Forage fish, small pelagic fisheries and recovering predators: managing expectations

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Small pelagic fishes (i.e. sardines [*Sardinops spp.*] and anchovies [*Engraulis spp.*]; hereafter ”forage fish”) support very large fisheries globally, but in recent years the catches of sardine and anchovy off California have been very low. Sardine catches were two orders of magnitude lower, and anchovy catches are an order of magnitude lower than the historical maximum catch rates in this region [*Hill et al.*, 2017; *NMFS*, 2009]. Declines in small pelagic fish biomass have occurred in spite of precautionary management including: very low exploitation rates, an environmentally informed harvest control rule for sardine, and generous reserve thresholds to provide a buffer for forage and stock recovery [*Hill et al.*, 2017; *NMFS*, 2009]. Clearly something is missing. In addition to commercial harvest, the non-commercial value of forage fishes in the California Current System is a fundamentally important resource base for fish, mammal and seabird predators [*Szoboszlai et al.*, 2015]. In recent years, the largest removals of forage fish in the California Current System are by demersal fish, marine mammals, seabirds [*Thayer et al.*, 2017] and then by fisheries, arranged in order of magnitude. Forage fish removals by commercial fisheries off California are currently $< 15\%$ of consumption by marine mammals. While there is considerable uncertainty in this estimate, it is likely to be approximately correct. For example, California sea lion [*Zalophuss californianus*], once a highly depleted marine mammal species, is now above 250,000 individuals ([*Laake et al.*, 2018]). Using a conservative, non-pup provisioning ration of $5\ kg/individual/day$ ([*Costa et al.*, 1991; *Williams et al.*, 2007]), the forage fish harvest would be $446,000\ mt$ (metric tons) $/year$. If even a tenth is anchovy, this is greater than human harvest, without considering other marine mammals, marine birds or higher trophic level fishes.

The sardine fishery off California has been closed since 2015 following a stock assessment ([*Hill et al.*, 2015]) estimating biomass less than the reserve threshold of $150,000\ mt$; a limit set to protect the sardine stock. Anchovy have been fished in the last decade ($2006-2016$) in the absence of a catch limit, although there is a reserve threshold, and catches have been very low ($1,020-17,284\ mt$ [*Lowther and Liddel*, 2016]). In 2016 a catch limit for anchovy was set at $25,000\ mt$, but actual catches ($8,366\ mt$) remained well below the catch limit. Despite this, the catch limit was challenged by environmental NGOs seeking to close the fishery, and the District Court ruled against the National Marine Fisheries Service (NMFS) for failing to apply “best available science” ([*MacCall et al.*, 2016]) when setting the catch limit. The court ruling, which at the time of writing may still be appealed, required NMFS to revise the catch limit. NMFS relied on historical data to establish the initial catch limit, rather than the analysis by *MacCall et al.* [2016], which had some problems $-$ first, the spatial coverage was inadequate for an accurate biomass estimate ([*FRD*, 2016]), and second, the anchovy biomass estimate by *MacCall et al.* [2016] was less than the estimated consumption by marine mammals alone, which should not be the case unless the turnover of anchovy was phenomenally high. The timing of the lawsuit was unfortunate, in that NMFS acoustic-trawl survey data available shortly after the court case estimated the anchovy biomass at $150,000\ mt$

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([*Zwolinski et al.*, 2017]). At a biomass of more than $150,000\ mt$, a catch of $< 25,000\ mt$ would still be precautionary for these fast growing fish.

The focus on commercial fishery catches ignores an important source of sardine and anchovy mortality. Recovery of marine mammal populations implies large changes in natural mortality of forage fish. Following the introduction of the Marine Mammal Protection act in 1972, NMFS has monitored mammal populations in the California Current System and developed criteria to evaluate population recovery. It is now apparent that some of these populations, such as the California sea lion have recovered and are approaching carrying capacity [*Laake et al.*, 2018]. When food limitation contributes to mortality, populations can be expected to exhibit density dependent mortality, or difficulty in adequately feeding their young [*McClatchie et al.*, 2016; *Wells and Others*, 2017], and may exert significant pressure on forage resources in their feeding range. The impact of mammalian predators on forage is far larger than the impact of current fishing levels off southern California, and the mammals are only one component of the predator complex exploiting forage fishes [*Szoboszlai et al.*, 2015; *Thayer et al.*, 2017]. Given that natural predation is the largest removal of forage fish in the California Current System, we believe that the January 2017 court order was misguided because it failed to address wider issues than the anchovy catch limit. First, does the commercial forage fishery have a right to exist? Second, what kind of natural ecosystem is desirable in the modern day context? And last, is restoration of forage fish to some stable pre-fishery level desirable or even possible?

