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Short communication

Inferred ocean distributions of genetically similar Chinook salmon stocks compared across run timing and river/hatchery of origin

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ABSTRACT

Klamath River Fall Chinook (KRFC) salmon from the Klamath-Trinity Basin are central to management of the ocean salmon fishery off the coasts of northern California and southern Oregon, with tagged KRFC serving as proxies for other stocks including spring run (KRSC). There has been no formal comparison of fall versus spring run ocean distributions, and published studies using genetic stock identification do not distinguish the runs. We modeled the spatial distribution of hatchery-origin fall versus spring run, inferred from coded-wire tag recoveries in the ocean commercial (troll) fishery while explicitly accounting for fishing effort, sampling rate, and release of sublegal-sized fish before sampling. Distributions for all stocks were confined to a similar core range, but varied seasonally, and with higher relative density of KRSC in the north. Only equivocal evidence was found for differences by age or within-basin source hatchery. The potential for such differences should be considered for analyses of coarser groupings in these and other stocks. Sensitivity analyses revealed differences in distributions inferred from recreational versus commercial fishery data, emphasizing the importance of recognizing the limitations of fishery-dependent data in representing the underlying spatial distribution of fish populations rather than spatial patterns in their interactions with specific fisheries.

1. Introduction

Ocean fisheries for Chinook salmon (*Oncorhynchus tshawytscha*) off the coast of North America are inherently mixed stock fisheries, managed to promote fishing opportunity on strong stocks while constraining impacts on weaker stocks to acceptable levels (PFMC, 2016; PSC, 2017). Managers use harvest models parameterized for select data-rich indicator stocks, which typically have a hatchery origin component that is tagged with coded-wire tags (CWT) on the assumption that fishery impacts on other stocks of interest will be similar to carefully selected indicators, but the suitability of such indicator stocks is rarely tested rigorously. There have been increasing calls for the use of genetic stock identification (GSI) in management, in part because GSI would allow directly quantifying the catch of untagged fish and GSI information could be used to test the suitability of some hatchery indicators (PSC, 2008). At the same time, it is important to realize that substantial heterogeneity may exist among the individual stocks or stock components that are combined into a single genetic reporting group, a possibility that we explore using a case study of Klamath River Chinook, a stock complex of high management and conservation interest.

The Klamath-Trinity River basin in northern California and southern Oregon supports the second-largest Chinook salmon stock complex in California. Klamath River Fall Chinook (KRFC) salmon play a central role in management of the ocean salmon fishery off the coasts of northern California and southern Oregon. KRFC is an actively managed stock under the Pacific Fishery Management Council's salmon fishery management plan (PFMC, 2016) with conservation objectives defined based on exploitation rate limits and escapement goals. KRFC experienced low 2015–2016 escapements and a very low escapement was forecast for 2017. This resulted in the declaration that the KRFC stock was approaching an overfished condition (PFMC, 2017). KRFC also serves as the indicator stock for the Southern Oregon Northern California Chinook stock complex, and the current Endangered Species Act consultation standard for the threatened and data-poor California Coastal Chinook stock is based on limiting the anticipated harvest rate on KRFC (NMFS, 2000; O'Farrell et al., 2012, 2015).

Although fall run Chinook salmon are numerically dominant in the Klamath-Trinity River basin (Williams et al., 2013), spring run (KRSC) salmon are present as well. From the perspective of ocean fisheries management, KRSC are considered part of the larger stock complex and are not presently managed with stock-specific measures.

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Phenotypically, fall versus spring run fish within the Klamath-Trinity Basin display distinctive life histories, but there is less genetic differentiation between fall versus spring run fish from the Trinity River than there is between fall run fish from the Trinity versus Klamath Rivers (Kinziger et al., 2013). A petition to list KRSC under the United States Endangered Species Act was denied (NOAA, 2012), but KRSC was identified as a stock of critical concern by Moyle et al. (2017).

The suitability of KRFC as an indicator for KRSC, particularly with respect to interactions with the ocean fishery, depends on the similarity between the two run timings in their ocean spatial distribution. Differences in the ocean spatial distribution between fall and spring run fish from the same basin have been observed for other Chinook salmon populations (Weitkamp, 2010), but we are not aware of any published analyses of KRSC ocean distribution.

Published information on the ocean spatial distribution of Klamath River Chinook (KRC, encompassing both run timings) is limited. Inferences of spatial distribution from patterns in catch per unit effort (CPUE) based on recoveries of CWTs from KRFC fish recovered in the commercial and recreational ocean fisheries are implicit in the Klamath Ocean Harvest Model used in fishery management (Mohr, 2006), but estimates of spatial distribution are not directly provided. Three papers describe spatial patterns in CPUE of Klamath River Chinook (KRC, not distinguishing fall from spring run) based on GSI applied to 5 years of recreational fishery data in California (Satterthwaite et al., 2015b), 2 years of commercial fishery data in California and Oregon (Satterthwaite et al., 2014), or 1 year of commercial fishery data in California and Oregon (Bellinger et al., 2015).

