GARRETT MAHALA
EDITOR

# Seabirds and Songbirds

## HABITAT PREFERENCES, CONSERVATION AND MIGRATORY BEHAVIOR

BIRDS - EVOLUTION, BEHAVIOR AND ECOLOGY

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# CONTENTS

# PREFACE

Humans have altered and created entirely new environments to which animals have either adapted or been extirpated. Urban environments are one of the most extreme examples of how humans have changed previous habitats. Urban environments present massive challenges for birds living in these spaces and the impacts can be seen on all aspects of their behavior including how they communicate with one another. This book discusses how seabirds and songbirds have adapted for life in urban areas, how it has impacted their migratory behavior, and also examines the ecology and conservation of these two species.

Chapter 1 - Worldwide, bird migration plays a definitive role in the wide dispersal of bird-transported ticks. As spring unfolds in the Northern Hemisphere, wild migratory birds move northward en route to the boreal forest spanning central and eastern Canada, and become parasitized by bird-feeding ticks when they make landfall at tick endemic areas. Their bird-tick studies reveal engorged Neotropical ticks, which are indigenous to Central America and the northern region of South America, on migratory flycatchers, thrushes, and warblers. With their versatile mobility and vast distribution, migratory birds can act as maintenance hosts for the wide dispersal of pathogenic microbes. Certain passerines, such as the American Robin, *Turdus migratorius* L., can act as reservoir hosts of the Lyme disease bacterium, *B. burgdorferi* sensu lato (s.l.), and help to perpetuate spirochetal infection within a tick population. These hematophagous ectoparasites can transmit infectious microorganisms (i.e., bacteria, piroplasms, viruses) to avian hosts and, subsequently, after bird parasitism, can transmit these pathogenic microbes to vertebrate hosts, including humans. Ticks may simultaneously be co-infected with one or more pathogens that can have a broad diversity of genotypes. When birds become heavily infested with ticks, these avian hosts have the capacity to initiate a new population of ticks. Within an ecosystem, songbirds may be involved in a multi-tick enzootic cycle consisting of several tick species. Within one West Coast bioregion, the authors show that songbirds amplify *B. burgdorferi* s.l. in a 5-tick enzootic cycle. One heavily infested Fox Sparrow, *Passerella iliaca* (Merrem), in this Pacific Northwest locality was parasitized by avian coastal ticks, *Ixodes auritulus* Neumann, and had a *B. burgdorferi* s.l. infection rate of 81%. Canada-wide the authors have discovered *B. burgdorferi* s.l. in six different *Ixodes* species of ticks collected from passerine birds. Since wild birds widely disseminate *B. burgdorferi* s.l.-infected ticks, people do not have to frequent an endemic area to contract Lyme disease.

Chapter 2 - Seabirds can serve as fundamentally important components of biodiversity of insular ecosystems, playing an important role as vectors of marine-derived nutrients, increasing primary production which in turn is transferred through the food web, and influencing the numbers and types of primary and secondary consumers. The status and trends of seabirds can be an excellent indicator of the impacts of human activities on their populations and communities. These impacts include loss of breeding sites through trampling and grazing by introduced domesticated animals; mortality by introduced mammalian predators such as rats, dogs and cats; egg and chick harvest; and interactions with local and regional fisheries. These impacts have occurred on most human-inhabited islands, ranging from the tropics to the sub-polar regions. Until the 1990s, the general state of knowledge about seabirds of oceanic islands in Chile was poor, since virtually no basic ecological information such as population size, breeding biology or the extent of conservation problems had been compiled for many species.

Human communities of oceanic and coastal insular systems in Chile currently possess only a small percentage of people who retain local traditional ecological knowledge, as a result of the recent influx of immigrants during the second half of the 20th century and the progressive decline of the ancestral native population. The relationship of recently arrived human communities with the biodiversity of the insular systems has been restricted to the use and exploitation of resources to satisfy basic needs for the human population (e.g. heating, food). Many of these activities have a negative impact on the biodiversity of the island, including seabirds. As a resource, seabirds were usually ignored by island communities because they did not provide any immediate benefit. In the 1990s, initiatives of national and foreign researchers began in different islands of Chile to elucidate basic aspects of the ecology and conservation status of several seabird species. The information generated was shared with the island communities associated with these seabird species in order to increase awareness and build support for conservation actions. This community engagement was undertaken based on the understanding that island communities, especially isolated ones, have particular characteristics that distinguish them from the inhabitants of the continent. These include a strong sense of belonging to the place, a heightened sense of community among residents, a detachment from the nearby continental areas, and a sense of not belonging to the central government that manages the island.

Here the authors document community engagement experiences and results on five significant Chilean seabird islands distributed in a wide latitudinal range: (1) Robinson Crusoe, Santa Clara and Alejandro Selkirk islands (the Juan Fernández Archipelago) (34° S), inhabited by six species of procellarids (Pink-footed Shearwater *Puffinus creatopus*, Kermadec Petrel *Pterodroma neglecta*, De Filippi’s Petrel *Pterodroma defilippiana*, White-bellied Storm-Petrel *Fregetta grallaria*, Juan Fernández Petrel *Pterodroma externa* and Stejneger´s Petrel *Pterodroma longirostris*); (2)Mocha Island (38° S) where the Pink-footed Shearwater *Puffinus creatopus* breeds; (3) Puñihuil Island, Chiloé (42° S) with a mixed-colony of Humboldt (*Spheniscus humboldtii*) and Magellanic (*Spheniscus magellanicus*) penguins; (4) Guafo Island, Quellón town (44°S) with the largest colony of Sooty Shearwater *Puffinus griseus* in the world; and (5) Navarino Island (55°S), Cape Horn Biosphere Reserve, that is inhabited by rich ensembles of seabirds and shorebirds, including cormorants, plovers, sandpipers, steamer-ducks and geese. On all of these islands, islanders have participated in initiatives that support the conservation of resident seabird species, including the cessation of chick and egg harvests, development of special interest tourism around birds, removal of introduced animals and responsible pet ownership, and as a general rule, inclusion of birds as co-inhabitants of the community.

Chapter 3 - Interactions between pelagic seabirds (albatrosses and petrels, Procellariiformes) and fisheries occur in all oceans of the globe, virtually in all fisheries, and are dominated by the effect of fishing on birds. Despite the fact that provisioning of fishery discards and offal to birds can be viewed as beneficial, incidental mortality in fisheries is by far the main at-sea threat albatrosses and petrels are facing nowadays, and certainly the main cause of declinations in populations recorded in modern days. This chapter offers an overview of interactions between pelagic seabirds and high-seas Argentine fishing fleets, including longliners, trawlers and jiggers. The first section of this review looks into the nature of interactions between seabirds and fisheries, particularly in the Southwest Atlantic Ocean. The second section seeks to define the fishing effort of the different fleets operating in national waters providing a summary of extant fishery regulations and management measures related to the main target species, the Argentine hake *Merluccius hubbsi*. The third section explores available information regarding conservation status and use of marine space by seabirds attending and interacting with a number of high-seas fisheries, including bycatch levels and mitigation measures, as well as issues dealing with the implementation and compliance of conservation and management measures. The fourth section provides insight into the use of fishery discards and offal by non-breeding pelagic seabirds attending vessels, taking the Black-browed Albatross *Thalassarche melanophris* as a case study. Finally, the fifth section reviews the up-to-date scientific, legal, and political actions taken to protect seabirds in Argentine waters, referring to possible steps for implementing an ecosystem approach to national fisheries within the frame of Argentina's National Plan of Action – Seabirds.

Chapter 4 - The importance of ocean pollution, including pollution from plastics, has been recognized for a long time. However, the current generation and disposal of plastic worldwide has no precedent. Plastic litter accounts for 50-80% of waste items stranded on beaches, floating on the ocean surface and lodged in the seabed. Floating plastic debris is usually ingested by marine animals by mistake, or because it resembles their natural food. This plastic intake by animals such as seabirds can produce entanglement, intoxication, internal wounds, digestive tract blockage and ulcers among other conditions. While these damages are important, further concerns have arisen about plastics sorbing potentially hazardous hydrophobic chemicals. These compounds found in the waters where plastics are, can be plastic additives from other degrading plastics such polychlorinated biphenyls (PCBs) or chemicals from other sources like persistant organic pesticides (POPs), both with the capacity of being sorbed by plastics. However, the importance of the ingestion of plastic-derived chemicals present in the natural prey of seabirds through biomagnification, compared with the amount of these chemicals intake via plastic debris is still being studied. The finding of PCBs and POPs in the ingested plastic pellets and plastic fragments, have led to additional research aimed at assessing the relative potential of plastic as a vector of pollutants transport. The results of these studies are until now contradictory, largely because the role of the dilution and cleaning mechanisms of the studied chemicals are under debate. The impact of plastic debris on individuals is well known although it is not entirely clear how plastic ingestion at the individual level could impact the whole population and how this will impact entire ecosystems. For example, one strategy to mitigate damage caused by ingested plastics is to regurgitate them, so the transference of these plastics to chicks is not uncommon while being fed. As most chicks are unable to regurgitate plastic fragments, these accumulate in their stomachs eventually causing death. At present, the implications of chemicals sorbing on the population size of seabirds is unknown. The effectiveness of using seabirds as monitors has increased considerably in recent years. Sampling the stomach contents of beached birds, birds killed accidentally by fishing activities or by examining regurgitated pellets of predators that feed on seabirds can be useful as well. Nonetheless, there are still questions to answer before the authors can confidently assess the impact of plastic waste on the environment through seabirds. For example: Is there a linear relationship between pollutants sorbed and the surrounding plastic debris? Or do birds reach a point where they become saturated by these chemicals independently of their plastic ingestion? Throughout this chapter the authors will evaluate the progress made to answer the open questions about the impact of plastic debris on seabirds and discuss the future of seabirds as a group and their use as monitors of plastic pollution to evaluate the health of ecosystems.

Chapter 5 - Recently, humans have altered and created entirely new environments to which animals have either adapted or been extirpated. Urban environments are one of the most extreme examples of how humans have changed previous habitats. Urban environments present massive challenges for birds living in these spaces and the impacts can be seen on all aspects of their behavior including how they communicate with one another. Here, I review how birds, have adapted their singing behavior for life in urban areas. First, I examine how birds’ diets in urban areas differ from their diets in other environments and the implications of these differences for birds’ song quality and production. I also briefly examine some of the effects that urban environments have on the ecology of avian species, which can affect avian singing behavior. I will then review some of the differences between urban and other environments and relate these differences to the birds’ singing behavior. Finally, I conclude that urban environments can dramatically affect avian ecology and communication and I suggest that this may ultimately affect evolution in urban bird populations.

Chapter 6 - Socotra Cormorants (*Phalacrocorax nigrogularis*) are regionally endemic, vulnerable seabirds limited to the Arabian Gulf and Sea of Oman regions. Global populations have undergone catastrophic declines, with several major colonies gone completely extinct in the central western Arabian Gulf. Major threats include breeding habitat loss due to oil exploitation, disturbance at breeding colonies, fisheries by catch and occasional hunting. Six of 12 large colonies have become extinct in the United Arab Emirates. Colonies in the western Gulf seemingly have suffered considerably, with much lower numbers compared to historic records. In comparison, the single colony on Siniya Island, Umm Al Quwain, in the eastern Arabian Gulf is arguably the largest in the UAE and possibly the entire Gulf with an increasing population of about 35,000 breeding pairs. Breeding studies indicate variable reproductive success possibly linked with habitat features, weather, diet and impact of predators. Planted trees on the island provide protection from soaring temperatures early in the breeding season and improve breeding performance. The island hosts native Red Foxes (*Vulpes vulpes*) and feral cats (*Felis catus*) that have a negative impact on the breeding performance. Additionally, ample evidence exists of conflict with fishermen. Many birds die annually to fishermen’s nets or lines and fishermen generally perceive them to be competitors. Diet studies indicate that fish taken by cormorants have almost no overlap with commercially important species. The island is subjected to periodic disturbance by fishermen collecting sea grass from lagoons. Additionally, the island is littered with a wide range of plastic and other debris. Current trends in the population could be offset if any or all of the threats continue to increase. Conservation and management of this population must focus on removing plastics, eliminating disturbance during breeding seasons, engaging local fishermen to reduce by-catch mortality, protecting coastal areas to safeguard foraging sites, and creating awareness.

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*Chapter 1*

# BIRDS WIDELY DISPERSE PATHOGEN-INFECTED TICKS

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## ABSTRACT

Worldwide, bird migration plays a definitive role in the wide dispersal of bird-transported ticks. As spring unfolds in the Northern Hemisphere, wild migratory birds move northward en route to the boreal forest spanning central and eastern Canada, and become parasitized by bird-feeding ticks when they make landfall at tick endemic areas. Our bird-tick studies reveal engorged Neotropical ticks, which are indigenous to Central America and the northern region of South America, on migratory flycatchers, thrushes, and warblers. With their versatile mobility and vast distribution, migratory birds can act as maintenance hosts for the wide dispersal of pathogenic microbes. Certain passerines, such as the American Robin, *Turdus migratorius* L., can act as reservoir hosts of the Lyme disease bacterium, *B. burgdorferi* sensu lato (s.l.), and help to perpetuate spirochetal infection within a tick population. These hematophagous ectoparasites can transmit infectious microorganisms (i.e., bacteria, piroplasms, viruses) to avian hosts and, subsequently, after bird parasitism, can transmit these pathogenic microbes to vertebrate hosts, including humans. Ticks may simultaneously be co-infected with one or more pathogens that can have a broad diversity of genotypes. When birds become heavily infested with ticks, these avian hosts have the capacity to initiate a new population of ticks. Within an ecosystem, songbirds may be involved in a multi-tick enzootic cycle consisting of several tick species. Within one West Coast bioregion, we show that songbirds amplify *B. burgdorferi* s.l. in a 5-tick enzootic cycle. One heavily infested Fox Sparrow, *Passerella iliaca* (Merrem), in this Pacific Northwest locality was parasitized by avian coastal ticks, *Ixodes auritulus* Neumann, and had a *B. burgdorferi* s.l. infection rate of 81%. Canada-wide we have discovered *B. burgdorferi* s.l. in six different *Ixodes* species of ticks collected from passerine birds. Since wild birds widely disseminate *B. burgdorferi* s.l.-infected ticks, people do not have to frequent an endemic area to contract Lyme disease.

## TICKS PARASITIZE WILD BIRDS

Several bird species play a vital role in the wide dispersal of ticks. Worldwide, hard-bodied ticks (Ixodida: Ixodidae) parasitize wild birds, and some of these hematophagous ecoparasites are reservoirs of zoonotic pathogens. Wild birds are normally parasitized by bird-feeding ticks that are questing in low-level vegetation. Passerines, commonly called songbirds, are responsible for wide dispersal of ticks during short- and long-distance flight, especially during spring and fall migration. The main influx of ticks in Canada occurs when migratory passerines make landfall at tick endemic areas throughout the United States of America and, likewise, along the southern fringe of Canada. Subsequently, migratory passerines disperse fully engorged ticks haphazardly across Canada en route to the boreal forest.

The earliest bird-tick studies in Canada were conducted by John D. Gregson [1]. He identified blood-sucking ticks from seven orders of wild birds, namely webbed swimmers (Pelicaniformes); seabirds, shorebirds (Charadriiformes); falcons (Falconiformes); pheasants, chicken-like birds (Galliformes); true owls (Strigiformes); woodpeckers (Piciformes); and perching birds (Passeriformes). Country-wide, he identified nine different tick species detached from wild birds. As well, seabird ticks, *Ixodes uriae* White on King Penguins, *Aptenodytes patagonicus* Miller (Order: Spenisciformes), which breed in the subantartic islands, greatly expands the biogeographical range of ticks on Aves.

In addition, Anderson and Magnarelli [2] reported the European sheep tick, *Ixodes ricinius* (L.), and the taiga tick, *Ixodes persulcatus* (Schulze), in Eurasia on avian hosts, including birds of prey (Accipitriformes), waterfowl (Anseriformes), pigeons, doves (Columbiformes), near passerines (Cuculiformes), cormorants (Suliformes), diving birds, grebes (Podicipedidae), and rails (Gruiformes).

Our bird-parasite studies have focused extensively on ticks and Lyme disease across Canada. The main source of ticks for our tick-host studies has been bird banders, wildlife rehabilitators, and veterinarians. Overall, bird-transported ticks can harbour a myriad of pathogenic microbiota, including the etiological contagion of Lyme disease.

The Lyme disease spirochete, *Borrelia burgdorferi* sensu lato (s.l.) Johnson, Schmid, Hyde, Steigerwalt and Brenner is heterogenous [3], and consists of at least 21 genospecies worldwide. Several of these genospecies, including *B. afzelii*, *B. andersonii*, *B. americana*, *B. bissettii*, *B. burgdorferi* sensu stricto (s.s.), *B. lusitaniae*, and *B. valaisiana*, are known to be pathogenic to humans [4]. Not only is *B. burgdorferi* s.l. present in bird-feeding ticks, it is harboured in the blood and tissues of certain wild birds [5, 6]. Globally, Lyme disease has been detected in over 80 countries.

In North America, the blacklegged tick, *Ixodes scapularis* Say, is the primary vector of Lyme disease east of the Rocky Mountains and, likewise, along the West Coast, the western blacklegged tick, *Ixodes pacificus* Cooley and Kohls, transmits *B. burgdorferi* s.l., to avian and mammalian hosts. Bird-feeding ticks can carry a wide array of microbial pathogens, including bacteria, piroplasms, and viruses [7]. In particular, *I. scapularis* is known to carry bacterial, protozoan, and viral pathogens, namely *Anaplasma phagocytophilum* (human granulocytic anaplasmosis), *Babesia* spp. (e.g., *B. microti*, *B. odocoilei*) (babesiosis), *Bartonella* spp. (e.g., *B. henselae* bacteria), *B. burgdorferi* s.l. (Lyme disease), *Borrelia miyamotoi* (relapsing fever group spirochete), deer tick virus (Powassan virus group), *Ehrlichia phagocytophila* (granulocytic ehrlichiosis [*E. equi*]), and *Mycoplasma* spp. (e.g., *M. fermentans* [cat scratch disease]). Notably, several different pathogens have been documented in a single tick, and triple coinfections have been detected in *I. scapularis* from vertebrate hosts, including passerines [8-10]. In Eurasia, Russian-based researchers documented multiple pathogens in a single bird-transported *I. ricinus* tick [11]. Overall, many different genospecies and genotypes of *B. burgdorferi* s.l. have been detected in songbird-transported ticks and their avian hosts [12].

## MIGRATORY SONGBIRDS TRANSPORT TICKS

Historically, Harry Hoogstraal, pioneer tick researcher, provided the earliest report of ticks on wild birds that were migrating northward through Egypt to Asia and Europe [13]. These bird-carried ticks included *Ixodes frontalis* (Panzer), *Haemaphysalis punctata* Canestrini and Fanzago, *Haemaphysalis sulcata* Canestrini and Fanzago, *Hyalomma aegyptium* L. and *H. marginatum* Koch. The latter 2 tick species are epidemiologically or experimentally associated with Crimean hemorrhagic fever, Q-fever, tularaemia, tick typhus and brucellosis. Of note, these ticks were observed far from their normal geographic range. Researchers subsequently reported migratory birds flying in reverse direction from Europe and Asia to Africa via Sudan and Egypt [14]. Although microbial infection was not reported, they noted that certain tick species have the potential to carry several Eurasian-based human pathogens.

Collectively, during our pan-Canadian tick studies (1996-2014), we have documented 22 species of ixodid ticks belonging to 3 genera (*Amblyomma*, *Haemaphysalis*, *Ixodes*) on wild birds (Table 1). These bird-transported ticks represent four avian orders: seabirds (Charadriiformes); falcons (Falconiformes); chicken-like birds (Galliformes); and perching birds (Passeriformes).

**Table 1. Ixodid tick species collected from wild birds across Canada, 1996-2014**

| *Amblyomma* | *Haemaphysalis* | *Ixodes* |
|---|---|---|
| *A. americanum* | *H. leporispalustris* | *I. affinis* |
| *A. humerale* | | *I. baergi* |
| *A. imitator* | | *I. brunneus* |
| *A. longirostre* | | *I. dentatus* |
| *A. maculatum* | | *I. minor* |
| *A. rotundatum* | | *I. muris* |
| *A. sabanerae* | | *I. pacificus* |
| | | *I. scapularis* |
| | | *I. spinipalis* |
| | | *I. uriae* |
| | | *I.* species A† |
| | | *I.* species B† |
| | | *I.* species C† |

† undescribed ticks collected from Neotropical passerines during northward spring migration.

Since we know the indigenous areas of many of the ticks on Neotropical passerines, we extrapolate that these ticks have been carried from their native land in South and Central America during spring migration. Based on the known areas of Neotropical ticks collected from passerine migrants, we posit transcontinental and intercontinental transport of ticks. Epidemiologically, migratory passerines and raptors have the capacity to quickly fly great distances during migration, and play a pivotal role in transporting bird-feeding ticks thousands of kilometres. Inevitably, wild birds can easily disperse ticks over notable distances because they move much faster than terrestrial wingless hosts.

