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Review

Information gaps limit our understanding of seabird bycatch in global fisheries

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ABSTRACT

Seabirds, as foragers in marine waters for at least part of their lifecycle, encounter the global fishing fleet in search of marine resources. While fishing gear is designed to catch fish and invertebrates, it also catches unintended species, including seabirds. We reviewed bycatch incidence for 378 marine and coastal bird species in 18 different gear types, and found that 60% (228 species) have been recorded interacting with at least one type of fishing gear. At least one species from each of the taxonomic groups analyzed (generally at the family level) has been documented interacting with fishing gear. With respect to two measures of degree of interaction, four families have a high degree of documented interaction: Gaviidae (loons or divers), Podicipedidae (grebes), Diomedeidae (albatrosses) and Sulidae (boobies and gannets). Set and drift gillnets (among the most studied gear types), have the greatest number of documented species interactions: 92 and 88 species, respectively. Hook gear (longlines and handlines) have documented interactions with 127 species. Together these four gear types have documented bycatch of 193 species. The waters of the Arctic, the Caribbean, the Guinea and Canary Currents in the Atlantic, the Indian Ocean and Asia have been poorly studied. Particular gear types, including industrially-deployed seines, and the artisanal fisheries sector also constitute significant gaps in our knowledge of seabird bycatch patterns worldwide.

1. Introduction

Seabirds, along with pinnipeds, cetaceans, elasmobranchs, chelonians, and non-target fish and invertebrate species, when caught inadvertently in fishing operations, constitute fishing bycatch. Bycatch may amount to between 8% (Kelleher, 2005) and 40% of global marine fisheries landings (Davies et al., 2009). Although the greatest threats to seabirds are thought to occur at their breeding islands, Croxall et al. (2012) indicate bycatch is a top threat facing seabirds.

All seabirds share several characteristics which render them vulnerable to anthropogenic threats. Among comparably speciose groups, they are the most threatened (Croxall et al., 2012): 29% of seabird species are listed by the International Union for Conservation of Nature (IUCN) as Critically Endangered, Endangered or Vulnerable (Croxall et al., 2012, Spatz et al., 2014). Demographically, most species are long lived animals with long generation times. Geographically speaking, many species rely on a limited breeding range yet travel widely over large expanses of ocean outside of the breeding season. This combination renders the group vulnerable to both specific events and threats on their breeding grounds, as well as a wide range of threats as they travel throughout their global range. Croxall et al. (2012) and Paleczny et al. (2015) note that pelagic species are considerably more threatened than coastal species.

Seabirds are a polyphyletic group which depend on the marine environment for all or part of their life cycle. Some species depend entirely on marine resources to feed themselves and their offspring (the vast majority of the Procellariidae, for example), while others only rely on marine resources during the non-breeding season (e.g., loons/divers *Gavia spp.*). Still others exhibit a remarkable plasticity for both terrestrial and marine resources year-round (e.g. brown-hooded gull (*Chroicocephalus maculipennis*). All species are tied to land for at least a short period during their life (and usually annual cycle) in which they lay eggs and raise chicks. This may be as short as 2 months in some high Arctic nesting species [e.g., Ross's gull (*Rhodostethia rosea*) or as long as 13 months [wandering albatross (*Diomedea exulans*)].

Despite their diverse and highly variable life-histories, geographic distributions, and foraging ecologies, seabirds now encounter a diversity of gears and intensity of fishing unprecedented in human history. Humans, in their own quest for marine food resources to feed their burgeoning population, have developed a huge range of equipment to ensnare, hook, scoop up, and entangle a large variety of fish and

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invertebrates. While fishing is an ancient human activity, the materials and methods as well as geographic scope and scale of the present-day fishing industry place it squarely within the Anthropocene (Pauly et al., 2005, Steffen et al., 2007). Fossil fuels have enabled access to new regions and depths, and longer storage times (Pauly et al., 2002, 2005, Swartz et al., 2010a). Fishing intensity has increased (Swartz et al., 2010a). Newer gear materials (particularly synthetic fibers) do not decay in the marine environment and continue to capture target and non-target animals even once the gear has been lost – known as "ghost-fishing" (Macfadyen et al., 2009). High technology devices such as echo sounders, sonar, spotter planes, and radio and GPS enabled FADs (fish aggregating devices; Itano et al., 2004) are now employed to locate and capture seafood to meet the global demand for human consumption, forage fish (bait or fish meal for feeding to livestock or farmed fish) and fish oils (Pitcher, 2001, Valdemarsen, 2001, FAO, 2016). Global marine landings amounted to around 80 million tonnes landed annually between 2009 and 2014. Approximately 87% of all fisheries production (including aquaculture and inland fisheries) went to direct human consumption and it accounted for 17% of animal protein consumed in 2013, for example (FAO, 2016). These landing values, however, are likely highly underestimated (Pauly and Zeller, 2016).

Seabirds inevitably encounter vessels or equipment engaged in fishing. Unsurprisingly, productive waters that attract seabirds for foraging are also targeted by global fishing fleets (Karpouzi et al., 2007). The threats facing seabirds at sea might seem distant from the plates of diners, yet consumers of seafood worldwide are unwitting participants in a system that kills thousands of seabirds every year. Žydelis et al. (2013) (gillnets) and Anderson et al. (2011) (longlines) have estimated that each of these gears kills hundreds of thousands of seabirds annually. Fishers suffer as well: the economic losses incurred by fishing communities resulting from bycatch, although poorly quantified, include: damaged equipment, wasted fuel, bait loss, reduced target catch, loss of juvenile fishery resources, and the opportunity cost of the time needed to process and discard unwanted organisms (Gandini and Frere, 2012).