In the context of multiple use of natural resources, small fisheries, managed in a precautionary way, should be compatible with recovered predator populations. For example, in the last 40 years, marine mammal assessments (see [http://www.nmfs.noaa.gov/pr/sars/species.htm]) show that California sea lions have recovered at near maximal rates while small pelagic fisheries, managed in a precautionary manner, continued to exist (see catches on the Pelagic Fisheries Information System [http://pacfin.psmfc.org/]). Sardine and anchovy fisheries, comparable to the historical fisheries off California, are far different from the smaller fisheries of the last decade. In our opinion, such small fisheries have a right to exist. The question is, how large should the fisheries be allowed to become? This bears directly on the second question of what kind of ecosystem is desirable off modern southern California? Do we want the natural predator populations to grow sufficiently to consume all of the forage resources available to them, at which point they will show density dependence? Or are we willing to accept a somewhat lower forage fish population threshold at which density dependent stresses become evident in the natural predators, and permit the commercial sector to harvest a fraction of the forage resource? Finally, while it is recognized that fishing pressure on pelagic forage fish can increase the probability, and even the rate, of stock collapse [*Essington et al.*, 2015], it is well documented that forage fish populations collapse repeatedly and these collapses are a common feature of sardine and anchovy population dynamics, even in the absence of commercial fishing [*Baumgartner et al.*, 1992; *Field et al.*, 2009; *McClatchie et al.*, 2017]. The inescapable conclusion, from long time series palaeoceanographic studies, is that sardine and anchovy populations are not stable, and so it is not possible to restore them to some stable pre-fishery level, because it does not exist. The repeated collapse and recovery of these forage fishes occurred during periods when marine mammals and other predators were at very low exploitation levels, which also supports the case that there were times when forage was low and the predator populations would have experienced density dependent stresses.

It is tempting to assume that ecosystem-based fishery management approaches are the answer, but no one knows how the California Current System functioned in the absence of humans. A key question is whether the system is characterized by high forage fish standing stock (units of $mass/volume$), or by high productivity ($mass/volume/time$) but low standing stock. Palaeoceanographic studies of forage fish scales in sediment cores clearly indicate that upwelling, primary production and the biomass of forage fishes have varied over orders of magnitude at different temporal scales [*Skrivanek and Hendy*, 2015]. But do sediment fish scale records reflect high standing stock of forage fishes? Or do fish scale records indicate biomass that was rapidly consumed and flowed through higher trophic levels before being deposited to the sediment as fish scales? If the California Current System functions as a tightly coupled system, with long-lived predators, then standing stocks of forage fishes should be low when predators are abundant. If the California Current System is loosely coupled, then standing stocks of forage fishes may accumulate when production exceeds the capacity for higher trophic levels to consume it. This surplus standing stock would arguably be available to the fishery. The true nature of the California Current System may never be known, but it is clear that following the recovery of marine mammal and seabird predators, and the recovery of over-harvested fish stocks, there is, and will continue to be, an increase in competition between protected resources, higher trophic level fisheries, and direct harvest of forage fishes. Large standing stocks of forage fishes are unlikely to be a common feature of the restored California Current System. It seems unrealistic to assume closing the tiny anchovy fishery will have the desired biological effect of creating a larger anchovy standing stock when predator populations have recovered. More attention to the role of predation and competition in determining small pelagic fish biomass is likely to be a more useful approach to managing expectations regarding forage fish biomass.

Future research should include estimating abundance of pre-recruit forage fishes since the relationships between adults and environmental variables are weak ([*McClatchie*, 2013]), possibly due to the variable effects of predator mortality. While pre-recruits are also preyed upon, we expect them to show a clearer relationship to environmental variability, and to be less variable than ichthyoplankton abundances, due to lower rates of mortality. More effort should also be expended to estimate forage fish abundance in the foraging range of predators near their breeding colonies. Forage fishes are highly mobile and their full range is not available to breeding predators. It would be possible to determine times and locations where forage fishes should be managed to facilitate successful breeding by predators, and to develop a mechanism facilitating coexistence of both predators and small forage fisheries. Finally, anchovy, sardine, mackerels (*Scomber japonicus* and *Trachurus symmetricus*) and market squid (*Doryteuthis opalescens*) form a community of forage species. Since marine mammals and other top predators are highly adept at prey switching, it is not reasonable to consider natural mortality on one species without considering the standing stocks of the other forage species. We suggest a portfolio approach to the management of small pelagic fisheries ([*Link*, 2017]).

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References

Baumgartner, T., A. Soutar, and V. Ferreira-Bartrina (1992), Reconstruction of the history of Pacific sardine and northern anchovy populations over the past two millennia from sediments of the Santa Barbara Basin, California, *California Cooperative Oceanic Fisheries Investigations Reports*, *33*, 24–40.

Costa, D., G. Antonelis, and R. DeLong (1991), Effects of El Niño on the foraging energetics of the California sea lion, in *Pinnipeds and El Niño: responses to environmental stress*, edited by F. Trillmich and K. Ono, p. 156165, Springer-Verlag, Berlin.