In North America, there are 3 major flyways (Atlantic, Mississippi, Pacific) that transect the continent in a north-south direction. Several North American researchers have documented short- and long-distance movement of ixodid ticks consisting of 4 genera: *Amblyomma*, *Dermacentor*, *Haemaphysalis*, *Ixodes*, especially during spring migration [15-18]. In Canada, tick researchers have documented *B. burgdorferi* s.l.-infected *I. scapularis* immatures (larvae, nymphs) on migratory passerines [19-23], and millions of these ticks are widely dispersed coast to coast during spring migration. Recently, Scott and Durden identified a songbird-transport tick, *Ixodes minor* Neumann that was collected from a Common Yellowthroat, *Geothlypis trichas* (L.) in Toronto, Canada during northward spring migration [24]; this extralimital tick is the northernmost documentation of this neotropical tick species in North America, and points out the potential for passerines to carry ticks long distances.

During fall migration, bird-tick researchers studied ticks on songbirds in the upper Midwest [25], and found migrants were carrying ticks southward. Some of the ticks were infected with *B. burgdorferi* s.l. As well, Durden et al. [26] documented *Ixodes* and *Amblyomma* ticks during fall migration infected with *B. burgdorferi* s.l., and determined that songbirds act as southward-shifting disseminators of borreliae.

Certain migratory birds are noted for transcontinental and transoceanic travel and, at the same time, can transport ticks [27]. Many seabirds and shore birds are highly mobile and undertake long, complex flight paths of thousands of kilometres. Some of these birds breed in the subantarctic islands, and make transequatorial migration to the northern parts of the Atlantic and Pacific oceans. Seabirds carry the seabird tick, *Ixodes uriae* White, which has been collected from both the Southern and Northern Hemispheres, infected with *B. burgdorferi* s.l., especially *B. garinii* [28]. The presence of *B. garinii* in *I. uriae* in distant islands indicates transhemispheric exchange of Lyme disease spirochetes by seabirds [28]. Gylfe et al. [29] provides the first *B. burgdorferi* s.l. isolates from seabirds, and documents these birds as reservoir hosts, and *I. uriae* as the vector. Along the eastern seaboard, Smith et al. [30] detected *B. garinii* in *I. uriae*.

The FarAsian-Australian flyway provides an expansive corridor for avian transport of ticks on a north-south axis during bimodal migration within this flyway. Within this extensive flyway, Doube [31] documented the Australian paralysis tick, *Ixodes holocyclus* Neumann on ground-frequenting birds in southeastern Australia; this tick species also bites small mammals, cattle, and humans.

On the West Coast of North America, researchers show a wide range of *Ixodes* species ticks on wild birds. In the upper Midwest, Hamer et al. [32] reported long-distance travel during northern spring migration of Neotropical migrants carrying *Amblyomma nodosum* Neumann, which is indigenous in Brazil. During our bird-tick studies, we have annually collected *Amblyomma longirostre* Koch, which are indigenous to northern South America and southern Central America, from Neotropical migrants (i.e., warblers and flycatchers) during spring migration. This tick species has been reported in central and eastern Canada during spring migration, which indicates bird parasitism for an estimated 5-10 days during a flight of over 3000 km. Using light-level geolocators on Neotropical passerines, Stutchbury et al. [33] tracked the flight path of several migrants, and revealed one particular Purple Martin, *Progne subis* (L.), which departed the Amazon basin, averaged 577 km/day. As well, Brewer et al. [34] reported a White-throated Sparrow, *Zonotrichia albicollis* (Gmelin) flying 681 km in a single day. Similarly, Hunt and Eliason [35] reported Blackpoll Warblers, *Setophaga striata* (Forster), flying 3000 km for 88 hours (820 km/day), non-stop, over water during fall migration from the eastern seaboard of New England and Maritimes to South America. In essence, wild birds expand the geographic range of ticks, and may concomitantly spread tick-associated pathogens.

## ASSOCIATION OF SONGBIRDS IN TICK HABITATS

Ground-foraging songbirds act as important reservoirs of infection within tick populations. In the upper Midwest, 38% of the songbirds infested with *I. scapularis* had *B. burgdorferi* s.l.-infected larvae [36]. During Canadian studies related to bird parasitism, Scott et al. [23] found that *I. scapularis* immatures, which were collected from songbirds, had an infection prevalence of 36% for *B. burgdorferi* s.l.

In order to initiate and maintain a blacklegged tick population, several basic components are needed. Since transovarial transmission of *B. burgdorferi* s.l. does not occur in *I. scapularis* ticks [37], larvae must acquire infection during the initial blood meal from spirochete-laden hosts. Additionally, when a senesent female has laid all her eggs, and dies, her dead remanent body gives off an odoriferous smell that attracts ground-foraging birds and land-inhabiting mammals. Because newly hatched, host-seeking larvae and the dead female are in juxtaposition, the larvae ambush and parasitize any scavenger that frequents this site. This innate survival tactic has allowed ticks to sustain their presence in nature over many millennia. Ixodid tick researchers reveal that songbirds can become heavily infested with larvae, especially where a gravid female deposits her eggs [38]. Not only does the female tick pellet become a lure for hosts, it acts as a compact source of energy-laden nutrients. The spent tick gives off fermenting vapours that increase the luring appeal of the female pellet, which contains carbohydrates, fats, protein, and micronutrients. Interestingly, an energy-rich off-white adipose deposit is present in the posterior section of the idiosoma (posterior body segment) of the female remanent, and it provides a storehouse of nutrition for scavengers. Moreover, several tick researchers have observed that songbirds, quail, and chickens feed on live ticks to obtain energy reserves [14, 39, 40]. In some tick microenvironments, predation of ticks by wild birds is high. One notable example of bird predation of ticks is the Yellow-billed Oxpecker, *Buphagus africanus* Brisson, of sub-Saharan Africa [41].

## SONGBIRDS ACT AS RESERVOIR HOSTS FOR *BORRELIA BURGDORFERI*

Certain wild birds have the innate physiology to act as reservoir hosts for select pathogenic microorganisms, including *B. burgdorferi* s.l. Based on early bird-tick studies, Anderson and Magnarelli [15] proposed that songbirds have the potential to act as reservoir hosts of *B. burgdorferi* s.l., and transport spirochetes and ticks to new foci. As well, Anderson et al. [16] isolated the first Lyme disease spirochetes from a songbird, namely a Veery, *Catharus fuscescens* Stephens, to elucidate reservoir competency. In the upper Midwest, McLean et al. [42] isolated *B. burgdorferi* s.l. from the blood of a passerine, viz. Song Sparrow, *Melospiza melodia* (Wilson), while along the East Coast, researchers isolated *B. burgdorferi* s.l. from *I. scapularis* larvae collected from several songbirds, including Carolina Wren, *Thryothorus ludovicianus* (Latham); Common Grackle, *Quiscalus quiscula* (L.); Swainson's Thrush, *Catharus ustulatus* (Nuttall); Northern Cardinal; and Veery (16, 26, 43].

In the European Union, Kurtenbach et al. [44] provide the first documentation that gallinaceous birds (Common Pheasants, *Phasians colchicus* L.) act as reservoir hosts *of B. valaisiana*. When *I. ricinus* nymphs were collected from feral pheasants in southern England more than 50% of the engorged nymphs were infected with *B. garinii* or *B. valaisiana*. Both of these *Borrelia* genospecies present a health risk to humans. In central Europe, *I. ricinus* larvae, which were collected from songbirds, were infected with *B. garinii* and *B. valaisiana*, these findings indicate that these songbirds, namely the Blackbird, *Turdus merula* (Brehm), and the Song Thrush, *Turdus philomelos* (L.), are reservoirs of borreliae. Throughout the European Union, certain passerine act as harbingers of *B. burgdorferi* s.l. [45-48]; in some cases, spirochetes were cultured from blood from these avian hosts [48-50].

In far-western North America, Morshed et al. [20] detected *B. burgdorferi* s.l. in a larva of an avian coastal tick, *Ixodes auritulus* Neumann collected from a Fox Sparrow, *Passerella iliaca* (Merrem); this discovery constitutes the first report of *B. burgdorferi* s.l. in an ixodid larva feeding on a bird in western North America. During our recent bird-tick studies, we noted that 21 (81%) of 26 *I. auritulus* immatures (22 larvae, 4 nymphs), which were collected from a Fox Sparrow along coastal British Columbia, were infected with *B. burgdorferi* s.l.; this is the highest spirochetal infection rate that we have ever observed in ticks collected from passerine birds. Enzootically, this bird species has the potential to act as a disseminator of borreliae, especially within established populations of Lyme disease vector ticks. Songbird-transported ticks, which parasitize both mammals and humans, can transmit *B. burgdorferi* s.l. from mammals to humans, especially in a localized enzootic tick cycle. As interconnecting vectors, larvae of certain bird-feeding ticks (i.e., *I. pacificus*, *I. ricinius*, *I. scapularis*) can attach to a *B. burgdorferi* s.l.-infected mice, take a blood meal, drop to the ground, crawl to a cool and moist microhabitat, molt to nymphs in the leaf litter and, subsequently, bite and transmit spirochetes to birds and mammals, including humans. In essence, reservoir-competent songbirds consistently act as an intermediary bridge to channel *B. burgdorferi* s.l. from mammals and humans.

Richter et al. [5] discovered that the American Robin, *Turdus migratorius* L., will retain *B. burgdorferi* s.l. endogenously for up to 6 months. Using xenodiagnostic methods, these researchers put spirochete-free *I. scapularis* larvae on *B. burgdorferi*-infected robins, and allowed them to take a blood meal and feed to repletion. After the larva-nymph molt, unfed nymphs were put on mice, and the parasitized mice became spirochetemic. Within an enzootic site for *B. burgdorferi* s.l., the American Robin serves as reservoir-competent host, and provides an ongoing source of spirochete-infected ticks. Throughout the breeding, nesting, and fledgling periods, these ground-dwelling birds encounter Lyme disease vector ticks. Notably, American Robins can act as borrelial reservoirs throughout the temperate season, and may become infected again after a period of non-infectivity. The presence of *B. burgdorferi* s.l.-infected *I. scapularis* larvae collected from wild birds further suggests a link between certain avian hosts and reservoir competency.

Coinfestation of birds by multiple tick species can occur. Scott et al. [23] witnessed 3 different species of ticks co-feeding simultaneously on a single passerine during northward spring migration. Explicitly, passerines constitute a core functional group that act as reservoir-competent hosts for Lyme disease spirochetes. Overall, migratory songbirds play a pivotal role in the dissemination of borreliae during short- and long-distance movement.

## SONGBIRDS DISSEMINATE ZOONOTIC PATHOGENS

Avian hosts have the physical capacity to widely disseminate zoonotic pathogens. Wild birds may act as reservoirs for several agents, including arboviruses, influenza A virus, piroplasms, enterobacterial pathogens and drug-resistent bacteria, and *B. burgdorferi* s.l. [27]. In nature, birds are the amplifying hosts of West Nile virus. As well, aquatic waterfowl may be asymptomatic carriers of influenza A virus. Pertinent to subarctic latitudes, arboviruses have been found in ticks on migratory birds in Finland [51].

In the European Union, borreliae were initially detected in larval and nymphal *I. ricinus* ticks that parasitized several bird species [46]. DNA probes, which consisted of *fla* and *ospA* genes, revealed the presence of *B. garinii*. The presence of *B. garinii* in *I. ricinus* larvae, which were collected from wild-caught birds (i.e., Eurasian Blackbird, *Turdus merula* L.; European Robin, *Erithacus rubecula* (L.); European Blackcap, *Sylvia atricapilla* (L.); and Great Tit, *Parus major* (L.) indicate that these avian hosts are borrelial reservoirs. As well, Poupon et al. [52] revealed that northward and southward migratory passerines, which were infested with larval and nymphal ticks, were infected *with B. valaisiana* and *B. garinii*. Likewise, Comstedt et al. [53] detected four *Borrelia* genospecies (i.e., *B. afzelii*, *B. garinii*, *B. burgdorferi* s.s., *B. valaisiana*), plus the relapsing fever group spirochete, *B. miyamotoi,* in ticks collected from migratory passerines. In Portugal, Norte et al. [54] surveyed passerines and detected *B. valaisiana*, *B. garinii*, *B. turdi,* and *B. miyamotoi* in ticks collected from wild birds. Pathologically, *B. burgdorferi* s.l.-infected ticks put the public at risk.

In the Baltic region, Lyme disease spirochetes are present in ticks collected from passerines. Movila et al. [55] detected nine different tick-borne pathogens in 3 tick species (i.e., *I. ricinus, I. frontalis*, *H. maginatum*) collected from migratory birds. These pathogens include: *B. garinii*, *B. afzelii*, *B. valaisiana*, *A. phagocytophilum*, Candidatus *Neoehrlichia mikurensis*, *Ricksettsia helvetica*, *Ricksettsia aeshlimanii*, and *Babesia venatorum* and the tick-borne encephalitis virus. As well, Hildebrandt et al. [56] documented several zoonotic pathogens in bird-feeding ticks collected from migratory birds mist-netted on a Baltic Sea island along coastal north-eastern Germany. These tick-borne pathogens included *Babesia divergens*, *Babesia microti*, *A. phagocytophilum,* and members of the spotted fever group (i.e., *Ricksettsia monacensis*, *R. helvetica*). Alekseev et al. [11] provide the first evidence of human monocytic ehrlichiosis (HME) and human anaplasmosis (formerly human granulocytic ehrlichiosis) microbiota in immature *I. ricinus* ticks collected from passerines. At the same site, *B. afzelii*, *B. garinii*, and *B. burgdorferi* s.s. were detected in *I. ricinus* attached to passerines.

In the Far East, Ishiguro et al. [57] documented the movement of passerine migrants from Mongolia, and onward to China, to Korea, and to Japan, and these avian hosts were transporting tick infected with *B. garinii*. Seabirds play an integral role in the global transmission cycle of *B. burgdorferi* s.l., especially involving *I. uriae,* which migrates long distances between seabird colonies, and transports these ticks between the Southern and Northern Hemispheres [28].

In Sweden, *B. burgdorferi* s.l., which was extracted from seabird-transported *I. uriae* nymphs, matched isolates from *I. ricinus* ticks collected on nearby islands. In South America, wild birds carry several *Amblyomma* spp. ticks, and some of them are infected with ricksettial microorganisms [58].

In North America, Levine et al. [59] reported *B. burgdorferi* s.l. in 3 tick species (i.e., *Ixodes dentatus* Marx*, Haemaphysalis leporispalustris* Packard, and *I. scapularis* (denoted as *I. dammini*) collected from passerine migrants in Virginia.

Additionally, Durden et al. [26] documented eight species of ticks on passerines along coastal southern United States of America, and isolated *B. burgdorferi* s.l. from skin biopsies obtained from these migratory passerines and from songbird-transported ticks. Moreover, the lone star tick, *Amblyomma americanum* (L.), and *I. scapularis,* which are both transported by songbirds, harbour filarial nematodes that can infect the circulatory system of humans [60].

## SONGBIRDS START TICK POPULATIONS

Songbirds have the propensity to start ixodid tick populations. During the pioneer phase of Lyme disease epidemiology and ecology, tick researchers noted that heavily parasitized ticks have the potential to initiate new tick populations [15, 17].

In a remote area of southeastern Ontario, Scott et al. [61] provide substantial evidence to show the establishment of *I. scapularis* forming an enzootic tick cycle of *B. burgdorferi* s.l. Although it would be impossible to capture the actual event, and see it develop day by day, recent tick scenarios of previously undiscovered blacklegged tick populations in eastern and central Canada, show substantive evidence for songbirds as tick colony propagators. Since the white-tailed deer, *Odocoileus virginianus* Zimmermann, is not a reservoir-competent host, cervids were discounted as initiators. Biogeographically, blacklegged tick populations on offshore islands underscore the involvement of passerines in starting new tick colonies.

Recently, we collected 17 *I. scapularis* (8 nymphs, 9 larvae) from a Swainson’s Thrush, *Catharus ustulatus* (Nuttall) on 7 June 2014 at Toronto, Ontario. If these engorged ticks had not been detached by bird banders, this heavily infested migrant could handily initiate a new Lyme disease endemic area. Songbirds provide a zoonotic mechanism to covertly introduce *B. burgdorferi* s.l.-infected larval and nymphal *I. scapularis* to a tick habitat, especially during spring migration.

While collecting food during the nesting, fledgling, and post-nesting periods, songbirds will naturally scatter spirochete-infected ticks in the locale, which can potentially infect people and domestic animals. Because songbirds widely disperse Lyme disease vector ticks, people do not have to go to an endemic area to contract Lyme disease.

## SONGBIRDS TRANSPORT TICKS CARRYING RELAPSING FEVER GROUP SPIROCHETE

The relapsing fever group spirochete, *B. miyamotoi* Fukunaga et al., is pathogenic to humans, and is present throughout the Holarctic region of the world. This spirochete is carried by certain ixodid tick species, including *I. pacificus, I. persulcatus, I. ricinus,* and *I. scapularis* [62]. *Borrelia miyamotoi* is transmitted transovarially and transstadially, and can coexist with *B. burgdorferi* s.l. in a vector tick. Consequently, an unfed larva can transmit *B. miyamotoi* directly to its host during its first blood meal. In the northeastern United States, Scoles et al., initially reported *B. miyamotoi* in *I. scapularis* [63], and indicated that *B. miyamotoi* is not detected by Lyme disease serology. However, patients with spirochetemia can now use PCR amplification and DNA sequencing to differentiate *B. burgdorferi* s.l. and *B. miyamotoi* sourced from blood [64].

In Canada, Dibernardo et al. [65] reported *B. miyamotoi* in ixodid ticks collected in each province from British Columbia to Nova Scotia and, no doubt, these *B. miyamotoi*-infected ticks were initially dispersed by migratory passerines. Wild birds will undoubtably play an ever-increasing role in the wide dispersal of *B. miyamotoi* Canada-wide and globally.

In Michigan, U.S.A., Hamer et al. [66] provided the initial documentation of *B. miyamotoi* and *B. andersonii* in bird-transported *I. scapularis*; both of these borreliae are pathogenic to humans. In their study, the majority of *B. miyamotoi*-positive ticks were removed from Northern Cardinals. As well, in the same study, six bird species were implicated as reservoirs for *B. andersonii*. Not only are songbirds hosts for *I. scapularis*, they serve as intermediate reservoirs for *B. miyamotoi* and *B. andersonii*. The presence of *B. miyamotoi* and *B. burgdorferi* s.l. in ticks parasitizing passerines underpins the ecological complexity of these zoonotic pathogens within enzootic tick-host associations.

## EFFECTS OF TICKS ON SONGBIRDS

Ticks normally attach to the head of the birds, especially around the eyes, mouth, and within auricular feathers (Figure 1). In order to prevent bird predation during preening, ticks instinctively select these non-reachable sites to attach to the skin. Some bird parasitism studies have focused on the health effects of blood-sucking ectoparasites on avian hosts. In particular, Norte et al. [67] evaluated the presence of feeding ticks on songbirds in Western Europe, and found that *B. burgdorferi* s.l.-infected ticks increased the heterophyl/ lymphocyte ratio of Eurasian Blackbirds suggesting increased stress.

Along the Pacific coast, American Robins died from heavy infestations of *I. auritulus* females [20]. In essence, bird parasitism may have a detrimental effect on avian hosts and, ultimately, may result in fatal outcomes of host birds.

Photo credit: Charlotte England.

Figure 1. Swainson's Thrush parasitized by engorged nymphs of the blacklegged tick, *Ixodes scapularis*, below and anterior to the right eye.

## COINFECTIONS IN TICKS CARRIED BY BIRDS

Coinfections are apparent in bird-feeding ticks. Migratory birds carry zoonotic pathogens, and contribute greatly to the global spread of emerging infectious diseases [27]. European researchers detected *Borrelia* and *Chlamydophila* in cloacal and throat swabs of migratory passerines, and showed that such infections can be endogenous in birds [68]. Based on the broad diversity of *Borrelia* spp. reported in songbird-transported ticks in North America, there is a great potential to have these infected ticks imported into Canada during spring migration. Interestingly, several genotypes of *B. burgdorferi* s.l. have been reported in widespread regions of Canada [23, 69, 70]. Crowder et al. [71] conducted multilocus genotype analysis of borreliae in field-caught ticks collected from various parts of the United States of America and Europe, and detected 53 distinct genotypes of *B. burgdorferi* s.s. Epidemiologically, some of these genotypes were shared between continents, which suggests transatlantic exchange via ticks on migratory birds. Notably, a significant number of *I. scapularis* and *I. ricinus* ticks had more than one *B. burgdorferi* s.s. genotypes. These findings show a diversity of genotypes in ticks across wide geographic regions, and these diverse genotypes can cause dire clinical consequences. Because of the heterogeneity of borreliae in songbird-carried ticks, Lyme disease patients are apt to fail to seroconvert because borrelial genotypes may not be present in standard Lyme disease serology [72, 73]. Rudenko et al. [74] reported cross-species recombination of *B. burgdorferi* s.l. isolated from an *I. minor* nymph collected from a single Carolina Wren, *Thryothorus ludovianus* (Latham). Based on molecular-level, multi-locus analysis, it was discovered that the *B. burgdorferi* s.s. housekeeping gene, *niff*, was incorporated into another homologous locus of another bird-associated genospecies, *B. americana*. This event supports the hypothesis that diversity and evolution of Lyme disease spirochetes is driven mainly by the host.

