Chinook salmon

In the northeast Pacific, Chinook salmon range from central California through Alaska (Shelton et al. 2019). Chinook salmon home to their natal rivers with high fidelity, supporting both mixed-stock ocean fisheries and place-based terminal fisheries that depend on specific stocks. Wide-ranging ocean distributions mean that salmon cross state and national boundaries. Treaties and other legal arrangements apportion allowable harvest among the United States, Canada, and multiple Tribes and First Nations on both sides of the U.S.-Canada border. The multi-jurisdictional nature of Chinook salmon distributions and their fisheries management, as well as considerable ecological (Willson and Halupka 1995, Ford et al. 1998, Schindler et al. 2013), subsistence (Poe et al. 2015), and cultural (Campbell and Butler 2010) values of Chinook salmon, makes simple summary statements about management and economic value challenging.

For simplicity, this vignette therefore focuses on Chinook salmon fisheries occurring south of Cape Falcon, OR. Fisheries management in this area is primarily done under the auspices of the Pacific Fishery Management Council, the states of Oregon and California, and the Yurok, Hoopa, and Karuk Tribes in the Klamath-Trinity River Basin. Closure of commercial ocean troll fisheries in this area in 2017 were predicted to result in the loss of \$5.8-\$8.9 million in income, \$12.8-\$19.6 million in sales, and 200-330 jobs (Richerson et al. 2018), but this does not account the economic value of recreational and subsistence fisheries.

Ocean fishing seasons in this area depend primarily on the application of harvest control rules (HCRs) to preseason abundance forecasts of two “indicator stocks” (Sacramento River Fall Chinook, SRFC and Klamath River Fall Chinook, KRFC) as well as ESA consultation standards for threatened California Coastal Chinook (CCC) and endangered Sacramento River Winter Chinook (SRWC). Numerous environmental factors, including stream temperatures and flows experienced by juveniles (Friedman et al. 2019), early season upwelling and prey retention (Wells et al. 2016), and predation (Friedman et al. 2019) have been related to the productivity and abundance of these stocks. Although environmental covariates have been considered in forecasts for these stocks (Winship et al. 2015, Satterthwaite et al. 2020), the currently applied forecasting models are a “sibling regression” for KRFC that predicts age a ocean abundance at the start of year y based on river returns of age a-1 in year y-1 (Peterman 1982) and a model for SRFC that predicts “adult” abundance based on the return of “jacks” the previous year along with an autocorrelated error term (Winship et al. 2015) that may implicitly, but not explicitly, capture autocorrelated environmental drivers.

SRFC are primarily harvested and primarily return to rivers two years after ocean entry (mostly spread over one to three years), while KRFC are primarily harvested and primarily return to rivers three years after ocean entry (mostly spread over two to four years). Thus the 2014-2016 marine heatwave (MHW, Jacox et al. 2018) was directly experienced by adults harvested or returning to rivers in 2014-2016, but also affected juveniles entering the ocean that primarily contributed to harvest and escapement in 2016-2018 (SRFC) or 2017-2019 (KRFC). The period shortly after juvenile entry is often considered the “critical period” in setting cohort strength for salmon (Beamish and Mahnken 2001).

Both KRFC and SRFC were declared overfished in 2018 based on low geometric mean escapements for 2015-2017 (PFMC 2019a,b), and as of 2020 both stocks remained overfished

(PFMC 2020a). For KRFC, river run size in 2016 was the lowest on record since 1983 and 2017 was the second-lowest on record since 1992, while for SRFC the 2017 escapement was the second-lowest on record since 1983 and the 2016 escapement was below average and below the spawning escapement goal specified by the HCR. SRFC pre-fishing abundance rebounded slightly in 2018 (likely the last cohort affected by the MHW at ocean entry) and was above average in 2019 (likely the first cohort with little direct experience from the MHW). KRFC spawner abundance rebounded in 2018, but 2019 spawning abundance was only slightly (12%) higher than 2017.

