, O'Farrell et al. 2012) and credible cohort reconstructions require an adequate number of CWT recoveries. Guidelines exist for the number of CWT'd fish to be released and recovered in order to perform cohort reconstructions. For Chinook salmon indicator stocks assessed using cohort reconstruction methods, the Pacific Salmon Commission (PSC) has recommended a target tagged release size of 200,000 CWT'd fish (PSC CWT Workgroup 2008). Furthermore, the PSC has established a guideline for Chinook salmon that at least 20 CWTs (of all ages combined) should be recovered, per sampling stratum, in eight of ten years (see page XV in PSC CWT Workgroup 2008).

However, it is not clear whether these targets and guidelines are appropriate for all populations and fishery management methods. For example, the marine survival rate of many stocks has decreased over time, resulting in fewer CWT recoveries. Conservation measures have lowered exploitation rates for many stocks, which results in fewer CWT recoveries from fisheries. For fishery management purposes, exploitation rates are increasingly being estimated at finer levels of stratification (e.g., month, area, fishery, age) which can lead to few CWT recoveries per stratum and thus less precise estimates (Hankin et al. 2005).

Cohort reconstructions for Sacramento River winter Chinook (SRWC) salmon have been performed using data from a CWT program that marks and tags approximately 200,000 fish per year. Ocean fisheries have been managed based on information derived from this level of tagging, though there has been concern over few tag recoveries in some recovery strata and the resulting effect on precision. There is reason to believe that the number of CWT recoveries expected for CC-Chinook salmon could be greater than for SRWC given a similar number of released tags. SRWC are nearly all harvested at age-3 and have smaller length-at-age relative to other Chinook salmon stocks (Satterthwaite et al. 2012). As a result, a smaller proportion of the cohort is of legal size for retention in ocean fisheries, providing fewer opportunities for CWT recovery. Additionally, SRWC may experience higher mortality than CC-Chinook salmon during downstream migration through the highly altered Sacramento River, delta, and San Francisco Bay environments. Despite these conjectures, we currently do not have estimates of CC-Chinook salmon early life survival and ocean fishery harvest rates, and therefore there is substantial uncertainty regarding the number of CWT tag recoveries that might be expected from initiation of a new marking/tagging program.

In this appendix, we derive the number of CWT recoveries expected from a variety of CWT release group sizes and escapement survey sampling rates using Klamath River fall Chinook (KRFC) salmon life history and fishing mortality rate estimates as proxies for CC-Chinook salmon.

Methods

To derive the expected numbers of CWT fish recovered in ocean fisheries and escapement areas from a single release group, we constructed a simple cohort model consisting of an annual sequence of discrete mortality events: natural mortality, followed by fishing mortality, followed by maturation (i.e., a Type-1 model structure [Ricker 1975]). The model notation is defined in Table 1.

Table 1. Model notation.

Symbol	Definition
a	Subscript: age
o	Subscript: ocean
r	Subscript: river
λ	Sampling fraction
d	Natural mortality rate
h	Fishery harvest rate
i	Fishery impact rate
m	Maturation rate
R	Release group size
T	Expected number of CWT fish recovered

At age 1 and age 2 we assume the released fish experience natural mortality only. A portion of the surviving fish then matures at age 2 and returns to the river for spawning, while those that do not mature remain in the ocean and advance to age 3. The age 3 fish then experience the full sequence of mortality events: ocean natural mortality, followed by ocean fishing mortality, followed by maturation. Those that survive the year and do not mature remain in the ocean as age 4 fish and the annual cycle repeats, as it does for age 5 fish. We assume a maximum age of 5 years; the age 5 fish that survive ocean natural mortality and ocean fishery mortality all mature. With respect to fishery mortality, we distinguish between the fishery impact rate (which includes harvest, release, and dropoff mortality) and the fishery harvest rate (which includes harvest only). Only the harvested fish are available for CWT sample recovery. The natural mortality, harvest, impact, and maturation rates are conditional rates. That is, they are expressed as a fraction of the fish alive at the time of the respective mortality or maturation event.