Pertinent to other tick-associated pathogens, *A. phagocytophilum* has been reported in American Robins in North America and, likewise, other wild birds in Eurasia (11, 75].

Additionally, passerine-transported ticks may be infected with pathogenic microorganisms, including *Ricksettia*/*Coxiella* and tick-borne encephalitis virus. After a larva-nymph or nymph-female molt, ticks can transmit one or more tick-associated suitable pathogens to suitable vertebrate hosts, including humans.

## SONGBIRDS ACT AS CONNECTING LINKS IN MULTI-TICK ENZOOTIC CYCLE

In tick-conducive habitats, wild birds act as important carriers in shifting zoonotic pathogens from wildlife hosts to humans. For instance, Scott et al. [23] documented a 4-tick enzootic cycle of *B. burgdorferi* s.l. on Vancouver Island, British Columbia, Canada that consists of *I. angustus* Neumann, *I. auritulus*, *I. pacificus*, and *I. spinipalpis*. In this coastal-forest habitat, *I. angustus* feeds primarily on small mammals, whereas *Ixodes auritulus* ticks feed exclusively on birds (i.e., passerines, grouse, and raptors). From a bird parasitism standpoint, both *I. pacificus* and *I. spinipalpis* parasitize avian and mammalian hosts. Not only do songbirds play a key role in maintaining and amplifying *B. burgdorferi* s.l. within this Pacific coast habitat, they serve as a spirochetal transit to humans. With the recent inclusion of *Ixodes cookei* Packard, a fifth interconnecting link is added to the enzootic cycle to circulate Lyme spirochetes within this coastal ecosystem. Although there may be one or more contiguous enzootic cycles of *B. burgdorferi* s.l. operating concurrently, in parallel, at this locality, the net effect is basically the same as one encompassing cycle. This 5-tick enzootic cycle of *B. burgdorferi* s.l. emulates a web-like interplay within a tick-bird-mammal community. Ecologically, this interaction of five tick species highlights the complexity of maintaining and perpetuating *B. burgdorferi* s.l. within this particular watershed habitat of British Columbia. Within this multi-tick cycle, Scott et al. [76] provide the first report of *B. burgdorferi s*.l.-infected ticks (*I. auritulus*) parasitizing a raptor (Cooper's Hawk, *Accipiter cooperii* (Bonaparte). This newfound, bird-tick association denotes that raptors are explicitly involved in the spread of Lyme disease. Medically, *I. angustus*, *I. cookei*, *I. pacificus*, and *I. spinipalpis* ticks parasitize humans, and may potentially transmit tick-borne pathogens.

## HEALTH IMPLICATIONS

Lyme disease is a multisystem bacterial infection that causes protean manifestations in humans. This zoonotic disease can generate a brutal assault on the body, and promptly converts a healthy person into a febrile individual with cognitive impairment and unending pain. Lyme disease can have significant morbidity, and may be acute, recurrent, or chronic. When Lyme disease advances in a host, *B. burgdorferi* s.l. evades host immunity and generates diverse, pleomorphic forms (i.e., spirochetes, round bodies, granules, blebs) and, combined together, produce gelatinous masses, called biofilms (persister cells). These polysaccarhide-based matrices typify chronicity of infection [77]. Signs and symptoms of Lyme disease may persist after short-term antibiotic treatment, and survive in deep-seated and immune-privileged sites [78-85]. Several tissues in the body are hard to penetrate with antibiotics, including ligaments and tendons [86, 87], muscle [88], brain [89-92], bone [93, 94], eyes [95, 96], glial and neuronal cells [97, 98], and fibroblasts/scar tissue [99]. Persistence of *B. burgdorferi* s.l. has been documented in several different mammalian hosts, including dogs [100, 101], gerbils [102], guinea pigs [103], hamsters [104], nonhuman primates (i.e., rhesus macaques) [105, 106], baboons [107], humans [108-111], laboratory mice [112-116], white-footed mice [117-119], rats [120] and horses [121, 122]. Insofar as *B. burgdorferi* s.l. has an immune-evasion mode during its activity, this stealth pathogen sequesters and survives in suitable hosts. If left untreated or inadequately treated, this zoonotic spirochetosis may ultimately result in fatal outcomes [123, 124].

Lyme disease is typically transmitted to avian and mammalian hosts by certain infected ticks; however, other modes of transmission are present. Passage of *B. burgdorferi* s.l. to humans and domestic animals may occur by: blood transfusion [125-127], congenital transmission [128-133], contact transmission [134], and sexual transmission [135-137]. Furthermore, *B. burgdorferi* s.l. has been detected in breast milk of Lyme disease patients [138]. In essence, Lyme disease can induce chronic, progressive illness that can have a wide diversity of pathological symptoms in vertebrates [139-141]. During treatment, patients can have flu-like Jarisch-Herxheimer reactions. Commercial laboratory testing, which are based on immune response, yields poor results for Lyme disease, and has a sensitivity of only 46% in patients who have been infected for more than 4-6 weeks [142]. Consequently, these tests currently miss more than half of the human Lyme disease cases in North America.

A reservoir-competent songbird, which is heavily infested with *B. burgdorferi* s.l.-infected ticks, can haphazardly disperse fully engorged ticks at stopovers, and consequentially initiate a chain of Lyme disease cases along its flight path. Such pathogen-laden ticks are an ever-growing concern and a public health risk to unsuspecting outdoor adventurers and workers.

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*Chapter 2*

# SEABIRDS AND ISLAND COMMUNITIES: BIODIVERSITY AWARENESS AS A TOOL FOR THE CONSERVATION OF INSULAR SPECIES

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## ABSTRACT

Seabirds can serve as fundamentally important components of biodiversity of insular ecosystems, playing an important role as vectors of marine-derived nutrients, increasing primary production which in turn is transferred through the food web, and influencing the numbers and types of primary and secondary consumers. The status and trends of seabirds can be an excellent indicator of the impacts of human activities on their populations and communities. These impacts include loss of breeding sites through trampling and grazing by introduced domesticated animals; mortality by introduced mammalian predators such as rats, dogs and cats; egg and chick harvest; and interactions with local and regional fisheries. These impacts have occurred on most human-inhabited islands, ranging from the tropics to the sub-polar regions. Until the 1990s, the general state of knowledge about seabirds of oceanic islands in Chile was poor, since virtually no

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basic ecological information such as population size, breeding biology or the extent of conservation problems had been compiled for many species.

Human communities of oceanic and coastal insular systems in Chile currently possess only a small percentage of people who retain local traditional ecological knowledge, as a result of the recent influx of immigrants during the second half of the 20th century and the progressive decline of the ancestral native population. The relationship of recently arrived human communities with the biodiversity of the insular systems has been restricted to the use and exploitation of resources to satisfy basic needs for the human population (e.g. heating, food). Many of these activities have a negative impact on the biodiversity of the island, including seabirds. As a resource, seabirds were usually ignored by island communities because they did not provide any immediate benefit. In the 1990s, initiatives of national and foreign researchers began in different islands of Chile to elucidate basic aspects of the ecology and conservation status of several seabird species. The information generated was shared with the island communities associated with these seabird species in order to increase awareness and build support for conservation actions. This community engagement was undertaken based on the understanding that island communities, especially isolated ones, have particular characteristics that distinguish them from the inhabitants of the continent. These include a strong sense of belonging to the place, a heightened sense of community among residents, a detachment from the nearby continental areas, and a sense of not belonging to the central government that manages the island.

Here we document community engagement experiences and results on five significant Chilean seabird islands distributed in a wide latitudinal range: (1) Robinson Crusoe, Santa Clara and Alejandro Selkirk islands (the Juan Fernández Archipelago) (34° S), inhabited by six species of procellarids (Pink-footed Shearwater *Puffinus creatopus*, Kermadec Petrel *Pterodroma neglecta*, De Filippi's Petrel *Pterodroma defilippiana*, White-bellied Storm-Petrel *Fregetta grallaria*, Juan Fernández Petrel *Pterodroma externa* and Stejneger´s Petrel *Pterodroma longirostris*); (2)Mocha Island (38° S) where the Pink-footed Shearwater *Puffinus creatopus* breeds*;* (3) Puñihuil Island, Chiloé (42° S) with a mixed-colony of Humboldt (*Spheniscus humboldtii*) and Magellanic (*Spheniscus magellanicus*) penguins; (4) Guafo Island, Quellón town (44°S) with the largest colony of Sooty Shearwater *Puffinus griseus* in the world; and (5) Navarino Island (55°S), Cape Horn Biosphere Reserve, that is inhabited by rich ensembles of seabirds and shorebirds, including cormorants, plovers, sandpipers, steamer-ducks and geese. On all of these islands, islanders have participated in initiatives that support the conservation of resident seabird species, including the cessation of chick and egg harvests, development of special interest tourism around birds, removal of introduced animals and responsible pet ownership, and as a general rule, inclusion of birds as co-inhabitants of the community.

## INTRODUCTION

Seabirds can play a role as important drivers of biodiversity of insular ecosystems, serving as vectors of marine-derived nutrients (Stapp & Polis 2003; Hawke & Newman 2004, Smith et al. 2011), increasing primary production which in turn is transferred through the food web, and influencing the numbers and types of primary and secondary consumers (Sanchez-Piñero & Polis 2000, Stapp & Polis 2003). Although seabirds vary in the extent to which they rely on terrestrial systems throughout their annual cycle, most seabirds depend extensively or exclusively on islands to provide breeding habitat.

As such, the status of seabirds living on islands can provide an effective indicator of the intensity of use and degree of degradation of island ecosystems; human activities in many insular systems, ranging from the tropics to the sub-polar regions, have negatively impacted seabird populations and communities (Schlatter 1987, Croxall et al. 2012, Libois et al. 2012, Nogales et al. 2013).

Until the 1990s the state of knowledge about seabirds of many oceanic islands in Chile was poor, since basic ecological information such as population size, breeding biology and the conservation status of many species had not been studied (Schlatter 1987, Schlatter & Simeone 1999, Simeone et al. 2003).

Since that time, our understanding of the status of, and issues confronting, seabirds in Chile has improved considerably. Significant threats to seabirds include loss of breeding habitat through trampling and grazing by managed domestic animals; predation by introduced mammals such as rats, dogs and cats; harvest of eggs and chicks by humans; and interactions with local fisheries (Schlatter 1984, Schlatter & Simeone 1999, Simeone et al., 2003).

Historically, island communities, either indigenous people or later immigrants, have maintained one of two positions related to seabirds: (1) disinterest/lack of knowledge or (2) use as a primary or secondary resource. Using seabirds as a resource has often been to meet subsistence needs, and, as such, also forms part of important sociocultural activities that help define the participants' cultural identity and provide links to their history, ancestors, land, art and environmental philosophy (Kirikiri & Nugent 1995). Some of these customary uses of wildlife are controversial because they are unsustainable at present (Redford 1992), such as the harvesting of chicks and eggs of some seabird species (Moller et al., 2004). Increasing social, economic, and ecological pressures such as technological change, human population growth, habitat destruction, species introductions, pollution and climate change may exacerbate the impacts of these traditional practices on seabirds (Moller et al. 2004). Thus, local human communities can play a major role in determining the persistence of seabird communities on islands.

To understand the relationship between local human communities and the insular ecosystems in which they live and on which they depend, it is necessary to determine whether or not general characteristics of island communities exist that may be used to inform conservation actions and planning. One of the few complete studies to date is that of Zissi et al., (2010), which used the perceptions of local people to describe 84 island communities in the region of the North Aegean Sea. The elements of this research can be useful to provide general characterizations of island inhabitants. Biddle (2014) described similar results for indigenous island people in Australia, both works identifying the following six attributes:

1. Island people identified themselves as a unity with few ‘overt’ distinctive groupings without types of social networks.
2. Islanders show low levels of intimate interpersonal relationships, due to culturally differentiated notions of friendship, limited personal resources (energy and time) due to daily tasks, and safeguarding of privacy, since friendships are perceived to foster gossip. In this sense, people are more interested in their “own good” in these communities. But since island communities frequently are composed of extended kin relations, extended family members often overlap with friends. As such, the levels of mutual aid, solidarity and help in cases of emergency as well as expectations of collective action in order to address a common issue or to organize a festival or a fair are relatively high. There is a contrast between interpersonal and collective

sociability organized around the moral and religious values of helping behavior and practical aid.

3. Even though inhabitants trust and help each other, they do not seem to share a common system of values in terms of mentality and lifestyle. Trusting and bonding relationships are not necessarily characterized by shared values, which are viewed as personal and private identifications. Nevertheless, island communities have strong, deep-rooted ties born through kinship networks within small and spatially dense settlements. Social ties facilitate trust and local cohesion, but they may include obligations that discourage rural inhabitants from active participation.
4. Islanders show feelings of satisfaction with their life and, importantly, attachment to the place. This arises from the great value island people place on the physical environment in multiple terms; experiences of socialization, source of economic activity and natural capital and aesthetics, and related to identifying two components of place attachment: rootedness or physical attachment and bonding or social attachment (Riger & Lavrakas 1981)
5. Trust in central administration and politicians is lacking. Islanders feel that they have limited links outside the immediate locality and poor participation in more wide-ranging networks, either economic or social.
6. Islanders have a sense of acceptance of a deprived social position and perceived low civic power. The deprived position derives from multiple possible causes, including poor material infrastructure, moderate albeit acceptable quality of principal services (electricity, sewage and water), infrequent transport links, lack of upgrading of rural roads and closing of educational institutions. The lack of linking social capital combined with limited resources is arguably responsible for the almost non-existent levels of civic trust.

Island communities of oceanic and coastal insular systems in Chile share to a great extent the attributes identified by Zissi et al., (2010) and Biddle (2014) in Greek and Australian island communities, respectively. However, Chilean island communities are characterized by having a low percentage of people who maintain their traditional ecological knowledge. This loss of local ecological knowledge is a result of the high rates of immigration arrived in recent times into these communities and the progressive decline of the ancestral native population. The relationship of recently arrived human communities with the biodiversity of the insular systems has been restricted to use and exploitation of resources to satisfy basic needs for the human population (e.g. heating/fuel, food). Many of these activities have a negative impact on the biodiversity of the island, including seabirds. As a resource, seabirds were ignored by island communities because they did not provide any immediate benefit. In the 1990s, initiatives of national and foreign researchers began in different islands of Chile to elucidate basic aspects of the ecology and conservation status of several seabird species. The information generated was shared with the island community associated with these seabird species in order to increase awareness and build support for conservation actions. This community engagement was undertaken based on the understanding that island communities, especially isolated ones, have particular characteristics that distinguish them from the inhabitants of the continent. These include a strong sense of belonging to the place, a heightened sense of community among residents and a detachment from the nearby continental areas, as well as a sense of not belonging to the central government that manages the island.

The main goal of this study is to document, based on our previous research and the research of other colleagues on these islands, the experience of island communities with conservation of seabirds on five islands of Chile distributed in a wide latitudinal range. All of these islands hold significant populations and/or communities of seabirds: (1) Robinson Crusoe, Santa Clara and Alejandro Selkirk islands, collectively the Juan Fernández Archipelago (34° S), where six species of procellarids breed (Pink-footed Shearwater *Puffinus creatopus*, Kermadec Petrel *Pterodroma neglecta*, De Filippi's Petrel *Pterodroma defilippiana*, White-bellied Storm-Petrel, *Fregetta grallaria*, Juan Fernández Petrel *Pterodroma externa* and Stejneger´s Petrel *Pterodroma longirostris*; (2) Mocha Island (38° S) where the Pink-footed Shearwater breeds; (3) Puñihuil Island, Chiloé (42° S), with a mixed-colony of Humboldt (*Spheniscus humboldtii*) and Magellanic (*Spheniscus magellanicus*) penguins; (4) Guafo Island, Quellón town (44°S) with the largest colony of Sooty Shearwater *Puffinus griseus* in the world; and (5) Navarino Island (55°S), Cape Horn Biosphere Reserve, that is inhabited by rich ensembles of seabirds and shorebirds, including gulls, cormorants, plovers, sandpipers, steamer-ducks and geese. On all of these islands, islanders have taken initiatives actions that support the conservation of resident seabird species. Conservation actions include to cessation of harvesting of chicks and eggs, development of special interest tourism around birds, removal of introduced animals and responsible pet ownership, and as a general rule, consideration of birds as co-inhabitants of the community. Our second goal is to use these case studies and experiences to identify strategies that will improve the practice of using community engagement to strengthen the effectiveness of seabird conservation on islands with human communities.

## FIVE CASE STUDIES OF BUILDING ISLAND COMMUNITY AWARENESS OF SEABIRDS IN CHILE

### Juan Fernández Archipelago

#### *Context*

The Juan Fernández Archipelago, located 670 km off the coast of central Chile, is a 9,002 ha Chilean National Park created in 1935 (Araya 2004). Since 1997, it is also a UNESCO International Biosphere Reserve (Hoffmann & Marticorena 1987, Bourne et al. 1992). The archipelago was nominated for World Heritage status in 1995, and is one of the sites considered as most valuable world natural heritage (Perry 1984) due to the high endemism of the flora (67%) (Guicking & Fiedler 2000). The 1984 General Assembly meeting for the International Union for the Conservation of Nature and Natural Resources (IUCN) identified the archipelago as one of the world's 12 most threatened national parks (Allen 1984). Since its discovery in 1574, the archipelago has suffered major modifications of all major terrestrial habitat types. Although deforestation and habitat alteration are significant factors, the greatest impact has been caused by introduced species, both plant and animal. Introduced mammals include goats, cattle, horses, cows, rabbits and feral cats (Bourne 1983, Cuevas & Van Leersum 2001). The eradication of these species, essential for the long-term conservation of the threatened seabird community as well as critically endangered endemic landbirds, although extremely challenging is technically and logistically feasible, with assessment plans already having been completed (Saunders et al. 2011)

For the island community some of these introduced species have represented money supply or food, such as rabbits, cows and goats (Guicking & Fiedler, 2000). They have used some of the introduced species as pets, such as coatis and cats, without considering them as a threat to their environment (Guicking & Fiedler 2000). Following their discovery in 1574, for 300 years the islands were used primarily by privateers and pirates as a source of wood, water and fresh food, and as a place of exile. Although there were earlier attempts to establish settlements, it was not until 1877 that a permanent village was founded on Robinson Crusoe Island. The other large island, Alejandro Selkirk served as a penal colony in the early 1900s and has since supported only a small summer population of 50 people engaged in fishing. The smallest of the three islands, Santa Clara, has never been inhabited. The local economy has depended primarily on the harvest of a species of spiny lobster (*Jasus frontalis*) and, to a lesser extent, tourism. Men are mainly engaged in fishing, although employment opportunities are slowly diversifying. Until recently, women had a minor role in the economy of the archipelago, but this scenario has changed, as women have taken a more active role in the creation of new businesses, especially those related to tourism, which is the second major economic activity in the archipelago. A third economic activity is small-scale agriculture, which has developed in recent times due to the decline in lobster captures in recent decades (Cuevas & Van Leersum 2001). Until the late 1990s, many islanders showed a relative lack of interest in nature and conservation issues on the island (Guicking & Fiedler 2000), reinforced by the fact that the main source of income for the community, the lobster fishery, was not terrestrial but marine (Cuevas & Van Leersum 2001).

## Conservation Problems for Seabirds

Information on the abundance, ecology and conservation status of the six breeding seabird species of the archipelago was scarce until the early 2000s (Bourne 1983, Schlatter 1987, Brooke 1987, Bourne et al. 1992, Guicking & Fiedler 2000 and Reyes-Arriagada et al. 2012). In 2001, the conservation non-profit organization Oikonos Ecosystem Knowledge began systematic studies of the ecology and conservation status of, and threats to, the threatened breeding seabird community of the islands (e.g., Hodum and Wainstein 2002, 2003, 2004). In addition to their negative impact on the Juan Fernández firecrown *Sephanoides fernandensis*, an iconic, endemic and currently critically endangered species, introduced species have historically affected three species of shearwater; the Pink-footed Shearwater *Puffinus creatopus*, Juan Fernández Petrel *Pterodroma externa* and Stejneger's Petrel *Pterodroma longirostris*. The first species is affected by trampling that collapses burrows and by competition with rabbits for burrow use; indeed, rabbits remove the eggs of shearwaters from the burrows. The other two species are mainly affected by trampling of goats. There is an unknown impact of predation by feral cats on other species such as the Kermadec Petrel *Pterodroma neglecta*, De Filippi’s Petrel *Pterodroma defilippiana* and the White-bellied Storm-Petrel, *Fregetta grallaria*.