Essington, T., P. Moriarty, H. Froelich, E. Hodgson, L. Koehn, K. Oken, M. Siple, and C. Stawitz (2015), Fishing amplifies forage fish population collapses, *Proceedings of the National Academy of Sciences*, (doi: 10.1073/pnas.1422020112).

Field, D., T. Baumgartner, V. Ferreira, D. Gutierrez, H. Lozano-Montes, R. Salvatteci, and A. Soutar (2009), *Climate Change and Small Pelagic Fish*, chap. Variability from scales in marine sediments and other historical records, pp. 214–284, Cambridge University Press.

FRD (2016), Egg and larval production of the central subpopulation of northern anchovy in the Southern California Bight, unpublished report for Pacific Fishery Management Council.

Hill, K., P. Crone, E. Dorval, and B. Macewicz (2015), Assessment of the Pacific sardine resource in 2015 for U.S.A. management in 2015-16, *Technical Memo NOAA-TM-NMFS-SWFSC-546*, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Southwest Fisheries Science Center.

Hill, K., P. Crone, and J. Zwolinski (2017), Assessment of the Pacific sardine resource in 2017 for U.S. management in 2017-18, *Technical Memo NOAA-TM-NMFS-SWFSC-576*, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Southwest Fisheries Science Center.

Laake, J., M. Lowry, R. DeLong, S. Melin, and J. Carretta (2018), Population growth and status of California sea lions, *The Journal of Wildlife Management*, (DOI: 10.1002/jwmg.21405).

Link, J. (2017), System-level optimal yield: increased value, less risk, improved stability, and better fisheries, *Canadian Journal of Fisheries and Aquatic Sciences*, *75*(1), 1–16.

Lowther, A., and M. Liddel (2016), Fisheries of the United States 2015, *Current fisheries statistics no. 2015*, U.S. Department of Commerce, NOAA, NMFS.

MacCall, A., W. Sydeman, P. Davison, and J. Thayer (2016), Recent collapse of northern anchovy biomass off California, *Fisheries Research*, *175*, 87–94.

McClatchie, S. (2013), *Regional fisheries oceanography of the California Current System. The CalCOFI program*, Springer, Dordrecht.

McClatchie, S., J. Field, A. Thompson, T. Gerrodette, M. Lowry, P. Fiedler, W. Watson, K. Nieto, and R. Vetter (2016), Food limitation of sea lion pups and the decline of forage off southern California, *Royal Society Open Science*, *3*(http://dx.doi.org/10.1098/rsos.150628).

McClatchie, S., I. Hendy, A. Thompson, and W. Watson (2017), Collapse and recovery of forage fish populations prior to commercial exploitation, *Geophysical Research Letters*, *44*(DOI: 10.1002/2016GL071751).

NMFS (2009), Our living oceans. Report on the status of U.S. living marine resources, 6th edition, *Technical Memo NOAA-TM-NMFS-F/SPO-80*, U.S. Department of Commerce, National Oceanic and Atmospheric Administration.

Skrivanek, A., and I. Hendy (2015), A 500 year climate catch: Pelagic fish scales and paleoproductivity in the santa Barbara Basin from Medieval Climate anomaly to the Little Ice Age (AD 1000-1500), *Quaternary International*, *387*(DOI: 10.1016/j.quaint.2015.07.044), 1–10.

Szoboszlai, A., J. Thayer, S. Wood, W. Sydeman, and L. Koehn (2015), Forage species in predator diets: Synthesis of data from the California Current, *Ecological Informatics*, *29*, 45–56.

Thayer, J., A. Szoboszlai, and W. Sydeman (2017), Predator forage needs: Comparison and model synthesis, in *International Symposium: Drivers of dynamics of small pelagic fish resources Mar 6-11, 2017, Victoria, BC, Canada*, http://meetings.pices.int/meetings/international/2017/pelagic/scope.

Wells, B., and Others (2017), State of the California Current 2016-17: Still anything but normal in the north, *CalCOFI Reports*, *58*, 1–55.

Williams, T., M. Rutishauser, B. Long, T. Fink, J. Gafney, H. Mostman-Liwanag, and D. Casper (2007), Seasonal variability in otariid energetics: Implications for the effects of predators on localized prey resources, *Physiological and Biochemical Zoology: Ecological and Evolutionary Approaches*, *80*(4), 433–443.

Zwolinski, J., D. Demer, B. Macewicz, S. Mau, D. Murfin, D. Palance, J. Renfree, T. Sessions, and K. Stierhoff (2017), Distribution, biomass and demography of the central-stock of northern anchovy during summer 2016, estimated from acoustic-trawl sampling, *Tech. Rep. NOAA-TM-NMFS-SWFSC-572*, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Southwest Fisheries Science Center.