Recommended Scientific Publications and Reports on Forage Fish and Dependent Marine Wildlife

With emphasis on forage fish of the Northeast Pacific

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Forage fish are generally small to medium-sized species that play a crucial role in marine ecosystems as food for other ocean wildlife. They include schooling fish such as anchovy, herring, sardine and smelt, as well as invertebrates like krill and market squid. Forage fish feed mainly on plankton and transfer energy from the bottom of the food web to higher trophic levels through their role as prey. In the Northeast Pacific, forage fish are a valuable source of food for dependent marine fish and wildlife such as Chinook salmon, brown pelicans, humpback whales, bluefin tuna, California sea lions and many other ocean animals.

Forage fish abundance is closely linked to oceanographic conditions and as a result, they are known to experience dramatic fluctuations in population size corresponding with changes in ocean productivity. Scientists have also determined that increasing fishing pressure on forage species during population declines increases the rate and magnitude of forage fish declines (Essington et al. 2015).

In recent years there have been dramatic declines in the abundance of some forage species, including Pacific sardine (Hill et al. 2017) and northern anchovy (e.g. MacCall et al. 2016). Between 2010 and 2014 fishing rates on Pacific sardine exceeded sustainable levels as the sardine population collapsed to its current depressed condition (Hill et al. 2017). The lack of sardine with the simultaneous decline of anchovy has directly impacted dependent marine wildlife like California sea lions (McClatchie et al. 2016) and brown pelicans (Henry 2015). A recently released study of northern anchovy, however, suggests the anchovy population off California may now be rebounding from its collapsed state (Zwolinski et al. 2017) while sardine remain at low levels (Hill et al. 2017).

The following are select scientific studies and reports documenting the collapse of Pacific sardine and northern anchovy populations, the linkage between forage fish abundance and predator survival and productivity, how commercial fishing pressure affects forage fish abundance, and scientific recommendations for management of forage fish fisheries. The below references are intended to highlight some of the main resources, and thus are not an exhaustive literature review.

I. Science on the recent Pacific sardine and northern anchovy collapse:

1. MacCall, A.D., W.J. Sydeman, P.C. Davison, J.A. Thayer. 2016. **Recent collapse of northern anchovy biomass off California.** Fisheries Research 175, 97-94. Available at: http://www.sciencedirect.com/science/article/pii/S0165783615301363

"Northern anchovy, an important component of the forage fish community of the California Current ecosystem, has declined substantially off southern California in the past decade. The estimated spawning biomass decreased by over 99% from 2005 to 2009, and merits the term "collapse"."

2. Thayer, J.A., A.D. MacCall, P.C. Davison, and W.J. Sydeman. 2016. **California Anchovy Population Remains Low, 2012-2016**. Available at: http://usa.oceana.org/sites/default/files/thayer_et_al_anch_biomass_update.pdf

"The extended time series (2012-2015) shows that stock [central subpopulation of northern anchovy] remains low after a collapse after 2005 (i.e., two orders of magnitude below the 2005 value)."

3. Zwolinski, J.P., Demer, D.A., Macewicz, B.J., Cutter, G.R., Mau, S., Murfin, D., Renfree, J.S., Sessions, T.S., and Stierhoff, K. 2016. **The distribution and biomass of the central-stock northern anchovy during summer 2015, estimated from acoustic-trawl sampling.** National Marine Fisheries Service. Available as Appendix 1 at: http://www.pcouncil.org/wp-content/uploads/2016/11/G4a_Sup_SWFSC_Rpt2_NOV2016BB.pdf

"In summer 2015, the biomass of the central subpopulation of northern anchovy was estimated using the acoustic-trawl method (ATM) to be 31,427 metric tons (t), CV = 24.6%."

4. Southwest Fisheries Science Center. 2016. **Egg and larval production of the central subpopulation of northern anchovy in the Southern California Bight**. Available at: http://www.pcouncil.org/wp-content/uploads/2016/10/G4a_SWFSC_Report_Anchovy_EggLarval_Production_NOV2016BB.pdf

"We calculated spatially weighted egg-production estimates for the central subpopulation of northern anchovy in the Southern California Bight in winter and spring for the period 1981-2015. Although there was little correspondence between the winter and spring time series, the indices indicated that anchovy abundance has been low since about 2008. Additional samples measured at a series of inshore stations for the period 2004-2015 also indicated that anchovy ichthyoplankton densities have been low…."

5. Hill, K.T., P.R. Crone, J.P. Zwolinski. 2017. **Assessment of the Pacific sardine resource in 2017 for U.S. management in 2017-18**. Pacific Fishery Management Council, April 2017 Briefing Book, Agenda Item G.5.a, Portland, Oregon. 146 p. Available at: http://www.pcouncil.org/wp-content/uploads/2017/03/G5a_Stock_Assessment_Rpt_Full_ElectricOnly_Apr2017BB.pdf

The Pacific sardine assessment documents a 95% population decline between 2006 and 2017.