## Sensitizing/Awareness

In 1997, the Chilean federal agency responsible for managing federal protected areas, the Corporación Nacional Forestal (CONAF) began a multi-faceted conservation project focused on the recovery of this highly complex ecosystem and using a socio-ecological approach. Because the local communities, San Juan Bautista on Robinson Crusoe and Colonia de la Rada on Alejandro Selkirk are surrounded by the park, and have historically used the entire archipelago to meet their resource needs, they cannot be excluded from any conservation project developed on the island. As such, the inclusion of and engagement with the local community in conservation planning and actions were recognized as being fundamentally important. Initially, one of the main conflicts was the community's negative perception of programs focused on control and eradication of rabbits, goats and fruit tree species, because they constituted local food source. To decrease the pressure of obtaining food produced on the island, the program promoted the importation of food from mainland Chile (Cuevas & Van Leersum 2001). In 2001, the NGO Oikonos in collaboration with the park administration and local community initiated a community-based conservation program for the seabird community of the archipelago, initially through awareness-building artistic and educational activities. Community-based activities have been ongoing and continuous since that time and have expanded in scope to include community talks and workshops, technical training, capacity building, volunteer opportunities, and an environmental education program for children. Specific examples of recent activities include creative writing workshops, drawing contests, informational brochures and posters, field trips to seabird colonies, and student involvement in monitoring a local shearwater colony. An important aspect of their approach is to train local residents, thereby creating and strengthening local capacities. There is now a team of trained local residents hired by Oikonos to work as field technicians and coordinators on a variety of conservation and restoration programs, including for the threatened seabird community (Hodum et al. 2013, Colodro et al. 2014). All of these activities have resulted in a generally positive change of attitude towards the seabirds of the archipelago, promoting the conservation of these species through active participation of the community. In addition, these programs have further reinforced the community's sense of place through the increased awareness of the unique natural heritage that their archipelago possesses.

## Mocha Island

### *Context*

Mocha Island (38° 22 'S, 73° 56' W) is one of the main offshore islands of the Chilean continental shelf. It has an area of 52 km$^2$ and has a great diversity of flora and fauna, mainly associated with forests dominated by olivillo (*Aextoxicon punctatum*), and by myrtaceous species in the upper elevations of the island (Lequesne et al. 1999). These forests are responsible for water retention from clouds and precipitation that people of the community use, and are protected as a National Reserve (Pefaur & Yáñez 1980). The island is a unique place for some species of breeding seabirds, highlighting the endemic Pink-footed shearwater *Puffinus creatopus* which breeds in the forests of the central part of the island. The coastal area is also an important site for other species of seabirds, such as the Imperial cormorant

*Phalacrocorax atriceps*, Rock cormorant *Phalacrocorax magellanicus*, Peruvian booby *Sula variegata*, peruvian pelican *Pelecanus thagus*, Magellanic penguin *Spheniscus magellanicus* and Humboldt penguin *S. humboldtii* breeding on the coast and nearby islets (Schlatter & Reyes-Arriagada unpublished doc).

Concerning the island community, it has been established that the native indigenous population was expelled from the island by Spanish colonists in 1687, and the island remained uninhabited for almost 200 years. Repopulation occurred around 1850 by farmers of central Chile, whose descendants constitute the current population of the island (Lequesne et al., 1999). The community has always depended on the forest biodiversity of the island for use in daily activities, causing degradation of natural habitats. As a result of extraction activities total deforestation was produced in the lower and flat part of the island. Today, introduced and crop species dominate and there are only small, dispersed and fragmented relicts of forest. At the edge of the forest, due to tree logging and subsequent erosion a shrubby ecotone dominates, separating the old-growth forests from disturbed grassland (Saavedra et al., 2003). The lifestyle of the island inhabitants is strongly influenced by the isolation from the continent. The few opportunities to travel to the mainland to buy supplies, especially perishable foods, along with the null importation of these products, their limited production on the island and the inability to store food because of the restricted use of electricity, makes saturated fats and carbohydrates the basic diet (Pasten et al., 2014).

## Conservation Problems for Seabirds

In the forest of National Reserve Isla Mocha, *Puffinus creatopus* breeds in colonies that are about 150 m above sea level (Guicking 1999, Guicking et al., 2001). A census conducted in 2008-2009 estimated a population of 19,440 breeding pairs, but because of difficulties in comparing these results with the few previously conducted surveys, it is not possible to establish population trends (Guicking 1999, Muñoz, unpublished data in Azócar et al., 2013). However, it has been suggested that the population has declined, due primarily to the harvest of fledgling chicks by the community for consumption. Traditionally, between March and May each year residents of the island took large numbers of chicks, which were distributed among the families of the community. This activity began in the early twentieth century, and to date it has not been possible to establish the extent of this practice. However in the late 1990s it was estimated that the collection reached 3,000-5,000 chicks per year (Guicking 1999). Often, longer burrows were destroyed in order to get the chicks from inside (Azócar et al. 2013).

In addition to harvesting, there is now predation pressure by rats, feral cats and probably dogs accompanying egg collectors, all of unknown magnitude (Guicking et al., 1999, Azócar et al., 2013).

## Sensitizing/Awareness

Since 2010, the National Forest Service CONAF, the Chilean government agency that administers the Isla Mocha National Reserve, has enforced the prohibition of harvesting chicks and eggs. The qualitative information provided by the rangers and local residents suggests that the harvest level has dropped dramatically since CONAF began the restriction, possibly totaling at present only a few hundred chicks per season (Herrera, personal communication to Azócar et al., 2013). In order to minimize the costs on the community by this restriction, this conservation strategy has been strongly supported by a community education program whose objective is raising awareness about the patrimonial importance of Pink-footed shearwater on the island. In particular, the NGO Oikonos in cooperation with CONAF, the Environment Regional Department and the American Bird Conservancy, have focused their efforts on the community, working with children and adults of the entire island. They have conducted environmental education initiatives, including lectures, workshops, soccer tournaments, and making affective passive animals (soft toys). Together with these actions there have been efforts to control predators such as domestic dogs and cats; the pet population has been censused and responsible ownership has been promoted, there have been campaigns for sterilization to control the canine and feline population and the capture of cats in the nesting colony using traps because of attacks on the shearwaters.

## Puñihuil Islets

### *Context*

The Puñihuil Islets lie exposed in the Pacific Ocean off the Isla Grande de Chiloé (41°55’ S, 74°02’ W).

Chico Islet and Grande Islet have areas of 1.54 and 2.65 ha, respectively, and are located 340 m and 700 m offshore, respectively (Reyes-Arriagada et al. 2013). Vegetation is composed mostly of understory bamboo (*Chusquea* sp.), bromeliads (*Fascicularia bicolor*, *Greigia sphacelata*), and herbaceous vegetation (*Holcus lanatus*, *Anthoxantum odoratum*, Simeone & Schlatter 1998). On these islets the largest mixed colony of two penguin species breed, Humboldt and Magellanic penguins (*Spheniscus humboldtii* and *S. magellanicus*, Duffy 1987, Wilson et al. 1995, Simeone & Schlatter 1998), with 86 and 477 breeding burrows in 2008 (Reyes-Arriagada et al. 2013). The biological relevance of this Humboldt/Magellanic penguin colony was recognized due to its potential for species hybridization, allowing studies of resource partitioning, behavioral interactions, diet comparisons, foraging ecology and habitat use (Wilson et al., 1995, Simeone & Schlatter 1998, Raya Rey et al., 2013).

At the time of its discovery in 1985 no threats were evident for this unique colony, and the site was not officially protected (Duffy 1987). Today there is an intense tourist activity from guided boat tours around the islets, mainly during the austral spring and summer (Skewgar et al., 2009). Access ashore to the islets is still forbidden under the Natural Monument regulations. Chico Islet had a population of goats until their removal in 1999 (Simeone & Schlatter 1998).

## Conservation Problems for Seabirds

For more than a decade after its discovery there was serious damage to the nesting burrows from trampling by goats introduced in 1988 and by unregulated tourism (Simeone &

Schlatter 1998). Trampling and overgrazing by goats alters the structure and composition of plant communities, causing habitat degradation and accelerating soil erosion, which results in the collapse of breeding burrows of seabirds. Additionally, according to the local residents of the cove near islets, mostly fishermen, these islands are the most accessible known places in Chile where the two penguin species breed, making this a popular tourist attraction in Chiloé. This has resulted in an unknown number of people visiting the colonies while no regulations or management plans were in place until 2009 (Reyes-Arriagada et al., 2013). Populations of both penguin species have been decreasing due to entanglement in artisanal fishing nets and illegal capture for consumption and bait (Simeone et al., 1999, Majluf et al., 2002, Pütz et al., 2011).

## Sensitizing/Awareness

In 1999 the colonies became officially protected by the Chilean Forest Service (CONAF). The islets became a Natural Monument, subject to some regulations as MPAs (Guarderas et al. 2008). Access to the penguin colony was forbidden as a main restriction, and all the resident goats were removed (Simeone & Schlatter 1998). However, tourist activities continued to occur around the islets through boat trips. Protection was reinforced by the Otway Foundation, a nongovernmental organization, which provided constant surveillance and environmental education to locals of the Puñihuil cove. Following these conservation measures penguins increased in numbers as a result of habitat improvement, attributable to the exclusion of tourists and removal of goats from the islets (Reyes-Arriagada et al., 2013). Furthermore, with the help of technical reports given to authorities, in 2009 a local county ordinance regulated tourism activity around the islets in Puñihuil, contributing to improve this activity within a framework of responsibility for tour operators. This technical information was socialized to the community of the Puñihuil cove through workshops warning them about the implications of the increase in tourist fleet operations and promoting preventive behavior and good practices around the islets. Currently the tourist activities at Puñihuil appear to be in line with recommendations of good practices for the penguin colonies, i.e., those developed in a context of responsibility toward the environment (Reyes-Arriagada et al., 2013). Examples of negative impacts on seabird colonies attributable to poorly managed tourism are abundant (see Carney & Sydeman 1999 for a review), but there are also examples of sustainable coexistence between tourism and seabird conservation, such as in penguin colonies (e.g., Boersma & Stokes 1995, Holmes 2007, Landau & Splettstoesser 2007, Powell et al. 2008). The effects of regulations such as the ordinance that improved the management of tourism in Puñihuil will be reflected in the penguin populations in the mid and long term (Reyes-Arriagada et al., 2013).

## Guafo Island

### *Context*

Guafo Island (43 ° 61 'S, 74 ° 75' W) is located at the northern end of the Chilean fjords near the southwest corner of Chiloé Island and the mouth of the Gulf of Corcovado. The island is of particular interest because of its relative isolation from the mainland and marked seasonal regime. It has an extensive coastline, varied aquatic systems and an inner area that allows a high availability of breeding sites for shearwaters (Reyes-Arriagada et al., 2009), with high productivity of the surrounding sea (Ramirez & Pizarro 2005). With an area of 30,000 ha and a coastline of 72 km, Guafo Island is a significant breeding habitat of birds, as it shows a considerable coastline and forest ecosystem for nesting of species of 13 of the 22 orders present in Chile. The Sooty shearwater *Puffinus griseus* is the main breeding species on the island with nearly 4 million breeding pairs, the largest colony in the world (Reyes-Arriagada et al., 2007). An important colony of Magellanic penguin *S. magellanicus* is also present with at least 1,700 breeding pairs, and there are several colonies of cormorant species along the coast (Reyes-Arriagada et al. 2009)

Historically, industrial and artisanal demersal and benthic fishing has benefited from the seas adjacent to Guafo Island because of upwellings rich in productivity (Ramirez & Pizarro 2005), but with not quantified impact for bycatch on seabird species, especially during the breeding season (Reyes-Arriagada et al., 2009). Until the 1960s a whaling plant operated on the island, which processed species of marine mammals that inhabit the waters surrounding the island, with an impact never quantified on populations of these large cetaceans. Currently artisanal fishermen stay temporarily on the island during summer, with a fleet of 120-150 vessels, which deliver their products in the town of Quellón in Chiloé Island, 120 km from Guafo Island. Fishermen do not make use of the land resources of the island, except for firewood extraction on a small scale.

The community associated with Quellón, in addition to extractive activities in the sea and small-scale agricultural activity, has a traditional tourism activity associated with the patrimonial culture and idiosyncrasy of Chiloé, in which ecological biodiversity and touristic elements were incorporated to a small extent in the tourist offer. In 2003 a revolution occurred in the region in terms of biodiversity assets, as a result of the discovery of aggregations of blue whales *Balaenoptera musculus* with feeding and breeding activities in the area (Hucke-Gaete et al., 2003). This fact, plus the recognition of other elements of the biodiversity, has meant that the Chiloé-Corcovado area, where communities of Guafo Island and Quellón town are located, is recognized today as important for conservation by national and international organizations such as IUCN, WWF, and TNC (Hucke-Gaete et al., 2006). Since then an increase of tourist activities focused on marine biodiversity of the area has occurred, with particular emphasis on the sighting of blue whales.

## Conservation Problems for Seabirds

The press has reported the sale of Guafo Island for coal mining, which is clearly a risk to the breeding population of Sooty Shearwater (Reyes-Arriagada et al., 2007).

The Sooty Shearwater has been classified as ‘‘Near Threatened’’ (IUCN 2014) due to the decrease in the abundance of the species in the California Current System (Veit et al., 1996) and the decline in populations and colonies in New Zealand (Hamilton et al., 1997).

These conservation problems may potentially affect the colonies of the austral Chilean archipelagos as a result of the introduction of predators and the interaction with fisheries (Reyes-Arriagada et al., 2007).

Interaction with other species of seabirds in the area has not been reported to date, although interaction occurs between the demersal fishery of the Patagonian toothfish *Dissostichus eleginoides* and the Black-browed albatross *Thalassarche melanophris* (Moreno et al., 2006) at the southern end of Guafo Island where the latter species benefits from fishery discards.

## Sensitizing/Awareness

Following the discovery of blue whales in the Chiloé-Corcovado area, complemented with the outstanding productivity and biodiversity of the area, its unique importance for many fish species, and marine mammals, as well as the growing number of threats to marine life in the area, national and international researchers promoted the establishment of a Marine and Coastal Multipurpose Protected Area in the Chiloé-Corcovado area. For this purpose, they used the blue whale as flagship and umbrella species (Hucke-Gaete et al., 2006). The proposal includes establishing monitoring plans leading to a comprehensive management plan, environmental education in local communities and environmental awareness at the national level, as well as the regulation and promotion of ecotourism related activities of interest to many local actors. Those tour operators who have started whale watching activities have noticed that not only this species provides opportunities for the development of ecotourism, but also other components of biodiversity including seabird species found in the area, provide opportunities for attractive field observations at sea in cases when whale sightings are not successful. This broader tourism offer on marine biodiversity sighting, including attractive seabirds, also reduces the pressure from tourists on the tourism operator to ensure whale sightings, the latter constituting only the "icing on the cake" in an ecotourism product that promotes marine biodiversity of the area as a whole. The information obtained on seabirds in the area of Guafo Island and surrounding seas has helped to supplement the database on biodiversity of species of interest for tourism, promoting their inclusion in conservation plans and increasing the demand by the community to keep ecosystems free of activities that may affect this source of local development.

## Navarino Island

### *Context*

Navarino Island is located within the Cape Horn UNESCO International Biosphere Reserve, which contains the southernmost forest ecosystems of the planet, and represents one of the most pristine wilderness areas in the world. It has a great diversity of ecosystems, and represents the southern distribution extreme of many animal and plant taxa from the species to the class level (Rozzi et al., 2007). The region is affected by the masses of Antarctic and subsurface waters related to the West Wind Drift from the South Pacific. Birds are the most diverse and abundant group of vertebrates, since there is a lack of large terrestrial mammals and herpetofauna (Rozzi et al. 2007, Rozzi & Jiménez 2013). Along the coast, there are significant colonies of Dolphin gull *Larus scoresbii*, Dominican gull *L. dominicanus*, Neotropical and rock cormorant, *P. brasilianus* and *P. magellanicus*, along with several marine species of geese and ducks, nesting dispersal in the upper limit of the high tide line (Pizarro et al., 2012). For human populations, the island represents the southernmost territory of the world with pre-Columbian settlement, currently with the presence of the ancestral of Yhagan people. In addition to members of indigenous groups, the community is composed of various actors, such as Chilean Navy base staff and their families (majority), fishermen, tour operators and people working in services (Rozzi et al., 2007), totaling about 2500 people. This diversity of people has different skills, interests and social, cultural and economic needs (Berghoefer et al., 2008) which need to coexist harmoniously.

Figure 1. Map of study areas in Chile, Southern South America.

## Conservation Problems for Seabirds

In the case of Navarino Island, one of the principal threats to coastal and marine birds is the spread of deliberately or accidentally introduced species such as the American mink *Neovison vison*, which exerts pressure primarily through egg predation, and the North American beaver *Castor canadensis* and muskrat *Ondatra zibethicus* (Anderson et al., 2006), which modify the composition and structure of watersheds and habitat. The American mink has recently established a feral population on Navarino Island where it is drastically affecting the reproductive success of ground nesting coastal seabirds, including solitary species (*Chloephaga picta*, *Tachyeres pteneres*) and colonial species (*Larus dominicanus*, *Larus scoresbii*, *Sterna hirundinacea*) (Schuettler et al. 2009). In the community there is still little awareness about the mink's impacts. However, a growing concern is expressed by local residents about the mink had caused the perceived decline of birds during the last number of years and feared negative consequences for tourism (Schuettler et al., 2011). Another threat to seabird populations and biodiversity in general is represented by exponential growth of the tourism industry by cruise ships in areas previously restricted by the Chilean Navy has led to an increasing number of landings on uninhabited islands and to unregulated tourism in channels and protected areas (Rozzi et al., 2007, 2010b). These places lack basic infrastructure, tour-guide information and park rangers; this type of unregulated tourism poses a threat to this remote wilderness region and to the breeding seabirds of the island (García 2004).

## Sensitizing/Awareness

The implementation of the Cape Horn Biosphere Reserve in 2005 has ensured the continuity of traditional activities and proposes their inclusion in a sustainable tourism development that benefits local people, particularly the Yhagan community, enriching the experiences of visitors (Rozzi et al., 2007, 2010b). From the point of view of the Government, the Cape Horn Biosphere Reserve aims to change a policy based on short-term extractive cycles to a long-term development point of view sustained in the ecological and cultural singularities of the territory. The Reserve promotes the value of ecological services for the wellbeing of communities and reveals the relevance of territory conservation to science, artisanal fisheries and sustainable tourism (Rozzi et al. 2007). The last, mainly through nature tourism, is the main attraction for visitors to the region (Chacón 2002, García 2004), because this area represents one of the last "wild" destinations for the global citizen who tends become more urbanized, industrialized and homogenized (Rozzi et al., 2010a). The research team of the Omora Ethnobotanical Park created the Sub-Antarctic Omora Bird Observatory in the year 2000 (Anderson et al., 2002), which has provided a useful starting point to gather basic information on the avifauna present in Navarino Island. As part of the activities of the Observatory, a plan of socialization and community education was implemented on the importance of the ornithological biodiversity heritage of the region. Emphasis is given to the K-12 levels for environmental education, because they show the most readiness to explore these issues. However, the adult population is also included, particularly the guides and tour operators who live in the town of Puerto Williams on Navarino Island. In order to increase the appreciation of birds by the local community, activities have included the identification of the most charismatic bird species for the community, importantly the Magellanic Woodpecker *Campephilus magellanicus*, incorporating environmental education strategies, development of educational material and outreach activities (Arango et al., 2007). Since 2000, these activities are carried on permanently in the school, with the help of researchers and practitioners from Omora Park (administrated by the University of Magallanes, Omora Foundation and Institute of Ecology and Biodiversity in Chile and the University of North Texas, in the United States), incorporating the topics of bird biodiversity in terrestrial and marine environments. Workshops and training for the adult community are also conducted through theoretical and field activities, emphasizing "face to face" encounters between human and birds to conduct activities such as the development of special interest tourism with low impact to the ecosystem through awareness, management and conservation of birds (Rozzi et al., 2010a). Thus four benefits are obtained by working with the community: i) these dynamics allow the residents of the community to discover the rich cultural diversity of Cape Horn; ii) field experiences help to interrelate this cultural diversity with birds and other species that inhabit the landscapes of Cape Horn, iii) the relationship between the two diversities allows workshop participants to make a synthesis to enable an understanding of sub-Antarctic biocultural diversity; and iv) finally, this understanding allows incorporation of the singularities of the sub-Antarctic biocultural diversity in regional education programs, policies and environmental decision-making relevant to the wellbeing of many inhabitants and biocultural diversity conservation (Rozzi et al., 2010a,b), including the diversity of seabirds in the island.

## DISCUSSION

There is a growing recognition that relying solely on conventional, disciplinary and specialized scientific approaches is insufficient in the face of the complexity of conservation problems. Complex adaptive systems involving human uses and impacts often cannot be separated from topics of value, equity and social justice, and they require a participatory approach in which scientists need to work with local people to promote autonomy in conservation actions of the community when scientific research or particular projects end (Ludwig 2001, Moller et al., 2004). Characteristics of the island communities may be viewed as positive, neutral or negative, according to strengthening strategies for conservation planning. We may consider the concept of social capital that consists of social ties, levels of trust and level of civic engagement as a negative point of view for conservation planning. Community networks, group membership and social participation, despite the relatively high levels of generalized trust, are of low relevance in life of island people. Social participation is a mechanism through which community identity is activated only under certain circumstances, such as in need or emergency and in collective social events. This type of social participation is unrelated to civic engagement (Zissi et al., 2010). But we may consider that participation in social events can be useful in conservation plans if these include activities such as soccer tournaments, song festivals, thematic parties, etc., focusing on the awareness for a particular species. In contrast, other aspects perceived by island communities can be used in a positive way to develop conservation management. Zissi et al., (2010), describe the rural island communities with pre-modern socio-economic features facing severe demographic imbalance. This work also illustrates island rural communities of high devotion with deep roots and psychological sense of place. Their residents depend very much on systems of symbols and meanings which are collectively shaped. Both primary and secondary ties play a significant role in people’s realities despite the competitiveness and tensions that frequently characterize small and spatially dense settlements.