The combination of restricted seasons resulting from low preseason abundance forecasts and low abundances of harvestable fish led to reduced harvest and incomes (Richerson et al. 2018, PFMC 2020b), although similar collapses have occurred in the past (Lindley et al. 2009). While not unprecedented, these reductions in fishing did result in multiple fishery disaster declarations - $3,864,904 for the California Klamath River Chinook Salmon Fishery, 2016 (Yurok Tribe); $8,886,000 for the Oregon and California Klamath River Fall Chinook Salmon Fishery, 2016 and 2017; $2,226,068 for the Klamath River Fall Chinook Commercial Fishery, 2018 (Yurok Tribe); a pending declaration for the Klamath River Fall Chinook Salmon Fishery, 2019 (Yurok Tribe); and multiple disaster declarations for salmon (multiple species) fisheries in Washington.

2017 stands out as a particularly low abundance year for adults from both stocks. While this is after the MHW, for SRFC it corresponds to marine entry in the middle of the MHW (2015) and for KRFC it corresponds to the returns of adults entering the ocean from 2013-2015, including two years of the MHW). Effects of the MHW on subadults or adults may have also contributed to low returns in 2016. For KRFC, brood year 2012 (ocean entry year 2013) made weak contributions to consecutive cohorts (PFMC 2019a). Although this predates the MHW, poor subadult or adult survival for this cohort would affect escapements in 2015 and 2016. Notably, preseason forecasts based on sibling regression overestimated escapements of KRFC in both 2015 and 2016 (PFMC 2019a), consistent with lower-than-average adult survival. For SRFC, brood year 2014 (ocean entry year 2015) stands out as the weakest, although an index of marine survival based on recreational fishery recoveries of age-2 fish from this cohort does not suggest unusually low survival (PFMC 2019b). SRFC abundances for 2015-2017 were all overforecast (PFMC 2019b), with the worst error in 2015 – for which jacks leaving the ocean before the MHW would be used to predict adults that experience the beginning of the MHW. Forecast error in 2016 was reduced in part due to the autocorrelated error term adjusting forecasts based on the overforecast the previous year, but 2016 abundance was still overforecast even with this adjustment.

The rebuilding plans for both of these stocks point to a variety of factors contributing to the low escapements in 2014-2017, and it would be a gross oversimplification to blame the overfished status or reductions in harvest on the MHW alone. Also, at least for SRFC, there are indications that the marine conditions it experienced off Central California were not as bad during the MHW as elsewhere in the California Current (PFMC 2019b). Nevertheless, the MHW does coincide with years of poor returns of adults and with ocean entry of cohorts that subsequently yielded poor returns.

Management models based on preseason forecasts partly but not entirely predicted these low abundances, and allowable harvest rates were adjusted downward accordingly, but not by as much as they would have been if the impacts of the MHW and other factors on abundance had been perfectly forecasted. Improved forecasts and the HCR-mandated adjustments in harvest levels alone would not have prevented the overfished declaration for KRFC (PFMC 2019a), but management errors did contribute to the overfished declaration for SRFC (PFMC 2019b); and reduced under-escapement from better forecasts might lead to faster rebuilding of either stock. This suggests there is some, but limited, potential for improved preseason forecasts to anticipate the effects of environmental shocks like the MHW; and accompanying adjustments to harvest management may partially ameliorate, but not eliminate, these effects. Even with perfect knowledge and foresight, however, poor environmental conditions will lead to reduced catch and reduced income, highlighting the importance to climate resilience of flexibility in switching to alternative fisheries and/or the accurate, timely, and equitable disaster assistance.

References

Beamish, R. J., and Mahnken, C. 2001. A critical size and period hypothesis to explain natural regulation of salmon abundance and the linkage to climate and climate change. Prog. Oceanogr. 49, 423–435.

Campbell, S. K., and Butler, V. L. 2010. Archaeological evidence for resilience of Pacific Northwest salmon populations and the socio-ecological system over the last 7500 years. Ecology and Society, 15: 17.

Ford, J. K. B., Ellis, G. M., Barrett-Lennard, L. G., Morton, A. B., Palm, R. S., and Balcomb III, K. C. 1998. Dietary specialization in two sympatric populations of killer whales (Orcinus orca) in coastal British Columbia and adjacent waters. Canadian Journal of Zoology, 76: 1456–1471.

