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Best practices for assessing forage fish fisheries-seabird resource competition

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ABSTRACT

Worldwide, in recent years capture fisheries targeting lower-trophic level forage fish and euphausiid crustaceans have been substantial (~20 million metric tons [MT] annually). Landings of forage species are projected to increase in the future, and this harvest may affect marine ecosystems and predator-prey interactions by removal or redistribution of biomass central to pelagic food webs. In particular, fisheries targeting forage fish and euphausiids may be in competition with seabirds, likely the most sensitive of marine vertebrates given limitations in their foraging abilities (ambit and gape size) and high metabolic rate, for food resources. Lately, apparent competition between fisheries and seabirds has led to numerous high-profile conflicts over interpretations, as well as the approaches that could and should be used to assess the magnitude and consequences of fisheries-seabird resource competition. In this paper, we review the methods used to date to study fisheries competition with seabirds, and present "best practices" for future resource competition assessments. Documenting current fisheries competition with seabirds generally involves addressing two major issues: 1) are fisheries causing localized prey depletion that is sufficient to affect the birds? (i.e., are fisheries limiting food resources?), and 2) how are fisheries-induced changes to forage stocks affecting seabird populations given the associated functional or numerical response relationships? Previous studies have been hampered by mismatches in the scale of fisheries, fish, and seabird data, and a lack of causal understanding due to confounding by climatic and other

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ecosystem factors (e.g., removal of predatory fish). Best practices for fisheries-seabird competition research should include i) clear articulation of hypotheses, ii) data collection (or summation) of fisheries, fish, and seabirds on matched spatio-temporal scales, and iii) integration of observational and experimental (including numerical simulation) approaches to establish connections and causality between fisheries and seabirds. As no single technique can provide all the answers to this vexing issue, an integrated approach is most promising to obtain robust scientific results and in turn the sustainability of forage fish fisheries from an ecosystem perspective.

1. Introduction

Industrial fisheries for forage fish, and to a lesser extent euphausiid crustaceans, have recently increased to meet growing demands for fish meal and nutritional sources for humans (Alder et al., 2008; Tacon and Metian, 2009; Nicol et al., 2012). Landings of forage fish and euphausiids, combined, have averaged ~20 million metric tons (MT) annually since the mid-1990s (Smith et al., 2011); forage fish stocks in this estimate include herring (*Clupea* spp.), sardines (*Sardinops* spp.), anchovies (Engraulidae), capelin (*Mallotus villosus*), sandeels (Ammodytidae), and sauries (Scomberesocidae) (Table 1). Seabirds, marine mammals, and large predatory fish also rely on these forage stocks for sustenance (Cury et al., 2000), and therefore may be in direct competition with fisheries for food resources (Smith et al., 2011; Pikitch et al., 2014; Rountos et al., 2015). Indeed, apparent competition between fisheries and top marine predators has led to numerous recent high-profile conflicts over interpretations (e.g., Cherry, 2014) and what approaches could and should be used in assessing competition between fisheries and seabirds (Crawford, 2007; Cury et al., 2011), marine mammals (Mangel, 2010; Conn et al., 2014), and marine predators in general (Hilborn et al., 2017).

Concerns about if and how fisheries compete with seabirds, as well as attempts to document and manage this issue, date back to the 1930s. In one of the first comments made about seabird-fisheries competition and how to resolve it, Murphy (1936) proposed that areas closed to fisheries around Peruvian seabird colonies could reduce competition between the humans and seabirds that target anchoveta (*Engraulis ringens*). Schaefer (1970) subsequently estimated that, in the early 1960s, Peru's ~16 million seabirds consumed upwards of 2.5 million MT of anchoveta yearly, and suggested that both the fishery and birds were responsible for annual stock fluctuations. Notably, climatic variations and effects on the fish were not considered by Schaefer at the time, although by the early 1970s, anchoveta stock fluctuations relative to major El Niño events became well known (e.g., Parrish et al., 1983). Subsequently, it was shown that the moderately strong El Niño event of 1972–1973 led to a decline in anchoveta productivity, and that the fishery and seabird population collapses at that time were associated with this climatic event (Pauly and Tsukayama, 1987; Jahncke et al., 2004).