By contrast, perceived civic is low due to their accounts of limited choices, poor resources, few links with external agents and their perception that they have no say in decision making. This implies that there is a good chance to promote a symbol of pertinence, with patrimonial character, enabling the community to generate, through recognizable and unique character elements, a local identity that can be used as a product to enhance economic benefits.

Remote locations are one of the destinations that today have become important for a tourist sector looking for this kind of less traditional tourism experiences. This activity usually is developed through practices of tourism of special interest in rural nature, and involving the connection with the environment, both in human and non-human dimension implying no overcrowding. For the community, tourism of special interest provides the opportunity to implement these thematic activities with a high degree of originality and exclusivity with respect to similar initiatives in other communities, by the own character of biodiversity present.

From the five cases described above, we identified seven features that are common, in terms of care and positive use that local community must do about the diversity of seabirds present on each island:

1. Presence of researchers that help to gather information on the biology, ecology and conservation status of species of seabirds.
2. Development of educational workshops for the school community of the island in at least one of the levels of education.
3. Development of educational and training workshops for local guides and tour operators living on the islands.
4. Use of bird species as charismatic, iconic and/or flagship species as part of community outreach and engagement.
5. Dissemination of education and conservation activities through the media, both locally and regionally.
6. Integration of NGOs and government agencies to help implement conservation activities.
7. Development of low impact tourism activities linked to seabird species and biodiversity of the area.

## TEN STRATEGIES TO IMPLEMENT CONSERVATION PLANS AT THE LOCAL LEVEL IN INSULAR ECOSYSTEMS

As a way to complement the statements described above and to systematize a socio-ecological conservation planning we used the principles proposed by Rozzi et al., (2006). Due to the integrative nature of these principles, they can be useful as a basis for implementing conservation plans for local Chilean island systems with similar characteristics. Rozzi et al., (2006) identified ten principles that have been effective for integrating long-term socio-ecological research in the implementation of sustainable environmental policies, in which participants from universities, local communities and the Chilean Government were involved. Also, the NGO Pacific Invasives Initiative has developed five social principles for partnerships with communities (Towns et al., 2011), that are in line with principles stated by Rozzi et al., (2006). Based on their implementation, these are described from lesser to greater complexity:

1. *In situ* experience of the community, researchers, policy makers, and others involved in "direct encounters" with humans and non-humans in their habitats of origin.
2. Participatory approach, not only providing information, but sharing work processes in education and conservation; understanding the problem through education and/or research.
3. Identification and implementation of charismatic species that act as symbols of local or regional biocultural richness.
4. Continuous dissemination of results, conflicts and actions through media.
5. Transdisciplinary integration of the sciences, the arts, philosophy and environmental decision-making.
6. Interagency cooperation, public and private.
7. Collaborative networking with research, education and/or conservation at local, regional, national and international levels to identify causes and define solutions to existing environmental problems, ensuring that communities participate in their implementation.
8. Economic sustainability, through activities that link biodiversity and local economic practices (e.g. programs of special interest tourism).
9. Administrative sustainability, through the provision of infrastructure, conservation areas and programs of long-term research.
10. Conceptual sustainability through the development of transdisciplinary research, education and conservation, coupled with local, national and international political, economic and environmental dynamics.

Finally, we must not forget that the conservation of seabird species on inhabited islands depends heavily on the engagement and commitment of the local community. Therefore, community-based seabird conservation projects should explicitly consider the continuity of project-related activities by the community, independent of whether ongoing funding sources exist. The lack of a long-term commitment to supporting such projects can cause communities to question the importance of the work and, in turn, can lead to disengagement and loss of local support. In the process of instilling cultural heritage and biodiversity values in the consciousness of the community, this focus should never be lost, because the island community will be instrumental in determining the long-term success of any conservation plan of the fauna and flora of the region.

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*Chapter 3*

# SEABIRD CONSERVATION IN FISHERIES: CURRENT STATE OF KNOWLEDGE AND CONSERVATION NEEDS FOR ARGENTINE HIGH-SEAS FLEETS

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## ABSTRACT

Interactions between pelagic seabirds (albatrosses and petrels, Procellariiformes) and fisheries occur in all oceans of the globe, virtually in all fisheries, and are dominated by the effect of fishing on birds. Despite the fact that provisioning of fishery discards and offal to birds can be viewed as beneficial, incidental mortality in fisheries is by far the main at-sea threat albatrosses and petrels are facing nowadays, and certainly the main cause of declinations in populations recorded in modern days. This chapter offers an overview of interactions between pelagic seabirds and high-seas Argentine fishing fleets, including longliners, trawlers and jiggers. The first section of this review looks into the nature of interactions between seabirds and fisheries, particularly in the Southwest Atlantic Ocean. The second section seeks to define the fishing effort of the different

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fleets operating in national waters providing a summary of extant fishery regulations and management measures related to the main target species, the Argentine hake *Merluccius hubbsi*. The third section explores available information regarding conservation status and use of marine space by seabirds attending and interacting with a number of high-seas fisheries, including bycatch levels and mitigation measures, as well as issues dealing with the implementation and compliance of conservation and management measures. The fourth section provides insight into the use of fishery discards and offal by non-breeding pelagic seabirds attending vessels, taking the Black-browed Albatross *Thalassarche melanophris* as a case study. Finally, the fifth section reviews the up-to-date scientific, legal, and political actions taken to protect seabirds in Argentine waters, referring to possible steps for implementing an ecosystem approach to national fisheries within the frame of Argentina's National Plan of Action – Seabirds.

## ACRONYMS

| | |
|---|---|
| **ACAP** | Agreement on the Conservation of Albatrosses and Petrels |
| **ACS** | Argentine Continental Shelf |
| **CCAMLR** | Commission for the Conservation of Antarctic Marine Living Resources |
| **CFP** | Consejo Federal Pesquero (*Federal Fisheries Council, Argentina*) |
| **CTMFM** | Comisión Técnica Mixta del Frente Marítimo (*Argentine-Uruguayan Joint Technical Commission of the Maritime Front*) |
| **DEJUPA** | Dispositivo para el Escape de Juveniles de Peces en las redes de Arrastre (*Juvenile Fish Bycatch Reduction Device for Trawl Net*) |
| **EEZ** | Exclusive Economic Zone |
| **FAO** | United Nations Food and Agriculture Organization |
| **INIDEP** | Instituto Nacional de Investigación y Desarrollo Pesquero (*National Institute for Fisheries Research and Development, Argentina*) |
| **IUCN** | International Union for the Conservation of Nature |
| **MINAGRI** | Ministerio de Agricultura, Ganadería y Pesca (*Ministry of Agriculture, Livestock and Fishing, Argentina*) |
| **PAN-AM** | Plan de Acción Nacional – Aves Marinas (*National Plan of Action – Seabirds, Argentina*) |
| **SAGPyA** | Secretaría de Agricultura, Ganadería, Pesca y Acuicultura (*Secretariat of Agriculture, Livestock, Fishing and Aquaculture, Argentina*) |
| **SSPyA** | Subsecretaría de Pesca y Acuicultura (*Under Secretariat of Fishing and Agriculture, Argentina*) |
| **SWAO** | South West Atlantic Ocean |
| **UNESCO** | United Nations Educational, Scientific and Cultural Organization |
| **VMS** | Vessel Monitoring System |

# 1. COMMERCIAL FISHERIES AND THEIR IMPACT ON SEABIRDS

## 1.1. Grown of Fisheries and Impacts on Marine Ecosystems

Since the 20th century, human population and technological capabilities at sea, as well as the demand for marine products, have grown on a large scale. Favored by the combination of population growth, rising incomes and urbanization, a steady growing of fish production and the improvement of distribution channels, the global fish food supply has grown considerably in the past five decades, with an average annual growth rate of 3.2%, exceeding the annual growth rate of human population (1.6%) (FAO, 2014). In particular, the catch of the world's marine fisheries increased five folds in less than 50 years, stabilizing around 90 million tons per year by mid-1990's (FAO, 2014). This increase has not only affected fishery resources globally but also altered the structure of marine ecosystems, resulting in severe depletion of populations at high trophic levels (e.g. seabirds, marine mammals, sea turtles and highly migratory fish), and spreading throughout communities of interacting species through indirect effects (Dayton et al., 1995; Montevecchi and Kirk, 1996; NRC, 2006; Pauly, 2010), leading to a current scenario where almost 61% of the world fish stocks are considered fully fished, nearly 29% overfished and the remaining 10% moderately exploited (Pauly et al., 2002; FAO, 2014). This indicates that the approach of modern day fisheries management (primarily focused in target species) have not provided the necessary framework for protecting fish populations and related/dependent species and their environments. For example, the common use of maximum sustainable yield in the management of single-species fisheries has largely led to stock depletions (Botsford et al., 1997; Christensen et al., 2003). Though the industry have been making global efforts to improve the size and quality of commercial landings, little attention has been given to the ecosystem implications of these extractive activities until recent years, including the magnitude and fate of bycatch and discarded target and non-target species (both benthic and pelagic, including seabirds, marine mammals and sea turtles) (Hall et al., 2000; Moore and Jennings 2000; among others), indirect effects such as the removal of one species leading the profit or detriment of another, and habitat impacts (Dayton et al., 1995; NRC, 2006). Finally, growing concern over the state of the marine environment, and the fisheries sustainability, has led to a shift in the focus of fisheries management, from a single-stock approach to management which takes into account the entire ecosystem, including humans (Browman and Konstantinos, 2004; Piatt et al., 2007; FAO, 2009a; Hobday et al., 2011). This means that the ecosystem effects of fishing should include a wide range of biological interactions from changes in predator-prey relationships and nutrient dynamics, effects on non-target species through incidental capture, "cascading" effects mediated by food-web interactions, and the loss or degradation of habitats (NRC, 2006; FAO, 2009a; Pauly, 2010).

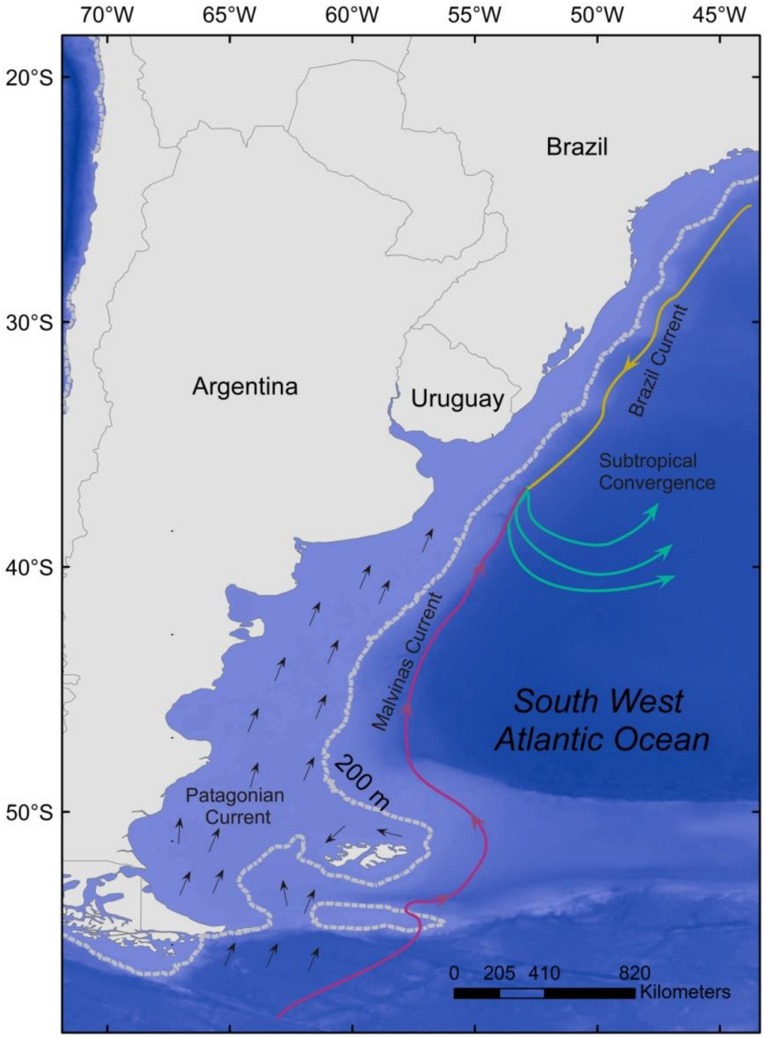

Figure 1. Southeast Continental Shelf of South America and its dominant water masses.

### 1.2. South West Atlantic: A Great Marine Productive Area

The marine ecosystem of the Southwest Atlantic Ocean (SWAO) ranges from 23° to 55°S thus extending throughout the southeastern coastal and shelf waters of Argentina, Uruguay and southern Brazil (Sherman et al., 1992; Bisbal, 1995). This area has attracted many commercial expeditions from several European and North American countries since the 17th century being the Estrecho de Magallanes (*Strait of Magellan*) the only route of communication between the Atlantic and the Pacific at those times. By the following century several marine mammal and seabirds' populations were heavily exploited by commercial activities, and native communities especially those from Tierra del Fuego archipelago (Goodall, 1979; Borla and Vereda, 2006). Scientific expeditions from Europe started during the mid-18th century increasing significantly during the nineteen century being the most famous expeditions of HMS *Beagle* (1831-1836) and of HMS *Challenge* (1876) setting modern oceanographic research. By the 20th century scientific focus was set on Antarctica via South America, being the most famous expedition of *Discovery* (1931-1935) developing marine sciences in the area. It's being over 50 years since UNESCO via several FAO's Fisheries Development Projects promoted the creation of a number research groups -thus increasing oceanographic studies in the area combined with several European and Asian cruises which updated the knowledge of biodiversity in the SWAO, also assessing its fishery resources (Cousseau and Perrotta, 2004; Bastida et al., 2005).

From an oceanographic point of view, the SWAO is regulated by two main water masses. On one hand, the Malvinas Current, a northward flowing branch of the sub-Antarctic Cabo de Hornos Current, influences both coastal and offshore areas as it separates on its way north and reaching Cabo Frio (Brazil) as a coastal upwelling. On the other hand, the Brazilian Current, a southbound branch of the South Equatorial Current, moves along the Brazilian coast (Boltovskoy, 1981; Guerrero and Piola, 1997). These two water masses meet at the Subtropical Convergence located around 35°S, affecting mainly oceanic areas and to certain extent the continental shelf (Figure 1). A third water mass, the Patagonian Current (of sub-Antarctic origin) is restricted to the coastal zone of Patagonia, flowing between the coast and Malvinas Current, reaching up north up to 38°S. In particular, the region covered by the Argentine Continental Shelf (ACS) is one of the most extensive marine areas of the world with *c.* 1,000,000 square kilometers and is comprised largely by an underwater plateau of less than 100 m deep and bathed by waters whose temperatures range from to 6° to 18°C. The relative influence of the Malvinas and Brazilian currents over the ACS coupled with other processes operating at a smaller scale such as tides, winds and river discharge generate several fronts promoting the production and/or concentration of phytoplankton and zooplankton, and the consequent development of major communities of fish, crustaceans and squid (Acha et al., 2004; Balech and Ehrlich, 2008). This is a rich marine ecosystem of global importance with high biodiversity endemism and high biomass of some species, offering abundant food for a number of local and migratory top predators including seabirds, marine mammals, and sea turtles (Croxall and Wood, 2002; Bastida et al., 2005; Favero and Silva Rodríguez, 2005; Campagna et al., 2008; González Carman et al., 2008), being regarded as one of the world's most productive ocean regions. The fish diversity of the Argentine Sea and adjacent waters between 34° and 55°S is very important, being comprised by 450 species out of which about 60 are relatively common and 40 commercially exploited (with seven species representing more than 70% of the total national catch) (Cousseau and Perrotta, 2004). Among the invertebrates, most marine biodiversity include benthic species (Briggs, 1996) and to a much lesser extent planktonic organisms (Boltovskoy et al., 2003).

## 1.3. Use of the Marine Space by Seabirds and Their Overlap with Human Activities

Albatrosses and Petrels (Order Procellariiformes) are amongst the most pelagic seabirds and occur in all of the world's oceans, spending most of their lives foraging over vast tracts of water. The large creatures called "albatross" are the greatest long-distance wanderers of earth. Their wing shape, similar to that of sailplanes, is ideal for exploiting prevailing winds, thus enabling them to glide maximizing forward movement with a minimum of drop of wind

(Warham, 1996). Flying fast and expending little energy, an albatross can search for food thousands of kilometers from it nest. Albatrosses and petrels convey a range of information on the marine environment as they can cover in relatively short time very large areas, locate prey very efficiently, and preying on multiple trophic levels often including commercially important fish (Monaghan, 1992; Einoder, 2009). Seabirds such as albatrosses and petrels (Figure 2) represent good models to investigate ecological questions in the wild due to their extreme life-history traits, including low fecundity and productivity, late age at maturity, and long life expectancy, characteristic of ‘K’-selected species (Warham, 1996; Gales, 1998). Most of these species show small breeding populations and many are in decline, as their demographic characteristics severely limit their rate of recovery (especially those species breeding biennially). The reasons for these declines are largely anthropogenic since humans have been killing (intentionally or incidentally) albatrosses since they went out into the oceanic region. Firstly, the widespread commercialization of feathers and oil in the late 19th century heavily impacted several albatross species in both hemispheres, driving some of them close to the extinction (Croxall, 1998; Medway, 1998). During the latter half of the 20th century and well into the 21st, the incessant drive to feed the worlds’ ever-expanding demand for seafood has by far made the greatest, yet most devious impacts on albatross survival. In modern days increased at-sea mortality of adults and juveniles in fisheries were linked to the global population declines of many albatrosses and petrels, which have been extensively recognized as one of the most threatened group of birds (Gales, 1998; Gales, 2008; ACAP, 2012a; BirdLife International, 2012). Of all the albatross demographic parameters, changes in adult and juvenile survival via incidental mortality in fisheries have the most immediately important factor influencing population trend. Consequently, at sea threats for these birds are of higher concern when compared with those affecting populations in the breeding grounds such as introduced predators (Gurevitch and Padilla, 2004; Croxall et al., 2012).

For many albatrosses and petrels the year-round at-sea distribution strongly correspond with those of high abundance of prey which are favored by the presence of temperature gradients, salinity or topographic accidents as continental slopes, shelves, sea mounts, among others (Ainley et al., 2005; Balance et al., 2006; Hyrenbach et al., 2007; among others). For many humans, the best fishing grounds are found above continental shelves (less than 200 m deep), where a rich diversity of phytoplankton and zooplankton flourish (Sherman et al., 1992; Sherman and Duda, 1999). The world’s most extensive continental shelves are located in high or mid-latitudes, chiefly in the northern Hemisphere. Still, the foraging distributions of several Procellariform species strongly overlap throughout their entire annual cycle with commercial fisheries globally (BirdLife International, 2004; Anderson et al., 2011). In the South Atlantic, the waters off Argentina and its shelf-break constitute an important ecosystem of global importance due to the high abundance and diversity of marine vertebrates, particularly seabirds (some 17 and 40 breeding and non-breeding species, respectively) (Yorio et al., 2005; Favero and Silva Rodriguez, 2005; Seco Pon et al., 2007; Tamini and Chavez, 2014), some of which travel very long distances from the Southern Ocean, Australia, New Zealand and the East Atlantic to forage there (Croxall and Wood, 2002; Favero and Silva Rodríguez, 2005; Seco Pon and Tamini, 2013; Tamini and Chavez, 2014).

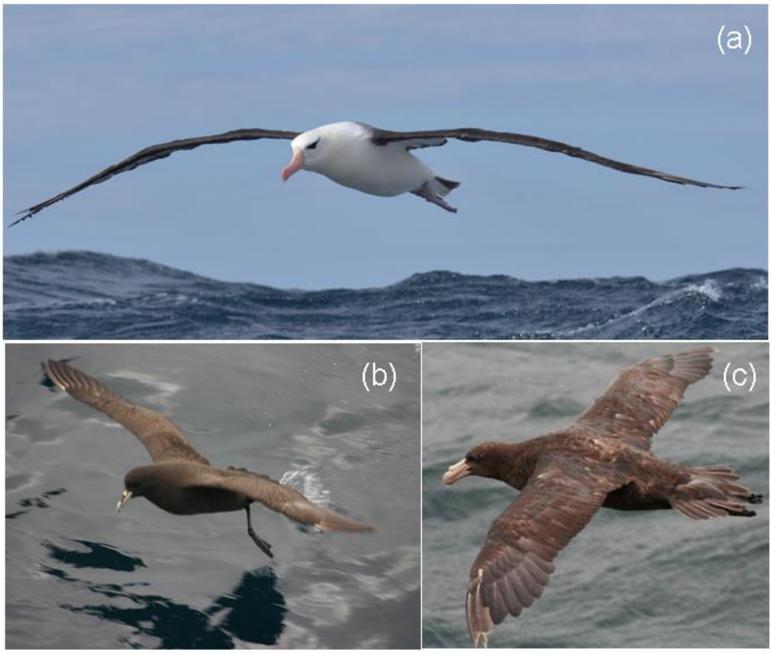

Figure 2. Procellariiforms species most commonly attending the Argentine Continental Shelf: the Black-browed Albatross *Thalassarche melanophris* (a), White-chinned Petrel *Procellaria aequinoctialis* (b), and Southern Giant Petrel *Macronectes giganteus* (c).