Friedman, W. R., Martin, B. T., Wells, B. K., Warzybok, P., Michel, C., Danner, E. M., et al. (2019). Modeling composite effects of marine and freshwater processes on migratory species. Ecosphere 10:e02743. doi: 10.1002/ecs2.2743

Jacox, M. G., Alexander, M. A., Mantua, N. J., Scott, J. D., Hervieux, G., Webb, R. S., et al. (2018). Forcing of multiyear extreme ocean temperatures that impacted California Current living marine resources in 2016. Bull. Am. Meteor. Soc. 99, S27–S33.

Lindley, S. T., Grimes, C. B., Mohr, M. S., Peterson, W., Stein, J., Anderson, J. T., Botsford, L. W. et al. 2009. What caused the Sacramento River fall Chinook stock collapse? NOAA Technical Memorandum, NMFS-SWFSC-447.

Pacific Fishery Management Council (PFMC). 2019a. Salmon Rebuilding Plan for Klamath River Fall Chinook. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

Pacific Fishery Management Council (PFMC). 2019b. Salmon Rebuilding Plan for Sacramento River Fall Chinook. Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

Pacific Fishery Management Council (PFMC). 2020a. Preseason Report I: Stock Abundance Analysis and Environmental Assessment Part 1 for 2020 Ocean Salmon Fishery Regulations. (Document prepared for the Council and its advisory entities.) Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

Pacific Fishery Management Council (PFMC). 2020b. Review of 2019 Ocean Salmon Fisheries: Stock Assessment and Fishery Evaluation Document for the Pacific Coast Salmon Fishery Management Plan. (Document prepared for the Council and its advisory entities.) Pacific Fishery Management Council, 7700 NE Ambassador Place, Suite 101, Portland, Oregon 97220-1384.

Peterman, R. M. 1982. Model of salmon age structure and its use in preseason forecasting and studies of marine survival. Canadian Journal of Fisheries and Aquatic Sciences, 39: 1444–1452.

Poe, M. R., Levin, P. S., Tolimieri, N., and Norman, K. 2015.Subsistence fishing in a 21st century capitalist society: From commodity to gift. Ecological Economics, 116: 241-250.

Richerson, K., Leonard, J., and Holland, D. S. 2018. Predicting the economic impacts of the 2017 West Coast salmon troll ocean fishery closure. Marine Policy, 95: 142–152.

Satterthwaite, W. H., Andrews, K. S., Burke, B. J. Gosselin, J. L. Greene, C. M., Harvey, C. J., et al. 2020. Ecological thresholds in forecast performance for key United States West Coast Chinook salmon stocks. ICES Journal of Marine Science 77:1503-1515.

Schindler, D. E., Armstrong, J. B., Bentley, K. T., Jankowski, K., Lisi, P. J., and Payne, L. X. 2013. Riding the crimson tide: mobile terrestrial consumers track phenological variation in spawning of an anadromous fish. Biology Letters, 9: 20130048.

Shelton, A. O., Satterthwaite, W. H., Ward, E. J., Feist, B. E., and Burke, B. 2019. Using hierarchical models to estimate stock-specific and seasonal variation in ocean distribution, survivorship, and aggregate abundance of fall run Chinook salmon. Canadian Journal of Fisheries and Aquatic Sciences, 76: 95–108.

Wells, B. K., Santora, J. A., Schroeder, I. D., Mantua, N., Sydeman, W. J., Huff, D. D., et al. 2016. Marine ecosystem perspectives on Chinook salmon recruitment: a synthesis of empirical and modeling studies from a California upwelling system. Mar. Ecol. Prog. Ser. 552: 271–284.

Willson, M. F., and Halupka, K. C. 1995. Anadromous fish as keystone species in vertebrate communities. Conservation Biology, 9: 489–497.

Winship, A. J., O'Farrell, M. R., Satterthwaite, W. H., Wells, B. K., and Mohr, M. S. 2015. Expected future performance of salmon abundance forecast models with varying complexity. Canadian Journal of Fisheries and Aquatic Sciences, 72: 557–569.