"As discussed above for both SSB [spawning stock biomass] and recruitment, a similar trend of declining stock biomass has been observed since 2005-06, peaking at 1.8 mmt [million metric tons] in 2006, and plateauing at recent historical low levels since 2014. Model ALT stock biomass is projected to be 86,586 mt in July 2017."

6. Zwolinski, J. and D.A. Demer. 2012. **A cold oceanographic regime with high exploitation rates in the Northeast Pacific forecasts a collapse of the sardine stock**. Proceedings of the National Academy of Sciences (PNAS) 109 (11). 4175-4180. Available at: http://www.pnas.org/content/109/11/4175.full.pdf

"The oceanographic conditions in the north Pacific have shifted to a colder period, Pacific sardine (Sardinops sagax) biomass has declined precipitously in the California Current, the international sardine fishery is collapsing… Also alarming is the repetition of the fishery's response to a declining sardine stock—progressively higher exploitation rates targeting the oldest, largest, and most fecund fish. Furthermore, our data indicate the recent reproductive condition of sardine is poor, and their productivity is below modeled estimates used to derive the current fishery-exploitation rates…Thus, a near-term recovery of this important stock is unlikely, depending on the return of warmer oceanographic conditions… and perhaps the adoption of a more precautionary strategy for managing the residual sardine population."

II. Science showing the northern anchovy population may now be rebounding:

1. Zwolinski et al. 2017. **Distribution, Biomass and Demography of the Central-Stock of Northern Anchovy During Summer 2016, Estimated from Acoustic-Trawl Sampling**. NOAA-TM-NMFS-SWFSC-572. Available at: http://www.pcouncil.org/wp-content/uploads/2017/04/G1b_Sup_SWFSC_Rpt_Apr2017BB.pdf

"A minimum biomass estimate of the central subpopulation of northern anchovy in summer 2016 using the acoustic-trawl method (ATM) was determined to be 151,558 metric tons (t), CV = 41.0%. The anchovy, ranging from the Mexican border to north of San Francisco, CA, but primarily observed north of Point Conception…"

III. Science and reports on the importance of forage fish to dependent marine wildlife:

1. McClatchie, S. et al. 2015. **Food limitation of sea lion pups and the decline of forage off central and southern California**. Available at: https://www.researchgate.net/publication/267899031_Food_limitation_of_sea_lion_pups_and_the_decline_of_forage_off_central_and_southern_California

"In the last decade off central California, where breeding female sea lions from San Miguel rookery feed, sardine and anchovy greatly decreased in biomass, whereas market squid and rockfish abundance increased. Pup weights fell as forage food quality declined associated with changes in the relative abundances of forage species.... A shift from high to poor quality forage for breeding females results in food limitation of the pups, ultimately flooding animal rescue centres with starving sea lion pups."

2. Henry, S.P., 2015. **Letter from Stephen P. Henry, United States Fish and Wildlife Service to Dorothy Lowman, Pacific Fishery Management Council** (May 14, 2015). Available at: http://www.pcouncil.org/wp-content/uploads/2015/05/G3a_USFWS_Rpt_JUN2015BB.pdf

"Northern anchovy availability within foraging distances of colonies is the most important factor influencing pelican breeding success within the SCB [Southern California Bight] (Anderson 1982)."

"Adult brown pelican mortality events along the California and Oregon coast were documented from December 2008 to March 2009 and January to February 2010, with emaciation or starvation identified as the primary cause of death in both events (Nevins et al. 2011)."

"California brown pelicans have also experienced a series of years of poor breeding success at Anacapa Island [off Southern California]. This general decline began in 2009 and continued in subsequent years…. Nearly complete colony failure occurred in 2012, when only five chicks are known to have fledged (Harvey et al. 2013)."

"… a long-term decline in anchovy abudance could have serious impacts on the California brown pelican population…"

3. Cury, P.M., I.L. Boyd, S. Bonhommeau, T. Anker-Nilssen, R.J.M. Crawford, R.W. Furness, J.A. Mills, E.J. Murphy, H. Österblom, M. Paleczny, J.F. Piatt, J.P. Roux, L. Shannon, and W.J. Sydeman. 2011. **Global Seabird Response to Forage Fish Depletion – One-Third for the Birds**. Science (334)6063 1703-1706.
   Available at: https://alaska.usgs.gov/products/pubs/2011/2011-1865.pdf

A global synthesis including Pacific Ocean forage fish: *"Using a comprehensive global database, we quantified the effect of fluctuations in food abundance on seabird breeding success. We identified a threshold in prey (fish and krill, termed "forage fish") abundance below which seabirds experience consistently reduced and more variable productivity. This response was common to all seven ecosystems and 14 bird species examined within the Atlantic, Pacific, and Southern Oceans."*