We parameterized this model based on the life-history and fishery mortality rates estimated for the KRFC composite stock (includes hatchery- and natural-origin fish) using cohort reconstruction methods (Mohr 2006[3]). The resulting KRFC estimated ocean harvest and impact rates were then converted to the model's sequential, Type-1 mortality schedule by dividing by the complement of the KRFC assumed natural mortality rate at age. Together with the resulting KRFC maturation rates, these age-specific rates were then averaged over the years 1993–2013 for use in the present model analysis. The age-1 natural mortality rate was based on the arithmetic mean of the estimated survival rates (0.02) of Trinity River Hatchery and Iron Gate Hatchery fingerling releases, estimated using cohort reconstruction methods (described in Winship et al. 2013[4]). We examined several combinations of assumed natural mortality rates for the older ages. The age 2 natural mortality rates evaluated included 0.4, 0.5, and 0.6, and the rate for age 3, 4, and 5 was assumed to be a proportion (0.2, 0.4, 0.6, 0.8) of the age-2 rate. The complete set of life-history rates used to parameterize the model is shown in Table 2.

[3]Mohr, M.S. 2006. The cohort reconstruction model for Klamath River fall Chinook salmon. Unpublished report. National Marine Fisheries Service, 110 Shaffer Road, Santa Cruz, CA 95060, USA.

[4] Winship, A. J., O'Farrell, M. R., and Mohr, M. S. 2011. Estimation of parameters for the Sacramento River winter Chinook management strategy evaluation. Unpublished report. National Marine Fisheries Service, 110 Shaffer Road, Santa Cruz, CA 95060, USA.

Table 2. Age-specific natural mortality rates *d*, harvest rates *h*, impact rates *i*, and maturation rates *m* used in this analysis.

Age (a)	d_a	h_a	i_a	m_a
1	0.98	0.00	0.00	0.00
2	0.40, 0.50, 0.60	0.00	0.00	0.05
3	$0.2d_2$, $0.4d_2$, $0.6d_2$, $0.8d_2$	0.07	0.08	0.48
4	$0.2d_2$, $0.4d_2$, $0.6d_2$, $0.8d_2$	0.16	0.17	0.91
5	$0.2d_2$, $0.4d_2$, $0.6d_2$, $0.8d_2$	0.16	0.17	1.00

Table 3. Sampling fractions λ and CWT release sizes *R* used in this analysis.

Variable	Value
λ_o	0.2
λ_r	0.01, 0.05, 0.10, 0.20
R	100000, 200000, 400000

We coupled these biological, life-history rates with alternative ocean and river CWT sampling fractions λ and CWT release group sizes *R* (Table 3) to derive the expected number of CWT'd fish recovered in the ocean and river escapement areas by simply multiplying the number alive at each stage by the appropriate rates. For example, if 200,000 fish are released, and 98% of age 1 fish die of natural mortality, 50% of age 2 fish die of natural mortality, 5% mature at age 2, and the spawner sampling fraction is 10%, the number of CWT age 2 fish expected to be recovered in the river ($T_{2,r}$) is

$$T_{2,r} = R \times (1 - d_1) \times (1 - d_2) \times (1 - i_2) \times m_2 \times \lambda_r \quad \text{(A1)}$$

$$T_{2,r} = 200{,}000 \times (1 - 0.98) \times (1 - 0.50) \times (1 - 0) \times 0.05 \times 0.10 = 10. \quad \text{(A2)}$$