Because the current GSI baseline cannot reliably distinguish KRFC from KRSC (Clemento et al., 2014), these GSI-based studies are not informative about KRSC distribution and may offer an inaccurate picture of KRFC distribution to the extent that results are confounded by unknown differences between KRFC and KRSC. Additionally, in almost all cases (one year of analysis in Satterthwaite et al., 2014 being the exception), these GSI-based studies have not considered fish age. Because the CCC consultation standard is based specifically on the harvest rate of age-4 KRFC (NMFS, 2000), it is important to understand whether and how spatial distribution of KRC varies with age. Since CWT data reveal the hatchery, release type, run timing, and brood year (BY) of origin for each sampled fish, analysis of archived data derived from comprehensive sampling of fisheries for CWT over the last several decades has the potential to address current knowledge gaps regarding age-specific spatial distribution of KRFC and KRSC. Analysis of CWT data also allows for a comparison between fall run fish sourced from the Trinity River Hatchery (TRH) and those released from Iron Gate Hatchery (IGH) on the Klamath River, to compare the magnitude of differences across run timings within the Trinity to the magnitude of differences across rivers within the fall run. Age-specific CWT data also allow adjusting CPUE to account for the effects of (spatially and temporally variable) minimum size limits on the proportion of fish contacted which are retained and available for sampling (Satterthwaite et al., 2013), facilitating more accurate comparisons of contact rates, and thus implied densities, across areas.

2. Methods

2.1. Data sources

Our analyses of spatial patterns in CWT recoveries were based on records from the Regional Mark Processing Center (RMPC, http://www.rmpc.org/). To obtain the relevant harvest data, we queried "Standard Reporting, All Recoveries" for all recoveries of Chinook salmon originating from the Klamath-Trinity Basin occurring in the recreational (fishery code = 40, 41, or 42) or troll (fishery code = 10) ocean salmon fishery (additional codes for commercial and recreational fisheries exist in RMIS, but are not used in the areas covered by this analysis). This yielded records of individual fish recoveries including their CWT tag code (allowing determination of source location, run timing, and age), fish length, date and port of landing, and the sampling rate associated with those landings. Due to the potential for confusion resulting from different "birthdays" for spring versus fall run fish, we define fish age as the number of calendar years elapsed since the brood year.

2.2. Choice of fisheries, years, and release types for analysis

We performed the bulk of our analyses on data from the commercial troll fishery due to substantially higher KRC tag recoveries compared to the recreational fishery (Supplementary Appendix A). We obtained data on fishing effort and minimum size limits from Pacific Fishery Management Council (PFMC) archives available at http://www.pcouncil.org/salmon/background/document-library/historical-data-of-ocean-salmon-fisheries/, extended back to 1983 using personal archives (Satterthwaite et al., 2013). Our analysis used recovery data from 1983 to 1989. Data on recoveries prior to 1983 were excluded due to a lack of effort and size-limit data, whereas data after 1989 was excluded due to substantial reductions in catch and effort, along with extended closures, that greatly reduced tag recovery rates and increased uncertainty in more recent years. We excluded fish landed north of Cape Falcon (45°46′N) due to low recoveries of KRC tags and current management practices focused on KRC impacts south of Cape Falcon, and sorted the remaining landings into seven ocean management areas as defined by the PFMC (PFMC, 2016, see Fig. B.1 in Supplementary Appendix B, the "MO" area was dropped from this analysis due to low tag recoveries and consequent problems with mixing of the Bayesian model used to estimate distributions).

In our primary analysis, we considered all release groups of a given run timing from a given hatchery together, in part to maximize sample sizes and aid model convergence. However, important differences have been documented in the maturation and exploitation rates of typical "fingerling" releases of young fall run fish in spring or early summer compared to "yearlings" held for extended rearing periods and released in the following fall (Hankin 1990; Hankin and Logan 2010). Although adequate sample sizes were not available to reliably estimate separate distributions for each release type each month, we present selected comparisons across release types as a sensitivity analysis (see Supplementary Appendix C). Similarly, because fisheries act as a filter in sampling the underlying ocean abundance of fish (e.g., commercial vessels often fish in deeper waters and farther from port), we performed similar analyses on CWT recoveries from the recreational fishery, with select comparisons presented in Supplementary Appendix D. These comparisons were all carried out for recoveries in July, the month with the most tag recoveries.

2.3. Models

We used contact rate as a proxy for fish density in a particular time and area, where "contacts" are defined to include all fish caught on a hook, whether retained in the harvest or not. We modeled the fishery/stock/age/time/area-specific contact rate using a Bayesian hierarchical model developed and described in Satterthwaite et al. (2013). In brief, we assumed that contact rate λ for a particular stock is a function of its density D and catchability q. We further assumed that q was constant across space for a given fishery, time, and stock, and therefore we only estimate λ rather than q and D, and assume that differences in relative λ reflect distributional differences. Under this assumption, the stock-specific contacts resulting from a single unit (angler-day) of fishing effort follows a Poisson distribution with mean λ, and the total stock-specific contacts C resulting from f angler-days of effort follow a Poisson distribution with mean $f\lambda$. In model elaborations with sufficient data to estimate more parameters, we account for overdispersion by using a negative binomial distribution in place of the Poisson, corresponding to drawing a value of λ from a shared gamma distribution before making a