## 1.4. Interactions between Seabirds and Fisheries

Interactions between seabirds and fisheries occur in all oceans of the globe, virtually in all fisheries and comprising at least 40 seabird species (BirdLife International, 2012). The majority of these interactions are direct consequence of seabirds feeding in the same (highly productive) areas where fisheries range, and/or an indirect consequence of the attraction generated by the discards and offal produced by vessels (Dayton et al., 1995). Interactions between seabirds and fisheries are dominated by the effect of fishing on birds and classified as direct or indirect either positive or negative (Tasker et al., 2000; Montevecchi, 2002). The entanglement or hooking of seabirds in different fishing gears and the provisioning of fishery discards and offal to birds are considered direct effects, and will be the topic of debate here. Seabird bycatch occurs in vessels using different fishing gears such as gillnet, pelagic and bottom longlines, and trawl nets, among others (Anderson et al., 2011; Zŷdelis et al., 2013). Gillnets (monofilament) either set and drift, are commonly used in a number of fisheries including Pacific *Oncorhynchus* spp. and Atlantic *Salmo salar* salmon, capelin *Mallotus villosus*, cod *Gadus* spp., and halibut *Hippoglossus* spp., among others. These gears caused mortality by capturing diving birds[1] (e.g. murres, shearwaters, cormorants, penguins, and sea

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[1] During its peak of fishing effort, gillnet fisheries killed up to c. 12 million Sooty *Puffinus griseus* and up to 21 million Short-tailed shearwaters *P. tenuirostris* (Uhlmann et al., 2005) between 1952 and 2001. Other species affected by gillnetting were the New-Zealand Yellow-eyed penguin *Megayptes antipodes* and murres *Uria aalgae* and *U. lomvia* in the North Atlantic and North Sea (Melvin et al., 1999; Darby and Dawson, 2000). Since 1991, the use of gillnets has been banned in international waters by Resolution 46/215 of the United Nations. However, gillnet fishing may occur within the 200 nautical miles off the coast in the country's

ducks) among other top predators (Bull, 2007; Bull, 2009). So far, mitigation measures for reducing the incidental catch of seabirds in gillnet fisheries is scarce. Methods based on alerting birds of the presence of the net and reducing the interactions by setting the nets at greater depths than diving birds have been identified as mitigation measures for these fisheries (Løkkeborg, 2011). After high-seas gillnets were banned in 1991, much of the fishing effort subsequently shifted its approach to the use of longlines (Brothers et al., 1999), an ancient fishing method used in all oceans around the globe (Bjordal and Løkkeborg, 1996). Longline fishing (both pelagic and bottom) was long considered as highly selective practice, primarily capturing the target species and causing little disturbance to the fishing habitat (Løkkeborg, 1999). However, bycatch in longline fisheries occur when seabirds try to snatch bait off the hooks as the longline is set. Longlines are attractive to seabirds as these fisheries use as bait small fish or squid normally beyond their diving depth, making these preys briefly available during the line setting (Brothers, 1991; Robertson, 1998; Anderson et al., 2011). Although the effects of longlines can vary, they tend to kill chiefly surface-feeding scavengers (like albatrosses) or surface-divers (such as Procellaria petrels) or opportunists, which flock around boats and try to steal the bait off of hooks (e.g. albatross, petrels, skuas and gulls). Longline bycatch of albatrosses and petrels[2], continue to be the greatest threat to pelagic seabirds globally (BirdLife International, 2012; ACAP, 2012a). Mitigation measures for reducing seabird bycatch in this type of fishery will be described elsewhere along this chapter (see Section 3.1).

Trawl fisheries became recognized as a threat to seabirds during the 1990s (Bartle, 1991; Williams and Capdeville, 1996) and in current days, considering that c. 30% of the global annual fishery catch is captured by trawl gear (Watson et al., 2006), it is estimated that 45% of the total annual seabird bycatch may be associated with these fisheries (Baker et al., 2007). Strikes with the vessels and warp and netsonde cables, and entanglements with nets and other components of the fishing gear[3] are the recorded causes of mortalities and serious injuries of seabirds (Wienecke and Robertson, 2002). Though trawl fisheries show high discard rates and lower bycatch relative to longline and gillnets, they are receiving greater attention as a conservation concern, not only for the bycatch of albatrosses and petrels recorded, but also for gannets, boobies and pelicans (Sullivan et al., 2006; Zador et al., 2008). Methods for reducing seabird interaction with trawl fishing gear will be discussed further ahead along the chapter (see Section 3.1). It should be stressed that birds hauled aboard either in hooks, nets and cables represent a small proportion of those actually killed during fishing operations (Weimerskirch et al., 2000; Brothers et al., 2010, Gilman et al., 2014).

Fishery discards and offal exists in virtually every high seas and coastal fishery around the globe (Champhuysen et al., 1995; Belda and Sanchez, 2003). Globally it is estimated that discard levels reached approximately 7 million tons (Kelleher, 2005). In this sense, the

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economic zones. In Europe, for example, coastal gillnets is widespread in the Baltic Sea and the North Sea. In a recent review, Zŷdelis et al. (2009) estimated that between 100,000 and 200,000 birds die annually, including sea ducks, diving ducks, cormorants and alcids during gillnetting operations.

[2] The largest bycatch of seabirds have been documented in the Southern and Pacific oceans, where annual mortality was estimated in 44.000 albatrosses in Japanese tuna fisheries over two decades ago (Brothers, 1991). In a global review, Anderson et al. (2011) estimated that 160,000 seabirds were killed globally each year in at least 69 longline fisheries reviewed. The highest levels of seabird bycatch were identified in the Gran Sol area, the Japanese pelagic tuna fleet in the North Pacific, the Namibian hake fleet and the Nordic demersal fleet.

[3] For example, in waters bathed by the Benguela Current, Watkins et al. (2008) estimated that c. 18,000 albatrosses per year were killed in association with bottom trawlers chiefly due to strikes with warps, although current mortality levels are much lower thanks to the implementation of mitigation in a range of fisheries.

provision of food via fishery discards (non-target species and/or undersize target species) and offal (including guts, heads, and tails) is for seabirds and other top predators attending fishing vessels a predictable and abundant source of food (Bartumeus et al., 2010). Although this resource could be understood as beneficial (subsidy) for these species (see Garthe et al., 1996; Bertellotti and Yorio, 2000), it is clear that for low productive seabird species such as albatrosses and petrels, the negative effect of incidental mortality on albatross populations is by far more important than any positive effect (Finkelstein et al., 2008). The role that fishery discards and offal play in the population dynamics of attending seabird species may not only be affecting the birds locally (Skov and Durnick, 2001) but also be more complex than previously thought (Wagner and Boersma, 2011). Although for some birds species fishery discards and offal have a positive net effect on their populations (Montevecchi, 2002), some studies suggest that discards and offal would not represent a subsidy at all, since its nutritional content is lower than the regular prey; coined the “junk-food” hypothesis (Romano et al., 2006; Grémillet et al., 2008). In the Cape hake *Merluccius capensis* fishery off the Benguela Current, for example, discards were significant only for non-breeding Cape gannets *Morus capensis* through reduction in their foraging effort and increasing survival (Grémillet et al., 2008). When breeding adults were forced to rely on discards due to overfishing, a decreased reproductive success was revealed, chiefly due to the lowered nutritional content of discards when compared with normal pelagic prey (Grémillet et al., 2008). Among seabirds, coastal foragers such as large gulls *Larus* spp. seem to be the major beneficiaries of fisheries discards and offal subsidizing their daily intake. However, some authors have postulated that the expansion of some Procellariforms such as the Northern Fulmar *Fulmarus glacialis* and the Southern Giant Petrel *Macronectes giganteus* has resulted, at least partially, from increased availability of fish offal and discarded fish from commercial fisheries operating in the North Atlantic and in Patagonia respectively (Fisher, 1952; Camphyusen and Garthe, 1997; Quintana et al., 2006). In line with this, other studies on coastal seabirds have recorded increase in productivity and a decrease in age at first reproduction (Garthe et al., 1996; Furness, 2003; Votier et al., 2004). In Argentine Patagonia, Bertelloti and Yorio (2000) estimated that discards produced in the San Matias Gulf fishery could provide food to more than 30,000 Kelp gulls *L. dominicanus* attending the coastal vessels. The offal generated onshore by processing factories located in Chubut could hold between 100,000 and 210,000 individuals annually. It is clear that this type of subsidy has been responsible of, at least partially, the population increase that this gull species has had in recent years (Bertellotti and Yorio, 2000; Lisnizer et al., 2011), which in turn has resulted in negative impacts on other coastal species through increased predation, competition for breeding sites and kleptoparasitism (Quintana and Yorio, 1999; Yorio et al., 2005). Furthermore, population increases of this gull may have brought detrimental effects on other taxa such as the Southern Right whales *Eubalaena australis* in Peninsula Valdes, as gulls have learnt to feed on the skin and fat of the whales affecting its behavior because of produced injuries (Fazio et al., 2012). Consequently, some apparent benefits of this type of anthropogenic subsidized food on a single species may in turn lead to unfavorable effects at an ecosystem level (Dayton et al., 1995; Gislason et al., 2000; Hobday et al., 2011).

**Table 1. Characterization of the Argentine high-seas fisheries**

| Name* | **Ice-trawlers** | **Freezer trawlers** | **Bottom-demersal longliners** | **Jiggers** |
|---|---|---|---|---|
| Fleet strata | Industrial "*freshie* " | Industrial freezer | Industrial freezer | Industrial freezer |
| Catch condition | Preserved fresh in ice | Deep frozen | Deep frozen | Deep frozen |
| Length (m) | 20-72 m | 30-118 m | 45-56 m | 32-72 m |
| Fishing gear | Demersal trawl-net | Demersal trawl net | Bottom-demersal longline | Automated lines |
| Target species | Argentine hake (*M. hubbsi* ), Chub mackerel (*S. japonicus* ), and skates *D. flavirostris* and *Bathyraja* spp. | Argentine hake (*M. hubbsi* ) | Patagonian tootfish (*D. eleginoides* ) and Kingclip (*G. blacodes* ) | Argentine squid (*I. argentinus* ) |
| Discard management | Not equipped with fish meal plants; discharged waste ocurrs without any processing | Equipped with fish meal plants; discharged waste ocurrs without any processing | Equipped with fish meal plants; discharged waste ocurrs without any processing | Equipped with crashers; discharged waste ocurrs without any processing |
| Number of vessels | 230 | 135 | 3 o 4 | 80 |
| Area of operation** | AEEZ | AEEZ | AEEZ | AEEZ |

*Fishing gear and target species were defined for each fleet strata on the basis of the Argentinean National Plan of Action - Seabirds (2010).

**AEEZ stands for the Argentinian Economic Exclusive Zone.

## 2. THE ARGENTINE HIGH-SEAS FISHERIES

### 2.1. Characterization of Fleets, Fishing Effort and Commercialization

The Argentinean Continental Shelf is a ground for large high-seas commercial fisheries, including longliners, trawlers, and jiggers (*National Plan of Action – Seabirds*, Plan de Acción Nacional – Aves Marinas, PAN-AM, 2010) (Table 1). Longliners (all freezing the catch onboard) are roughly between 45 to 55 m long, with 1000 to 2200 HP, and carrying capacities ranging from 180 to 800 $m^3$. Vessels are equipped with crushers, discharging waste (including discards and offal) without any processing from commercially valuable fish species. Although the patterns in the fishing operation might slightly change from year to year, each vessel commonly make some 5 to 6 trips per year, with each trip lasting c. 50 days in average (Favero et al., 2013). The national longline fishery can be divided into two categories or fleets according to the fishing gear used, the target species, and the area of operation as follows: (1) vessels using exclusively autoline (Mustad) system and primarily targeting Patagonian toothfish *Dissostichus eleginoides* using the Argentine shortfin squid *Illex argentinus* and jumbo squid *Dosidicus gigas* as bait in southern Patagonia over the continental slope, shelf break and in the vicinity of Namuncurá (Burdwood) Bank, and (2) vessels using Spanish or autoline system (some of which latter shifted to “cachaloteras[4]”, also known as the umbrella-and-stones system or Chilean mixed system, see Moreno et al., 2008 and Goetz et al., 2011) targeting both Patagonian toothfish and Kingclip *Genypterus blacodes*, and using the Argentine shortfin squid and sardines *Sardina* spp. as bait, and operating chiefly on the central Patagonian shelf and shelf break (Table 1) (PAN-AM, 2010).

The number of operative longliners is in current days between 3 and 4 and the total catch during 2012 was 2,117 tons, representing 0.31% of the total catch in Argentina (Ministerio de Agricultura, Ganadería y Pesca – MINAGRI, 2014). The trawl fishery contains c. 370 operative vessels[5] (ice- and freezer-trawl fleets combined) fishing in Argentine waters between 35° and 54°S (PNA-AM, 2010; Copello et al., 2014). The national (bottom-demersal) trawl fishery can be divided into two main fleets according to the preservation method of the catch and the area of operation as follows: (1) vessels preserving the fish exclusively in ice within plastic cubes (c. 0.05 $m^3$) and operating along the continental shelf between 37° and 48°S (c. 230 ice-trawlers), and (2) vessels freezing the catch onboard (c. 135 freezer-trawlers) in fishing grounds concentrated between 45° and 48°S, extending north up to 42°S (Table 1) (PNA-AM, 2010; Copello et al., 2014). The ice-trawl fleet is comprised by vessels roughly between 19 and 65 m long, with 500 to 1300 HP, having a carrying capacity of 140 to 390 $m^3$, and not equipped with fish meal plants thus discharging waste (discards) without any processing from commercially valuable fish species. Each vessel commonly operates a minimum of 130-150 days $year^{-1}$ and performs some 600 sets $year^{-1}$ during trips lasting between 4 and 15 days (Favero et al., 2011). While the part of trawl fleet that freezes

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[4] The “cachalotera” is a new technique adapted from longline fisheries used by artisanal fisheries targeting Patagonian toothfish in Chile. This system was modified to include a net-cone located on the secondary lines in order to reduce predation of the catch by toothed whales (*Orcinus orca* and *Physeter macrocephalus*). Although it was not originally designed for seabirds, this modification has shown to have very low levels of bycatch in birds (Moreno et al., 2008).

[5] If the national coastal fleet is added, then the size of the overall trawl fleet will varied between 800 and 1000 vessels (PAN-AM, 2010).

the catch onboard contains vessels roughly between 29 and 118 m long, with 1430 to 4100 HP, having a carrying capacity of 500 to 2600 m$^3$, and equipped with fish meal plants thus discharging waste (including discards and offal) without any processing from commercially valuable fish species. Each vessel commonly operates a minimum of 250 days year$^{-1}$ performing between 2800 and over 62,000 sets year$^{-1}$ in trips that last between 40 and 50 days. The main target species for both trawl fleets is the Argentine hake *Merluccius hubbsi* (c. 63% and c. 33% of the total catch, respectively) (MINAGRI, 2014), followed by Hoki *Macruronus magellanicus*, Kingclip and the Argentine shortfin squid *Illex argentinus*, among others, in the case of ice-trawlers (Favero et al., 2011). The ice-trawl fleet occasionally targets pelagic species like Argentine anchovy *Engraulis anchoita* and Chub Mackerel *Scomber japonicus*. The shrimp trawlers (considered as part of the freezer trawl fleet) targeting the Argentine Red Shrimp *Pleoticus muelleri* operates chiefly in waters of San Jorge Gulf, and thus excluded from this analysis. Finally, the national jigging fleet is comprised by c. 80 vessels ranging from 32 to 72 m long, with 1200 to 2000 HP, having a carrying capacity of 105 to 3900 m$^3$, and equipped with fish meal plants thus discharging waste (primarily offal and some discards) without any processing from commercially valuable fish species. Each vessel commonly operates a minimum of 200 days year$^{-1}$ and performs some 990 hours/lines year$^{-1}$ during trips that last around 100 days (Table 1). The target species for the jigging fleet is the Argentine squid *I. argentinus* (100% of the total catch in 2012) (MINAGRI, 2014).

In particular, the bottom-demersal longline fisheries started in Argentina in the late 1980s (based at ports in southern Patagonia) and reached their peak in fishing effort during the mid-1990s, when some 12 longliners were in operation, chiefly targeting Patagonian toothfish, Kingclip, and Yellownose skate *Dipturus flavirostris*, using either Spanish or Mustad gears. The longline fishery in Argentina has experienced an important reduction during the last decade or so both in the number of vessels and hooks set (*i.e.* from some 30 million to 5 million hooks set per year, Favero et al., 2013). By the late 1990s the number of bottom-demersal longliners had declined to the current level of 3 to 4 vessels, with average catches in the period 2000-2012 of 128,470 tons (MINAGRI, 2014). In contrast, the trawl fishery started in the early 20th century, firstly in southeastern Buenos Aires Province and latter spreading into Argentine Patagonia. Since its inception this fishery was geared towards fishing Argentine hake, among other species. The expansion of the trawl fleet began in the early 1960s and by the late 1990s the number of industrial trawlers and their captures had multiplied by 11 and 15 times respectively. This significant increase in the fleet size can be attributed to (1) the construction of domestic shipyards, (2) the importation of vessels under duty-licenses, and (3) lines of credit to the sector for the construction of high-seas vessels between the 1960s and 1970s (Bertelotti et al., 2001a; Bertelotti et al., 2001b). During the last two decades the national hake fishery has experienced crises such as the late 1990s, when total landings were less than 190,000 tons in 2000 (over a historic record of 1,341,000 tons in 1997). Since then, average catches in the period 2000-2012 were of 250,633 tons (MINAGRI, 2014). The national jigging fishery started during the mid-1940s and reached its peak of landings in the late 1990s (c. 550,000 tons), thus positioning the Argentine squid as the second economic important species of the Argentine Sea at that time. This observed increase in landings can be attributed mainly to an external demand that started in the late 1980s and continued during the 1990s with an increase in the number of operative vessels (Bertelotti et al., 2001a; Bertelotti et al., 2001b). Since then, the fishing effort of this fleet shifted from severe to moderate (at least 20% of the fleet was declared inoperative in 2000), with average catches in the period 2000-2012 of 4,000 tons (MINAGRI, 2014).

## 2.2. Fishery Regulations and Management Measures

The hake fishery will be the focus in this section as commercial fishing in Argentina is structured around the species (Cousseau and Perrotta, 2004). During the last two decades the national hake fishery has experienced economic crises as the one in the late 1990s referred above. Currently, an important proportion of the catch is discarded as undersized fish (non-commercial hake) in the trawl fleet (Tringali, 2012). It was estimated that the ice- and freezer-trawlers pooled discarded more than 77,000 tons of fish (or an annual mean of over 600 million individuals) between 1990 and 1997 (Dato et al., 2003). In addition, the Argentine shrimp *P. muelleri* fishery operating within the San Jorge Gulf discarded as bycatch between 17,000 and 46,500 tons of hake annually for the period 1998-2004 (Cordo, 2005; Góngora et al., 2012). Attempts to reduce the bycatch of juvenile hake or increase the escape of undersized fish through the nets began using the ice-trawl fleet as study case and finalized with the development of a bycatch reduction device called DEJUPA (*Dispositivo para el Escape de Juveniles de Peces en las redes de Arrastre* or Juvenile Fish Bycatch Reduction Device for Trawl Net) (Ercoli et al., 2000). The use of DEJUPA (along with the use of certain mesh size in the cod-end) is in current days mandatory for all bottom-demersal trawlers targeting hake under Resolution Consejo Federal Pesquero (CFP) (*Federal Fisheries Council*) No. 08/10, though compliance still partial[6]. In addition, a fishing closure issued by Provision Subsecretaría de Pesca y Acuicultura (SSPyA) (*Under Secretariat of Fishing and Agriculture*) No. 136 was established in 1997 at protecting juvenile hake in high-seas waters, covering c. 119,000 km$^2$. A modification to the previous fishing closure took place in 2000 (Resolution SAGPyA No. 265) further revised by the establishment of a committee for the management of the hake (Resolution SAGPyA No. 12/01). Since then, the core area of the fishing closure aimed at protecting juvenile hake has remained stabled, though partial openings and closures at its margins has occurred mainly driven by the hake spawning biomass estimated from scientific surveys leaded by Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP) (*National Institute for Fisheries Research and Development*), and to political and socio-economic shifts (Alemany et al., 2012). In current days[7], another fishing closure, in this case issued by Resolution Comisión Técnica Mixta del Frente Marítimo (CTMFM) (*Argentine-Uruguayan Joint Technical Commission of the Maritime Front*) No. 08 was established in 2012 for the protection of juvenile hake in the vicinity of the Argentine-Uruguayan Common Fishing Zone. The current status of the hake stock is

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[6] In spite of the use of bycatch reduction devices in fishing fleets such as the national ice-trawl fleet significantly reduces the bycatch of juvenile hake and other non-target species (Ercoli et al., 2000; Ercoli et al., 2001), and that the survival of fish passing through these selectivity devices is generally greater with respect to that of fish that escape through the meshes of the trawl net (Suuronen et al., 1996; Sardá et al., 2004; Gabr et al., 2007), crews reject the use of bycatch reduction devices such as the DEJUPA probably due to its belief that there is null selectivity (*i.e.* what eventually escapes the fishing gear hardly survives) and hence transfer to the industry the obligation of finding a market for overall production.