In the United States (U.S.), concern about potential detrimental impacts of fisheries on seabirds also rose in the early 1970s when the California brown pelican (*Pelicanus occidentalis occidentalis*) was listed as endangered. Although the pelican's demise was principally related to egg-shell thinning due to use of organochlorine pesticides (DDT, Anderson et al., 1975), the primary prey of pelicans in California at the time, northern anchovy (*Engraulis mordax*; Szoboszlai et al., 2015), was targeted by fisheries operating in proximity to southern California pelican colonies. This take of prey important for the pelican was thought to decrease nesting success and hamper the recovery of the species (Anderson et al., 1982). Indeed, concerns for the recovery of the pelican resulted in the first inclusion of the food resource needs of a seabird population in a U.S. Fishery Management Plan (FMP and amendment; PFMC/NMFS, 1978, 1983). In brief, the Northern Anchovy FMP control rule included a cutoff parameter, below which directed harvest was not allowed; this cutoff was set at 300,000 MT, and was informed, in part, by the relationship between brown pelican breeding success and regional anchovy abundance (PFMC/NMFS, 1983). This control rule was supported by recreational fishers concerned with game fish in the region that also relied on anchovy for sustenance. More generally, seabird-fisheries competition became a global concern in the 1970s and 1980s. Widespread declines in seabird populations were apparently related to the expansion (and in some cases collapse) of large-scale industrial fisheries for anchovies and sardines, as well as shifts in fisheries from groundfish to small pelagics, such as sandeels, which were important seabird food (Furness, 1978, 1982; Duffy, 1983; MacCall, 1984). The literature on seabird responses to fluctuations in food resources grew substantially at that time and is now diverse and substantial, covering aspects of seabird biology from foraging ecology to population biology (e.g., Cairns, 1987; Piatt et al., 2007). In addition to previous references, early evidence of seabird populations tracking changes in forage fish abundance came from southern Africa (e.g., Furness and Cooper, 1982; Crawford et al., 1983), Peru (e.g., Duffy, 1983), and Norway (e.g., Vader et al., 1990). More often, however, changes in vital rates, as a proxy for population fluctuations, were attributed to changes in prey resource availability (e.g., Anderson et al., 1982 on brown pelicans off southern California; Monaghan et al., 1989 for Arctic terns (*Sterna paradisaea*) in the North Sea). Changes in food resources are hypothesized as the mechanism for large-scale breeding failures of central Pacific seabirds relative to the major climatic events, such as the El Niño event of 1982–1983 (Schreiber and Schreiber, 1984) and even long-term ocean warming (Veit et al., 1996). This voluminous and ever-growing ecological literature stands in stark contrast to a recent paper (Hilborn et al., 2017) in providing robust evidence that seabird populations respond to prey depletion, whether it is due to a fishery or via some other mechanism such as environmental change.

Fisheries targeting forage fish may be detrimental to seabirds by

Table 1
Global landings (metric tons) of forage fish fisheries, 2010–2015, to illustrate the potential for fisheries-seabird resource competition. Data were obtained from the Global Capture Production Database (FAO, 2016).

Species	2010	2011	2012	2013	2014	5-year average
Krill, planktonic crustaceans	215,175	181,010	188,147	239,950	316,408	228,138
Herrings, sardines, anchovies	17,269,000	21,164,496	17,569,534	17,600,048	15,215,458	17,763,707
Atlantic sandeels	423,209	443,604	107,577	284,138	270,401	305,786
Pacific sand lance	237,938	187,559	175,892	161,949	153,433	183,354
Atlantic saury	7,436	5,628	15,329	8,547	1,560	7,700
Pacific saury	432,372	458,954	460,961	428,390	628,569	481,849
Capelin	506,897	853,449	992,491	763,948	282,833	679,924
Total	19,092,027	23,294,700	19,509,931	19,486,970	16,868,819	19,650,489