Several previous reviews have sounded the alarm about the magnitude and specifics of the seabird bycatch problem (Brothers et al., 1999, Lewison et al., 2005), informed policy (Northridge, 1991) and practice (Løkkeborg, 2011), and illuminated knowledge gaps (Anderson et al., 2011). These reviews, however, have been limited in scope: by gear type (Anderson et al., 2011, Brothers et al., 1999, Waugh et al., 2012) or geographic area (Robertson et al., 2003, Waugh et al., 2012). Our goal was to synthesize the available information on a global scale and across gear types. We present this information relative to taxonomic grouping, fishing gear type, and geographic region, to identify and highlight potential information gaps.

This analysis was made possible by the development of a database that responds to the needs of fisheries managers assessing seabird bycatch risk in fisheries across a range of gear types and around the world. This database is the backbone of the Seabird Maps and Information for Fisheries (SMIF) tool (www.fisheryandseabird.info). The tool accepts spatial queries, and based on species range maps, returns a set of species expected within the geographic area of interest. Each species has a standardized profile which includes basic ecology, life history information and documented interactions with fisheries gear. In the process of assembling the database, we created a synthesis of seabird bycatch references. This shows where information exists—what gear types have bycatch information and which do not— and geographically where bycatch studies have been carried out and where they have not. The gaps identified by our synthesis contextualize the available literature and can guide further research by indicating regions or fisheries lacking information and which gear types have been overlooked as sources of seabird bycatch.

The present analysis makes no attempt to quantify the magnitude of bycatch impacts, but uses a binary approach. The analyses of others (Dillingham and Fletcher, 2011, Veran et al., 2007, Rolland et al., 2010, Francis and Sagar, 2012, Oppel et al., 2011), however, have demonstrated that these impacts can have demographic level impacts which threaten the existence of some species.

2. Methods

2.1. Species list development

Our list of seabirds differs slightly from that of previous authors (Croxall et al., 2012, Žydelis et al., 2013, Spatz et al., 2014) in including approximately 35 additional species. This is a result of taxonomic updates [particularly within the Imperial shag (*Phalacrocorax atriceps)* and Audubon's shearwater (*Puffinus lherminieri)* complexes], newly discovered or re-discovered species [New Zealand storm petrel (*Fregetta maoriana)*, Pincoya storm petrel (*Oceanites pincoyae)*, Bannerman's shearwater (*Puffinus bannermani)* and Bryan's shearwater (*Puffinus bryani*)], and a slightly wider definition that includes species which could be considered marginally marine [e.g., American white pelican (*Pelecanus erythrorhynchos)*, White-winged tern (*Chlidonias leucopterus)*, and bufflehead (*Bucephala albeola*)].

We produced our list of seabirds by extracting all species in the Alcidae, Anatidae, Chionidae, Diomedeidae, Fregatidae, Gaviidae, Hydrobatidae, Laridae, Pelecanidae, Pelecanoididae, Phalacrocoracidae, Podicipedidae, Procellariidae, Spheniscidae, Stercorariidae, Sulidae, and two members of the genus *Phalaropus* (Scolopacidae) from the taxonomy accepted by the International Ornithologists' Union (IOU) (version 3.5). This yielded 555 species. By using BirdLife International's definition of "seabird," we extracted 351 species from this list. Four subspecies not recognized at the species level by the IOU were eliminated. All species new to science, as well as sister and daughter taxa of species present in the BirdLife stratification of the IOU list were included [e.g., the members of the former Audubon's shearwater (*Puffinus lherminieri*)]. This yielded a total of 371 species. Six extinct species were eliminated from the list. As research progressed, a further 13 species were added once it became clear that these additional species use the marine environment for a significant portion of the year and/or have been documented in marine fishing gear. This resulted in a final total of 378 species of seabird for which profiles were developed (see Tables A1 and A2 of *Online Appendix*).

We collected basic information on population status, foraging ecology, phenology, and ship-following behavior. For population status, we relied primarily on 2015 IUCN evaluations. Some species (11) accepted by the IOU are not recognized by BirdLife International, and not evaluated by the IUCN as to Red List status (particularly the Southern Ocean's Imperial shag complex (*Phalacrocorax atriceps)*, treated here as several species in the genus *Leucocarbo*).

2.2. Gear interaction definition

Gear interactions were gleaned from literature searches for each species by using the scientific name in conjunction with the terms ***bycatch*** and ***fishery***. Note that modern search engines treat the search terms ***bycatch*** and ***by-catch*** equally. For newly split species, the parent/sister or older species name was also used. Further search terms were pursued if those two terms did not yield useful results. These auxiliary search terms included ***mortality*** and/or were informed by knowledge of related taxa or other leads from the literature such as: specific gear types (e.g. ***hook*** or ***driftnet***) or specific places or countries, particularly in the case of leads from Robertson et al. (2003). Sources used were primarily in English or other Romance languages (French, Spanish, Portuguese, and Italian), but did include a few documents translated from the Russian and Japanese originals.

A species having any sort of known capture or entanglement in fishing gear, whether active or derelict, is considered to have a documented gear interaction. Here we defined a "gear interaction" as any incidence in which a seabird has been captured or comes into contact with fishing gear: this does not necessarily imply mortality.