[7] Other fishing closures include an Area of Restricted Effort (of c. 32,000 km$^2$) aimed at protecting concentrations of coastal demersal breeding species located within the vicinity of El Rincón estuary, from October 1st to March 31st of each year starting in 2000 (Resolution CFP No. 02/10).

considered as “recruitment overfishing” meaning that the reproductive biomass of the species is in such low level that jeopardizes the animals’ ability to reproduce and recover above equilibrium levels previous to 1997, a period in which hake descended below the species minimum critical level (Resolution Audit General’s Office 09/11). The use of hake bycatch reduction devices or other devices enhancing the escapement of juvenile fish and the reduction of the fishing effort have been suggested as the main management measures in order to recover both stocks of the species (Aubone et al., 2010; Irusta et al., 2010). Besides the abovementioned fishing closures, there are also no-spatial regulations such as the catch quotes and surveillance of vessel distribution through the use of vessel monitoring system (VMS) [Resolution Secretaría de Agricultura, Ganadería, Pesca y Acuicultura (SAGPyA) (*Secretariat of Agriculture, Livestock, Fishing and Aquaculture*) No. 367/98].

The Argentine Constitution provides the general national framework to protect marine wildlife including birds in the country. The National policy relevant to wildlife protection is also defined by the Ley Federal del Ambiente (*Federal Environmental Law*) (No. 25.675) enforced by the Consejo Federal del Medio Ambiente (*Federal Environment Council*), the highest environmental authority. The Ley Federal de Pesca (*Federal Fisheries Law*) (No. 24.922) is the central norm in fisheries issues within Argentina at the federal level. The regulation of maritime fisheries and aquaculture in Argentina presents a clear degree of dispersive rules, with different extent range between provincial jurisdictions and at the federal level. The Federal Fisheries Council is the governance practical body that has federal and provincial representation. The INIDEP conducts fishery research to guide management within waters of the Argentine territory (Law No. 21.673). This institute was trusted in 2001, through its onboard observers program, to conduct actions and methodologies needed for an adequate estimation of bycatch of marine top predators including seabirds during fishing activities of commercial fleets.

## 3. INCIDENTAL MORTALITY OF SEABIRDS

### 3.1. Conservation Status of Affected Populations

Recent reviews show the rapidly worsening conservation status of a number of albatross and petrel populations (ACAP, 2012a; BirdLife International, 2012). The International Union for the Conservation of Nature (IUCN) considers albatrosses (Diomedeidae) as the most threatened family of birds in the world. In 2012, all but five of the world’s 22 species of albatross were threatened with extinction, a significant contrast to the overall rate of 12% for the 9,799 worldwide bird species. Currently, three albatross species are recognized as *Critically Endangered*[8], five species are *Endangered,* seven species are *Vulnerable,* and other seven species *Near Threatened* (BirdLife International, 2014). For the three albatross species listed as *Critically Endangered,* it is either their extremely reduced breeding population or the significant decreasing population trends that are the criteria that most frequently qualifies the species for listing. For the five species listed as *Endangered*, the current overall population trends are all documented as decreasing, whereas for the seven albatross species listed as

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[8] According to the IUCN definition, any species identified as Critically Endangered faces an ‘extremely high risk of extinction in the wild’.

*Vulnerable*, it is their restricted breeding distribution that is the criterion that most frequently qualifies the species for being included in this category. The seven albatross species listed as *Near Threatened*, it is either their reduced exposure to fisheries or steady increase of their populations that is the criteria most frequently qualifies the species for being included in this category. In the case of the family Procellariidae, a high percentage (ca. 60%) of the petrel species is listed in any category of global threat (BirdLife International, 2014). Currently, nine petrel species are recognized as *Critically Endangered*, twelve species are *Endangered*, twenty species are *Vulnerable*, and other nine species are currently recognized as *Near Threatened*. The remaining petrels (43 species) currently warrant the lower category listing of *Least Concern* (BirdLife International, 2014).

In general terms, most major albatross South West Atlantic populations are either declining (by at least 1.4% per annum and 1.1% per annum in the case of Wandering and Grey-headed albatrosses breeding at Georgias del Sur respectively) or the trend is unknown due to lack of regular, comparable surveys (in the case of Light-mantled albatross breeding at Georgias del Sur) (ACAP, 2012b; ACAP, 2012c). These islands accounted for a high percentage (range = 20-50%) of the global populations of wanderings, grey-heads, and light-mantled albatrosses. The major threat affecting these three albatross species in the region is incidental mortality in longline fisheries operating chiefly in international waters outside national maritime jurisdictions (Tuck et al., 2011). However, the large Malvinas Islands Black-browed albatross population –comprising almost 70% of the global population- has increased at c. 4% per annum since 2005 (Wolfaardt, 2013)[9]. In addition, a number of other breeding sites of this species in the southern Pacific off Chile have shown c. 2.5% of annual increases between 2002 and 2011 (Robertson et al., 2014). This increase was attributed to reduced seabird bycatch after the implementation of mitigation in fisheries known to pose a threat to albatrosses, plus favorable feeding conditions partially linked with shifts in the abundance and distribution of prey (Catry et al., 2011; Wolfaardt, 2013; Robertson et al., 2014). On the other hand, main petrel populations breeding in the region are either stable or increasing (BirdLife International, 2014), although some species still declining, such as the White-chinned Petrel from Georgias del Sur. The islands hold c. 75% of the global population of this species; though colonies were reported declining by at least 1.65% per annum (ACAP, 2012d). A combination of an enhanced exposure to fisheries at sea and introduced (non-native) species at breeding grounds is the major threat affecting the conservation prospects of White-chinned petrels (ACAP, 2012d). Other species, such as the Brazilian endemic –the Trindade Petrel *Pterodroma arminjoniana*- has a very restricted range and is very susceptible to human impacts and stochastic events (BirdLife International, 2014).

## 3.2. How Seabirds and Fisheries Share the Marine Space?

The study of the at-sea distribution of pelagic seabirds is challenging because they spent most of their time at sea, thus bringing logistical difficulties in following them for a long period of time. Traditionally, seabird's distribution has been studied from capture-recapture data of marked animals using bands or dyed individuals (Sutherland et al., 2004) or from sightings made at sea by observers onboard vessels (Ballance, 2007). Nowadays, the

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[9] This estimation should be taken with precaution as the trends are not consistent between years and sites, and even between sub-colonies within sites.

miniaturized biologging devices deployed on live animals have enabled the detailed study of individual distribution patterns (Ropert-Coudert and Wilson, 2005; among others). Most of these devices apart from providing the geographical position of the animal might include other sensors to gather information regarding environmental variables such as temperature, depth, etc. (Ropert-Coudert and Wilson, 2005)[10]. The devices available nowadays include GPS, PTTs (platforms terminal transmitters), GLS (geolocators) and VHF (radiotransmitters of very high frequency) among others (Bridge et al., 2011). In addition to providing critical information on the movements and behavior of a variety of seabird species at sea, tracking data are increasingly being applied to management and conservation policy. The distribution data of tracked birds could be combined with data regarding the seascape of the birds, for example fishing effort, prey distribution and oceanographic variables (Louzao et al., 2011; Torres et al., 2011; among others). These kind of studies provide powerful tools for the conservation of threatened and endangered species (Bograd et al., 2010).

Tracking technologies have been widely used in the Argentinean Continental Shelf to gather information about pelagic seabird distribution (Phillips et al., 2006; Falabella et al., 2009; Quintana et al., 2010; Copello et al., 2013). Particularly, for the Black-browed albatross, the most abundant Procellariform species in this ecosystem and also one of the species with greater rates of bycatch (see section below), tracked data showed that during the non-breeding period adult birds were mostly distributed in waters within the continental shelves of Argentina, Uruguay and southern Brazil; from 29° to 51°S. Two large marine areas of greater use were identified: one from the mouth of Rio de la Plata toward the E and SE reaching the shelf-break, and another in El Rincón estuary and waters to the South (Copello et al., 2013). However, during the breeding period the albatrosses breeding in Malvinas colonies (51°S-61°W) showed a more restricted range located in waters to the W and SW of the nesting colonies (Catry et al., 2013). In contrast, for the Southern Giant Petrel -other important species in the large marine ecosystem of the Patagonian Shelf, adult birds from Arce and Gran Robredo islands (45°S-65°W) showed a similar distribution during the breeding and nonbreeding periods (Quintana et al., 2010; Blanco and Quintana, 2014). Besides of identifying temporal differences in the at-sea distribution (e.g. breeding vs. non breeding season), tracked data could also provide information about sexual segregation in foraging locations (Phillips et al., 2004b; Gonzaléz-Solís et al., 2008). In the case of the Southern Giant Petrel, males spent a great proportion of their time at sea in coastal areas while females explored mainly pelagic areas, regardless of the provenance of the birds nesting grounds (Quintana et al., 2010).

Considering fisheries are one of the main threat at sea to seabirds (see Section 1), it is crucial to understand the spatio-temporal relationship between the distribution of fisheries and seabirds. The spatial overlap is a necessary precondition for interactions and/or bycatch, and thus it can be used as a proxy of risk faced by the birds interacting with fisheries (Delord et al., 2010; Yorio et al., 2010; Tuck et al., 2011). The technological advances of satellite tracking have been also applied in fisheries management. For example, it is very common that fishery datasets are provided at a spatial resolution of 5° × 5° (e.g. Regional Fisheries

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[10] The first studies using remote sensing on seabirds, particularly in albatrosses and petrels, dates from the 90' (Strikwerda et al., 1986; Jouventin and Weimerskirch, 1990). Since then, there has been an exponential growth of studies using these technologies with almost half of the total Procellariform' species been tracked until now (www.seabirdtracking.org).

Management Organizations), however nowadays most of the fishing fleets around the globe have a satellite vessel monitoring system installed onboard for the rigorous monitoring, control and surveillance of fisheries activities (FAO, 1998). This conversion in data acquisition provided a better framework for overlapping modeling studies (see Votier et al., 2013, Granadeiro et al., 2014). In recent years Argentina converted its monitoring system for the obtainment of data on fisheries distribution from the traditional logbooks with a spatial resolution of 1° × 1° grid to a satellite vessel monitoring system with even higher resolution. This scenario had largely improved the context in which detailed studies on the interaction between seabirds and a range of fisheries can be conducted. In this regard, most of the studies about spatio-temporal overlap of pelagic seabirds and fisheries in the Argentine Continental Shelf showed a great magnitude of overlapping at different spatial scales (Copello and Quintana, 2009; Copello et al., 2014). In the case of the Black-browed albatrosses from Malvinas, during fall-winter period their distribution overlapped to different extents with two coastal trawl, three offshore trawl and one demersal longline fisheries.

The overlap was greater with both coastal fleets, followed by the ice-trawl fleet (Copello et al., 2014). For Southern Giant Petrels from Patagonian colonies, birds spent most of their time at sea within 1° x 1° areas where trawlers operated (68–98% of the time) and less than 28% of their time at sea (0–28.4%) within areas where jiggers and longliners operated (Copello and Quintana, 2009).

### 3.3. Seabird Attendance and Bycatch

The structure and dynamics of seabird communities in the South West Atlantic Ocean has been well documented (Olrog, 1958; Tickell and Woods, 1972; Rumboll and Jehl, 1977; Thurston, 1982; Veit, 1995), including spatial and temporal distribution (Montalti and Orgeira, 1998; Orgeira, 2001; Favero and Silva Rodriguez, 2005), and use of surrounding waters (Croxall and Wood, 2002; Huin, 2002; Quintana et al., 2010; Copello et al., 2013). The understanding of seabird’s assemblage composition and abundance attending specific commercial fisheries at the Argentinean EEZ has recently become clear to marine ornithologists and managers. Comprehensive studies have indicated that in virtually all high-seas Argentine fisheries, assemblages attending vessels are largely dominated by albatrosses and petrels, some of these being birds very well known for making an extensive use of fishery waste food resources as well as fishery discards or marine organisms facilitated during fishing operations, hence largely captured in fishing operations (Table 2). This holds true for longline and trawl fisheries operating off southern and northern Patagonia (Tamini et al., 2010; Favero et al., 2011; Favero et al., 2013; Seco Pon, 2014). Of the 12 species of albatross and 28 species of petrels feeding in waters of the Argentine Continental Shelf, the Black-browed followed by Southern and Northern royal albatrosses along with Giants, White-chinned and Cape petrels, and to a lesser extent Great and Sooty shearwaters, are associated to a different degree with fishing activities of high-seas fleets and thus have a significant risk of incidental mortality (Tamini et al., 2010; Favero et al., 2011; Seco Pon, 2014; Paz, 2014).

**Table 2. Summary of studies reporting capture rates of seabirds (birds per fishing days in trawl fleets and birds per 1000 hooks in longline fleets) in several Argentine high-seas fisheries from 2003 to 2014**

| Fleet/ Fishing gear | Location | Mean capture rate | Total annual mortality | Years | No. of operations observed | Sampling method | Species bycaught | Comments | Sources |
|---|---|---|---|---|---|---|---|---|---|
| Ice-trawler/ Demersal trawl-net for Argentine hake | Patagonian Shelf, off Argentina | 0.105 birds fishing day$^{-1}$ | >100 or >1000 birds | 2006-2007 | 328 trawls (72 fishing days) | DOO | BBA and SRA | Operational (presence of discards) and enviromental (seasonality) variables affecting interaction rates were detected | Favero *et al*. (2011) |
|  | Patagonian Shelf, off Argentina | 0.12 birds fishing day$^{-1}$ | n.d. * | 2009-2010 | 152 trawls (62 fishing days) | DOO | BBA | Operational (presence of discards) and enviromental (wind and sea conditions) variables affecting attendance and interaction rates | Seco Pon (2014) |
| Ice-trawler/ Mid-water trawl-net for Argentine anchovy | Patagonian Shelf, off Argentina | 0.70 birds fishing day$^{-1}$ | n.d. ** | 2011-2013 | 172 trawls (82 fishing days) | DOO | Largely unidentified *Puffinus* shearwaters; other species included GRI, MAG, WCP and BBA | n.r. | J Paz (unpublished data) |
| Freezer trawler/ Demersal trawl-net for Argentine hake | Patagonian Shelf, off Argentina | 0.09 birds fishing day$^{-1}$ | > 10.000 birds | 2008-2010 | 298 trawls (106 fishing days) | DOO | Largely BBA; possibly CAP, SGP, and WCP | n.r. | Tamini *et al*. (2010) |
| Freezer longliner/ Bottom-demersal longlin for Patagonian tootfish and Kingclip | Patagonian Shelf, off Argentina | 0.04 1000 hooks$^{-1}$ | 1160-7000 birds | 1999-2001 | 29 million hooks (2479 settings) | NDOO | Largely BBA and WCP; other species included CAP, GRH, GRP, SFU, SRA and TRI | Operational (stage of the fishing operation) and environmental (seasonality) variables affecting bycatch rates were detected | Favero *et al*. (2003) |
| Freezer longliner/ Bottom-demersal longlin Patagonian tootfish, Kingclip and Skates | Patagonian Shelf, off Argentina | 0.03 1000 hooks$^{-1}$ | > 7450 birds | 2001-2010 | 159 millon hooks (>100 fishing trips) | NDOO | Largely BBA and WCP; other species included CAP, GRA, GRI, MAG, KGU, NGP, SGP and WAN | Operational (type of fleet) and environmental (seasonality) variables affecting bycatch rates were detected | Favero *et al*. (2013) |

n.d. * not determined. An unknonw percentage of trawlers use netsonde cable during their dairy operations.

n.d. ** not determined. A very small percentage of the fleet is under a certification process currently in place.

n.r. not reported.

Total annual mortality was reported in several ways, e.g. between sets, cruises, seasons or areas. BBA = *Thalassarche melanophris*, CAP = *Daption capense*, GRA = *Puffinus gravis*, GRH = *Thalassarche chrysostoma*, GRI = *Puffinus griseus*, GRP = *Procellaria cinerea*, KGU = *Larus dominicanus*, MAG = *Spheniscus magellanicus*, NGP = *Macronectes halli*, SFU = *Fulmarus glacioloides*, SGP = *Macronectes giganteus*, SRA = *Diomedea epomophora*, TRI = *Diomedea dabennena*, WAN = *Diomedea exulans*, and WCP = *Procellaria aequinoctialis*. In sampling method, DOO = Dedicated onboard observers, NDOO = Non-dedicated onboard observers.

Incidental catch rates of seabirds in high-seas fisheries off Argentina were reported for the first time in longliners between 1994 and mid 1995 (Schiavini et al., 1998), although estimates were based on fishing effort in the Patagonian Shelf and the extrapolation on bycatch rates for neighboring (CCAMLR) waters. The study by Favero et al. (2003) showed the first estimates of incidental mortality rates of albatrosses and petrels in bottom-demersal longliners along the Patagonian shelf and shelf-break, using data recorded onboard fishing vessels by the National Observers Program belonging to INIDEP between 1991 and 2001. Estimated bycatch rate for that period was 0.04 ± 0.40 birds/1000 hooks, with a maximum rate per trip of 0.26 birds/1,000 hooks. On the basis of around 29 million hooks set annually, from 1,160 to 7,000 birds (largely Black-browed albatrosses and White-chinned petrels) were estimated to be killed during that period (Favero et al., 2003). A further decadal review revealed that the overall bycatch rate for the period 2001 to 2010 was 0.03 ± 0.02 birds/1,000 hooks, with cumulative mortalities for the decade estimated in 7,470 ± 2,500 birds/1,000 hooks (Favero et al., 2013; Table 2). This second study highlighted that mortality levels in longliners towards the end of the decade were substantially lower, and primarily attributed to (1) a general drop in fishing effort, (2) the closure in 2008 of the Yellow-nosed Skate, and (3) the progressive conversion, starting in 2008, of part of the fishing effort in the Patagonian Toothfish-Kingclip fleet from standard longlines to the use of ‘cachaloteras’ and pots. The closure of the Skate fleet was particularly relevant, given that this fleet was identified as the one with the highest occurrences of bycatch (Favero et al., 2013).

The study of seabird interactions -including incidental mortality- with other commercial fisheries, such as trawlers off Argentina began in 2006 with the first estimates of attendance and bycatch rates of pelagic seabirds in ice-trawlers operating along the Patagonian shelf and shelf-break, using data recorded onboard fishing vessels by the National Observers Program (from INIDEP) between 2006 and 2007 (Favero et al., 2011). This study showed tube-nosed (Procellariform) birds largely dominating the assemblages and the interactions with the fishing gear. A rate of 25.5 contacts per hour was estimated during the sampling; over 98% of the interactions corresponded to light contacts with the warp cables while birds were either on the water of flying. A very small percentage of these contacts were classified as severe or heavy (i.e. likely leading to mortality). Confirmed mortalities included Black-browed and Southern Royal albatrosses (Table 2) occurring only during fall and winter, and mostly along the shelf-break. Estimated total mortality rate was 0.017 birds per trawl hour and 0.105 birds per vessel day$^{-1}$; the annual mortality in this fishery was estimated in the order of several hundreds or even over 1,000 albatrosses (Favero et al., 2011). A more comprehensive study designed to furnish the study of interactions between pelagic seabirds and ice-trawlers operating along the Patagonian shelf provided data recorded onboard vessels by scientists specifically tasked between 2009 and 2011 (Seco Pon, 2014). Similarly, albatrosses and petrels largely dominated the assemblages but interacting more heavily with the fishing gear, particularly with the netsonde cable, a third wire known for posing another source of threat to seabirds attending trawlers (Wienecke and Robertson, 2002). This is novel and relevant information considering that literature generally refers the netsonde cables as being banned in several fishing grounds (Bartle, 1991; Weimerskirch et al., 2000) and it use has not been previously reported in the national trawl fisheries (González-Zevallos and Yorio, 2006; González-Zevallos et al., 2007; Favero et al., 2011), a factor that may impact on the estimated local annual mortality, given that some 80% of the overall interactions (contacts) happened with the netsonde cable in the above referred study. Confirmed mortalities included Black-browed albatrosses occurred only during spring and summer and mostly along the shelf. Estimated total mortality rate was 0.04 birds per trawl hour and 0.12 birds per day$^{-1}$ (Seco Pon, 2014). Favored by a very recent certification scheme starting in 2011, marine ornithologist and managers are beginning to understand the ecosystem effect of the Anchovy mid-water ice-trawl fishery in northern Patagonia (see Section 5.2.). This initiative revealed (via data gathered by the National Observers Program) Procellariiform (albatrosses and petrels) birds, followed by the Kelp Gull, dominating the assemblages and the interactions with the fishing gear for the period 2011-2013. Over 97% of the interactions belonged to light contacts with the net while birds were on the water (the remaining percentage of these contacts was recorded as severe or heavy). Confirmed mortalities included chiefly (unidentified) *Puffinus* shearwaters, Sooty shearwaters *P. griseus*, Magellanic penguins *Spheniscus magellanicus*, White-chinned petrels and Black-browed albatrosses. Estimated annual mortality was 0.70 birds' day$^{-1}$ (J Paz, unpublished data) (Table 2).