4. Smith, A., Brown, C., Bulman, C., Fulton, E., Johnson, P., Kaplan, I., Lozano-Montes, H. et al. 2011. **Impacts of fishing low–trophic level species on marine ecosystems**. Science, 333: 1147–1150,
   Available at:
   https://www.researchgate.net/publication/51510858_Impacts_of_Fishing_Low-Trophic_Level_Species_on_Marine_Ecosystems

A global synthesis including Pacific Ocean forage fish: *"Here, we use a range of ecosystem models to explore the effects of fishing low trophic level species on marine ecosystems, including marine mammals and seabirds, and on other commercially important species. In five well studied ecosystems, we find that fishing these species at conventional maximum sustainable yield (MSY) levels can have large impacts on other parts of the ecosystem, particularly when they constitute a high proportion of the biomass in the ecosystem or are highly connected in the food web."*

5. Bertrand et al. 2012. **Local depletion by a fishery can affect seabird foraging**. Journal of Applied Ecology 49:1168-1177. Available at: http://onlinelibrary.wiley.com/doi/10.1111/j.1365-2664.2012.02190.x/abstract

Reviewing South Pacific seabird foraging and Peruvian anchovy fisheries… "*We show that the foraging efficiency of breeding seabirds may be significantly affected by not only the global quantity, but also the temporal and spatial patterns of fishery removals.*"

IV. Recent science documenting that increasing fishing harvest rates impacts forage fish populations

1. Essington et al. 2015. **Fishing amplifies forage fish population collapses**, PNAS Early Edition, Available at: http://www.pnas.org/content/early/2015/04/01/1422020112.full.pdf

A global synthesis including Pacific Ocean forage fish: *"Forage fish population collapses shared a set of common and unique characteristics: high fishing pressure for several years before collapse, a sharp drop in natural population productivity, and a lagged response to reduce fishing pressure. Lagged response to natural productivity declines can sharply amplify the magnitude of naturally occurring population fluctuations. Finally, we show that the magnitude and frequency of collapses are greater than expected from natural productivity characteristics and therefore, likely attributed to fishing."*

2. Lindegren, M., Checkley, D., Rouyer, T., MacCall, A.D., and Stenseth, N.C. 2013. **Climate, fishing, and fluctuations of sardine and anchovy in the California Current.** Proceedings of the National Academy of Sciences 110(33):13672-13677. Available at: http://www.pnas.org/content/110/33/13672.full.pdf

An analysis of long-term Pacific sardine dynamics and the role of fishing during the sardine collapse in the 1950s. The authors found that sardine fishing during natural declines makes collapse more severe and delays future recovery. With respect to sardine fishing, "…*reducing exploitation would markedly affect the rate of decline (i.e., delay the stock collapse and accelerate its subsequent recovery).*"

3. Pinsky, M.L. & Byler, D. 2015. **Fishing, fast growth and climate variability increase the risk of collapse.** Proceedings of the Royal Society B 282:20151053. Available at: http://rspb.royalsocietypublishing.org/content/royprsb/282/1813/20151053.full.pdf

"Fast-growing populations and those in variable environments were especially sensitive to overfishing, and the risk of collapse was more than tripled for fast-growing when compared with slow-growing species that experienced overfishing. We found little evidence that, in the absence of overfishing, climate variability or fast growth rates alone drove population collapse over the last six decades. Expanding efforts to rapidly adjust harvest pressure to account for climate-driven lows in productivity could help to avoid future collapses, particularly among fast-growing species."

V. Recommendations for management

Several of the above referenced papers (Zwolinski & Demer 2012; Cury et al. 2011; Smith et al. 2011; Essington et al. 2015; Pinsky & Byler 2015) contain management recommendations for fisheries targeting fast-growing forage species, in particular the need to reduce fishing rates during natural stock declines or periods of low productivity. The Lenfest Forage Fish Task Force provides a comprehensive suite of management recommendations based on the level of scientific information available.

1. Lenfest Forage Fish Task Force. Pikitch et al. 2012. **Little Fish, Big Impact: Managing a Crucial Link in Ocean Food Webs**. Lenfest Ocean Program. Washington, DC. Summary. Available at: http://www.lenfestocean.org/~/media/legacy/lenfest/pdfs/online_fftf_summary.pdf?la=en

"Fisheries managers need to pay more careful attention to the special vulnerabilities of forage fish and the cascading effects of forage fishing on predators, according to the April 2012 report Little Fish, Big Impact. The report is from the Lenfest Forage Fish Task Force, a group of 13 preeminent scientists formed to provide practical advice on sustainable management."