Similarly, for this same cohort, if 20% of age 3 fish die of natural mortality, 7% are harvested at age 3, and the ocean harvest sampling fraction is 20%, the number of CWT age 3 fish expected to be recovered in the ocean ($T_{3,o}$) is

$$T_{3,o} = R \times (1 - d_1) \times (1 - d_2) \times (1 - i_2) \times (1 - m_2) \times (1 - d_3) \times h_3 \times \lambda_o \quad \text{(A3)}$$

$$T_{3,o} = 200{,}000 \times (1 - 0.98) \times (1 - 0.50) \times (1 - 0) \times (1 - 0.05) \times$$
$$(1 - 0.20) \times 0.07 \times 0.20 = 21. \quad \text{(A4)}$$

Results

Tables 4 and 5 display the expected number of CWT recovered fish in ocean fisheries and escapement, respectively, summed over ages and rounded to the nearest integer, under different assumptions about natural mortality rates, the number of CWT fish released, and the escapement survey sampling fraction. The gray shading in Tables 4 and 5 indicates when the number of recovered tags of combined age classes is fewer than the Chinook salmon guideline identified by the PSC CWT Workgroup (2008). We note however that our model provides an approximation of the expected number of recoveries, corresponding to the mean of numerous repeated realizations of a stochastic process. In any one year, the actual number of recoveries might be higher or lower than the expectation. Thus, to meet the PSC CWT Workgroup stratum guideline of at least 20 CWT recoveries in eight of ten years, we need to establish a buffer such that the expectation is greater than 20. By generally following the methods outlined in Appendix C of PSC CWT Workgroup (2008), we determined that the appropriate value of the buffered expectation was 26.

Table 4. The number of CWT recoveries in ocean fisheries, assuming an ocean fishery sampling fraction of 0.20. CWT recoveries are for all ages combined and depend on the age-2 natural mortality rate d_2, the age 3, 4, and 5 natural mortality rate, and the number of CWT fish released R. Gray shading indicates those combinations where the number of CWT recoveries is less than 26, the (adjusted) PSC CWT Workgroup (2008) minimum guideline.

		Age 3, 4, and 5 Natural Mortality			
d_2	R	$0.20d_2$	$0.40d_2$	$0.60d_2$	$0.80d_2$
0.40	100000	29	25	22	18
	200000	57	50	43	37
	400000	115	100	86	73
0.50	100000	23	19	16	13
	200000	46	39	32	26
	400000	93	78	64	51
0.60	100000	18	14	11	8
	200000	36	29	22	17
	400000	72	58	45	34

Table 5. The number of CWT recoveries in escapement surveys, expressed as a range reflecting assumed variation in the age 3, 4, and 5 natural mortality rate (as defined in Table 4), under a variety of river sampling rates. CWT recoveries are for all ages combined and depend on the age-2 natural mortality rate d_2, the number of CWT fish released R, and the river sampling fraction. Gray shading indicates those combinations where the lower end of the range in CWT recoveries is less than 26, the (adjusted) PSC CWT Workgroup (2008) minimum guideline.

		River Sampling Fraction			
d_2	R	0.01	0.05	0.10	0.20
0.40	100000	9–6	44–30	87–59	175–119
	200000	17–12	87–59	175–119	349–238
	400000	35–24	175–119	349–238	699–475
0.50	100000	7–4	35–21	71–43	141–85
	200000	14–9	71–43	141–85	283–170
	400000	28–17	141–85	283–170	566–341
0.60	100000	5–3	27–14	55–29	110–58
	200000	11–6	55–29	110–58	220–116
	400000	22–12	110–58	220–116	439–231

These results suggest that a CWT release size of 100,000 fish would likely provide inadequate CWT recoveries unless survival rates were higher than most model scenarios explored, sampling rates were higher than assumed, and/or ocean exploitation rates are higher than is currently the case for KRFC. With regard to escapement sampling rates, the results suggest a potential minimum level of 0.05. While these calculations suggest that a release size of 200,000 fish and escapement sampling rate of approximately 0.05 could yield adequate CWT recoveries for cohort reconstructions, this inference is dependent on the KRFC-derived life history and fishing mortality rate estimates we assumed. It is therefore ultimately unknown how representative these results are for CC-Chinook salmon.

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