Other trawl fisheries, such as the freezer fleet operating chiefly in southern Patagonia was the focus of the work conducted onboard fishing vessels by the staff of Albatross Task Force Argentina between 2008 and 2010. As in other high-seas fisheries, albatrosses and petrels largely dominated the assemblages and comprised also the bulk of the species that interacted more severely with the fishing gear during fishing operations. A rate of 33.5 contacts per hour was estimated during the sampling; over 25% of the interactions corresponded to heavy contacts with the warp cables while birds were mainly on the water, with confirmed mortalities including Black-browed albatrosses and Southern Giant petrels (Table 2). Estimated annual mortality for the freezer trawl fleet could be in the order of thousands albatrosses (Tamini et al., 2010). Finally, the information regarding seabird attendance or bycatch rates in jiggers operating off Argentina is scarce with preliminary information obtained via interview surveys with fishery observers and crew suggesting low levels of pelagic seabird attendance and bycatch (PNA-AM, 2010; Gandini and Favero, unpublished data).

### 3.4. Bycatch Mitigation and the Monitoring, Implementation and Compliance of Conservation and Management Measures

Seabird bycatch is unnecessary and preventable. In fact, it does not only has devastating consequences for seabirds (and other top predators) but also may turn fishing operations less efficient. Besides including moral and ethical responsibilities (Hall, 1996; Boersma and Parrish, 1998; Power Bratton, 2000), the existence of bycatch itself, beyond the levels at which they occur and the species involved (e.g. non-target fish, seabirds, among others), is not consistent with the principles of fisheries management under an ecosystem approach (Melvin and Parrish, 2001; Løkkeborg and Robertson, 2002; among others). The Code of Conduct for Responsible Fisheries developed by the Food and Agricultural Organization of the United Nations (FAO, 1995) promoted the maintenance and conservation of biodiversity through the reduction of the effects of fishing on non-target species. As a result of these policies in recent years a number of techniques or measures to mitigate bycatch of seabirds have been developed and described (Brothers et al., 1999; Melvin et al., 1999; Sullivan et al., 2006b; ACAP, 2013). Besides being effective in reducing the incidental capture of birds, mitigation measures should be practical and easy to apply in commercial fisheries, preferably not reducing the catches of the target species, and ideally, provide incentives for fishermen for their use (Gilman et al., 2003; Gilman et al., 2005). Among the variety of techniques that, while potentially reducing the likelihood of interactions between seabirds and high-seas fishing gear, there are a few that should essentially be considered best practice measures to be adopted into normal fishing operations.

The most effective measures to reduce incidental capture (refereed as to best practice[11] hereinafter) of albatrosses and petrels in demersal longline fisheries according to ACAP (2013) include the use of an appropriate line weighting regime to maximize hook sink rates close to vessels sterns to reduce the availability of baits to seabirds, actively deterring birds from baited hooks by means of bird scaring (tori) lines, and setting by night. In Argentina a binding measure including the use of above referred measures in demersal longliners was adopted in 2008 by Resolution CFP No. 8 (http://www. cfp.gob.ar/resoluciones/res08-2008.pdf), which entered into force in 2010. This resolution compel longline vessels using the Spanish system to use weights of 8.5 kg located at a minimum distance of 40 m or weights of 6 kg located at a minimum distance of 20 m in their lines. Vessels should also use bird scaring lines during the setting of the gear (though no details is given as to how to build tori-lines) and should set their longlines at night, except those using the weighting regimes delineated above. This resolution also emphasizes the need for deterring birds from baited hooks during line hauling operations.

For reducing seabirds interactions with trawl fisheries, best practices recommended by ACAP (2013) includes protecting the warp cables, managing offal discharge and discards, and reducing the time the net is exposed on the surface of the water. Mitigation measures aimed at avoiding or reducing interactions between seabirds and Argentinian trawl fishing gear gained fresh input with the study conducted by González-Zevallos and collaborators (2007) in the coastal hake trawl fishery operating within waters of the San Jorge Gulf. A plastic (traffic) cone attached to each warp cable reduced the number of birds entering the warp/water interface by 89% and no seabirds were killed while cones were attached to the warps. Though this measure is considered novel it is applicable for small vessels and there is a need to be trialed in a range of fisheries and areas to demonstrate efficacy (ACAP, 2013). The Albatross Task Force (ATF) of Aves Argentinas is developing mitigation measures -and assessing its efficacy- aimed at reducing seabird mortality in the large high-seas freezer trawl fishery in coordination with the INIDEP. Bird scaring lines designed to protect the warp cables and the construction of an off-set towed device (referred to as “Tamini Table”) to improve the performance of scaring lines and therefore maintaining these lines from entangling with warps are the main focus of the work conducted by ATF. Despite the progress achieved, issues dealing with the full implementation of the conservation measures

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[11] The following criteria applied by ACAP (2013) when recommending best practice fishing technologies and techniques to reduce the incidental mortality of albatrosses and petrels include that (*i*) individual fishing technologies and techniques should be selected from those shown by experimental research to significantly reduce the rate of seabird incidental mortality to the lowest achievable levels, (*ii*) fishing technologies and techniques, or a combination thereof, shall have clear and proven specifications and minimum performance standards for their deployment and use, (*iii*) fishing technologies and techniques shall be demonstrated to be practical, cost effective and widely available, (*iv*) fishing technologies and techniques should maintain or enhance the efficiency and if possible the catch of fishing operations. Measures that compromise efficiency of fishing operations are unlikely to meet with acceptance and compliance, (*v*) fishing technologies and techniques should, to the extent practicable not increase the bycatch of other taxa, and (*vi*) minimum performance standards and methods of ensuring compliance should be provided for fishing technologies and techniques, and should be clearly specified in fisheries regulations.

in longliners and the bycatch reduction in the large and complex trawl fishery remain partially addressed and need urgent attention (report on the first Workshop following up the PAN-AM, 2012).

In Argentina, the monitoring of the use of mitigation measures to reduce incidental capture of pelagic seabirds is recorded by two kind of onboard personnel: inspectors and observers. The inspectors have the capacity of applying the law by means of performing acts of infringement under Provision Subsecretaría de Pesca y Acuicultura (SSPyA) No. 424/2004. Some of the functions of the inspectors include reviewing the gear used by the vessel, also verifying that the vessel does not operate in a closure area, that it does not discard fish at sea, and any additional work that may be necessary to control the compliance with the fishing regulations, including the use of mitigation measures. However, there have been no records so far on the implementation of Resolution CFP No. 8 by onboard inspectors (report on the first Workshop following up the PAN-AM, 2012). Though observers cannot apply the law, they record fishery-related data and take actions and methodologies needed for an adequate estimation of bycatch of marine top predators including seabirds during fishing activities of commercial fleets under Resolution CFP No. 03/2001, plus any additional work that may be necessary to control the compliance with the fishing regulations, including the use of mitigation measures. The Argentinean waters are monitored by the onboard observers program belonging to the INIDEP, while the provinces of Rio Negro, Chubut, Santa Cruz and Tierra del Fuego have their own observers programs to monitor its coastal waters (González-Zevallos et al., 2012). Each program has its own characteristics such as administration, jurisdictions and type of fleet covered, though in recent years, several workshops took place aimed at standardizing protocols for data collection by either national and provincial observers programs. While for some fleets (based on their small number of vessels or due to particular interest) the levels of observer coverage are very high (e.g. longline), in certain fleets such as the trawl fishery the levels of coverage are still below those desired given due to limited human and financial resources, including the size of the fleet and its spatial and temporal dynamics throughout the year (report on the first Workshop following up the PAN-AM, 2012).

## 4. LOOKING AT SCRAPS: THE USE OF FISHERY DISCARDS

### 4.1. Black-browed Albatross and Ice-trawlers as Study Case

The growth of commercial fisheries during the last decades has resulted in enhancing volumes of discards (Alverson et al., 1994; Alverson, 1998) (but see Kelleher, 2005 for a recent update), which may play a significant role in the trophic ecology of many seabirds (Garthe et al., 1996; Montevecchi, 2002). Previous studies have showed, for example, an increase in productivity and longevity and a decrease in age at first maturity in scavenging marine birds, particularly gulls (Pierrotti and Annett, 1999; Arcos, 2001; Votier et al., 2004), and changes in their distribution at sea and/or the composition of their assemblages (Wahl and Heinemann, 1979; Abrams, 1983; Oro et al., 1995). Further, a key factor influencing prey selection, capture efficiency and food distribution among seabirds feeding behind vessels is the size of prey (Camphuysen et al., 1995; Furness et al., 2007; González-Zevallos and Yorio, 2011).

Studies regarding the consumption of discards at sea by seabirds attending South West Atlantic fleets is primarily restricted to coastal birds such as gulls in central Patagonia (Yorio and Caille, 1999; Bertellotti and Yorio, 2000; González-Zevallos and Yorio, 2006; González-Zevallos and Yorio, 2011; Marinao and Yorio, 2011), northern Patagonia (Seco Pon et al., 2012; Seco Pon et al., 2013), and in Brazilian waters (Branco, 2001; Branco et al., 2006). Information regarding the use of this anthropogenic resource by Procellariiform birds is scarce in the region (but see Thomspon, 1992; Thompson and Riddy, 1995; and Catry et al., 2011 for the Malvinas Islands and Bugoni et al., 2010 for Brazilian waters)[12]. The Black-browed Albatross is one of the most important species in the bycatch of a number of SW Atlantic fisheries, with up to 57% of total bycatch (Neves and Olmos, 1998; Baker et al., 2007; Watkins et al., 2008; Jiménez et al., 2009; Favero et al., 2011; Favero et al., 2013). Most of previous studies on Black-browed albatross' diet have been performed during the breeding season, showing a diet comprised by fish, cephalopods, and crustaceans. Some authors highlighted the importance and the occurrence of demersal fish, likely coming from demersal fisheries in the diet of these birds (Prince, 1980; Thompson, 1992; Reid et al., 1996; Cherel et al., 2002; Arata and Xavier, 2003). Still, little is known on the diet of this albatross species during the non-breeding season (but see Mariano-Jelicich et al., 2014 and Section 4.3)[13].

To understand the use of discards by non-breeding albatrosses attending Argentinian ice-trawlers, prey selection by birds was studied by experimentally discarding prey randomly obtained from the discard fraction of each catch onboard vessels[14] between 2009 and 2010 (Seco Pon, 2014). The Argentine hake, Longtail southern cod *Patagonotothen ramsayi*, Southwest Atlantic butterfish *Stromateus brasiliensis*, and the Argentine short fin squid *Illex argentinus* were the dominant component of the discard fraction of the fleet. Black-browed albatrosses (chiefly adult birds) dominated the space behind the vessel and the discharge chute. Around 66% of the experimentally offered prey was consumed by Black-browed albatrosses (chiefly adult birds). Individual albatrosses feed directly on experimental prey chiefly via surface seizing, and to some extent by surface diving, though events of kleptoparasitism were also recorded. While considering robbing of prey, the intra-specific kleptoparasitic behavior prevailed among adult Black-browed albatrosses attending trawlers. The estimated biomass subsidy in terms of discard use by Black-browed albatrosses in the mentioned study was around 3,300 tons per annum (Seco Pon, 2014).

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[12] The study conducted by González-Zevallos and Yorio (2011) was performed onboard the coastal ice-trawl fleet operating within the Golfo San Jorge, and although the Kelp Gull *Larus dominicanus* was the most abundant seabird species taking advantage of the experimentally discarded fish, the Black-browed Albatross was also recorded consuming discards close to the vessels.

[13] Previous studies using bird carcasses, and/or bird individuals retrieved from fishing operations (e.g. Colabuono and Vooren, 2007), may showed biases or partial results given that (1) carcasses may contain over-digested prey items and/or samples in bad shape that obscure the identification of prey, and (2) data from birds bycaught in fisheries belong to individuals effectively attending vessels and thus stomach contents may be strongly comprised by prey coming from such (anthropogenic) source (Barret et al., 2007).

[14] Fish and cephalopods were measured to the nearest 1 cm and experimentally discarded singly at 10 s intervals from the stern (always from the side of the vessel where the discharge chute was located) during daylight hours while regular discarding activities were taking place (adapted from González-Zevallos and Yorio, 2011).

## 4.2. Comparison with Other Trawl Fleets in the Area

Consumption of discards at sea by seabirds has been described in several regions around the globe (see review in Garthe et al., 1996; Tasker et al., 2000; Montevecci, 2002; Furness, 2003), including the North Sea (Hudson and Furness, 1988; Hüppop and Garthe, 1994; Camphuysen et al., 1995; Walter and Becker, 1997; among others), Baltic Sea (Garthe and Scherp, 2003), Mediterranean (Oro and Ruiz, 1997; Arcos and Oro, 2002), North Pacific (Jones and DeGange, 1988; Hunt et al., 2005), Australasia (Blaber et al., 1995; Petyt, 1995; Svane, 2005) and South Africa (Abrams, 1983; Ryan and Moloney, 1988). Regarding consumption of discards by pelagic seabirds in the target area of this chapter, Thompson (1992) showed that during the breeding season in Malvinas Islands, Black-browed Albatross chicks were fed extensively on commercially exploited species of squid and fish including *Loligo gahi* and Southern Blue Whiting *Micromesistius australis*. Further, the author estimated that the total quantity of waste generated by the *L. gahi* trawl fishery in 1990 amounted to c. 5% of the reported catch and that over 50% of this waste (chiefly *Loligo* and nototheniid fish) were scavenged by adult birds, reaching a total quantity of 1,000-2,000 tons per year during the chick rearing period. Also working in the vicinity of Malvinas Islands, Thompson and Riddy (1995) indicated that breeding Black-browed albatrosses may scavenge c. 8,000 tons of food per annum from “finfish” trawlers in 1990 and 1991, of which 2/3 is offal (comprised by guts, tails, and heads of *Merluccius* spp., *M. australis*, *Macruronus magellanicus*, and *Salilota australis*) and the remainder whole discards. Observations and experimental dumping of discards indicated that Black-browed albatross typically consumed discards equivalent in weight to 20-25% of the processed catch.

## 4.3. Understanding the Use of Fishery Discards by Means of Molecular Techniques

The study of seabirds’ diet is a fundamental tool for the analysis of several ecological processes such as predator-prey relationships, selection of wintering areas and detection of potential conflicts with anthropogenic activities, among others (Furness and Camphuysen, 1997; Barret et al., 2007). Several methods have been applied for the study of seabirds’ diet, including direct observations, analysis of pellets, faeces, spontaneous and induced regurgitation, and stomach contents, among others. In all cases, these methods have shown biases either over or under representing some particular type of prey, and showing a snapshot of the trophic spectrum (Barret et al., 2007; Karnovsky et al., 2012). Interestingly, the analysis of stable isotopes, among other biochemical methods, has been incorporated since mid 80’s to determine seabirds’ diet by means of determining the isotopic contribution of a variety of potential preys to the isotopic signatures in the birds, among other applications such as habitat selection and migration (Hobson, 2011). Stable isotope ratios, for example, allow an integration of dietary information over different temporal scales, they provide valuable information on assimilation rather than ingestion and depending on the tissue analyzed large sample sizes can be handled (Barret et al., 2007). Other remarkable advantages of stable isotopes over conventional methodologies are the possibility to infer the diet outside the breeding season (Mariano-Jelicich et al., 2008), and its capability to elucidate the degree of anthropogenic sources in seabirds’ diet (Moreno et al., 2010; Navarro et al., 2010; Votier et al., 2010; Ceia et al., 2012)[15]. In particular, the analysis of stable isotopes has been highlighted as powerful method and a great complement for conventional approaches (Inger and Bearhop, 2008; Hobson, 2011).

Most of diet studies on Procellariform birds in the South West Atlantic have been conducted during the breeding season (Thompson, 1992; Cherel et al., 2000; Cherel et al., 2002; but see Petry et al., 2007) and winter diet has been inferred through the analysis of isotopes ratios on feathers grown during that period (Quillfeldt et al., 2008; Phillips et al., 2009; Quillfeldt et al., 2010a; Quillfeldt et al., 2010b; Raya Rey et al., 2012). Moreover, the contribution of fisheries discards to Procellariforms' diet during the non-breeding season has been very recently reported through the analysis of stable isotopes on blood tissue of birds sampled at sea (Bugoni et al., 2010; Mariano-Jelicich et al., 2014). The study conducted by Mariano-Jelicich and collaborators (2014) via the analyses of C/ N stable isotopes revealed that in winter Black-browed albatross (1) foraged at subtropical and continental shelf likewise those individuals from Brazil (Bugoni et al., 2010) and (2) a high input of demersal fish species (such as *M. hubbsi, P. ramsayii, S. brasiliensis*) in the diet of birds captured in Argentine waters; these fish being the species most commonly discarded by demersal trawlers (mostly the Argentine hake) and, to a lesser extent, demersal longliners (*i.e.* Patagonian toothfish and Grenadier *Coelorhynchus fasciatus*). Given the feeding tactic used by these albatrosses, it is very unlikely that demersal fish species as those reported would be obtained in large quantities in the absence of any facilitation processes (Mariano-Jelicich et al., 2014). In line with this hypothesis, the study on consumption of experimental discards conducted onboard ice trawlers (Seco Pon, 2014) and the overlapping between ice trawlers and Black-browed albatrosses obtained from tracked data (Copello et al., 2014) strongly suggests that the contribution of demersal fish to the diet of these albatrosses during the nonbreeding season comes from the ice-trawl fleet.

Other abundant seabird species attending fishing vessels is the Cape Petrel *Daption capensis* (Sullivan et al., 2006; Tamini et al., 2010; González-Zeballos and Yorio, 2011). Preliminary results supports the contribution of demersal fish species to Cape petrels particularly discards from demersal longliners and trawler fleets via the analysis of stable isotopes (R. Mariano-Jelicich et al., unpublished data). These results reflect that (1) the use of fisheries discards is important even among seabird species with different feeding strategies, and (2) that the role of fishery discards on the diet of pelagic seabird species at the Patagonian Shelf deserves further investigation.

## 5. THE WAY FORWARD: THE NEED FOR AN ECOSYSTEM-BASED APPROACH

### 5.1. Current Research and Future Perspectives

As referred in earlier sections of this chapter, the Argentine Continental Shelf holds a very large diversity and biomass of marine top predators, including both coastal and pelagic

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[15] However, several aspects should be taken into account, such as a priori knowledge on the ecology of species, the geographic range in baseline isotopic values, habitat heterogeneity, discrimination factors, and variation in the turnover of tissues (Bond and Jones, 2009).

seabirds (see Favero and Silva Rodriguez, 2005; Yorio et al., 2005). Research projects focused on seabird ecology and conservation are conducted along the entire coast of Argentina and its Economic Exclusive Zone, from a number of organizations based in Patagonia (e.g. Centro Austral de Investigaciones Científicas, CADIC, Centro Nacional Patagónico, CENPAT, Centro de Investigaciones de Puerto Deseado, CIPD) and Buenos Aires Province (e.g. Instituto de Investigaciones Marinas y Costeras, IIMyC) to mention few examples of institutes from the National Research Council of Argentina (Consejo Nacional de Investigaciones Científicas y Técnicas, CONICET). Studies dealing with population assessments and long-term monitoring of chiefly coastal communities are, in modern days, complemented with studies of the behavioral aspects of birds at sea via the use of remote tags including VHF radio tags, platform terminal transmitters (PTTs), GPS loggers, global location sensors (GLS) and other more sophisticated devices, and including a range of Procellariform species breeding in Patagonia as well as remote areas of the Southern and Northern Hemisphere. As also referred in a previous section, the study of the interaction between seabirds and Argentine fisheries have so far recorded mortalities in a range of fisheries including high-seas demersal longliners and trawlers, as well as coastal trawlers. In all cases, threatened species were recorded attending vessels, interacting during the fishing operations and dying by getting hooked, entangled or colliding with different parts of the fishing gear.

Legal and political steps taken to protect marine top predators at sea such as the incorporation of protected areas in Argentine waters began with the creation in 2008 by Law 26.446 of a coastal park such as the Parque Interjurisdiccional Marino Costero Patagonia Austral (*Inter-jurisdictional Coastal Maritime Park Austral Patagonia*) in Chubut province (http://www. infoleg.gov.ar/infolegInternet/anexos/145000-149999/149238/ norma.htm), entering into force in 2009. This maritime park was created with the aim of conserving, managing and making a rational use of the marine and terrestrial species and their habitats in areas co-managed by the administration of national and provincial authorities. This park holds c. 80% of the total breeding population of the Southern Giant Petrel in continental Argentina (Quintana et al., 2006). In addition, a National Program for the Conservation of Southern Giant Petrel approved by the Consejo Federal del Medio Ambiente entered into force in 2013 by Resolution 259 (http://www.ambiente. gov.ar/?idarticulo=8621), constituting a complementary tool to the National Plan of Action – Seabirds issued by the Consejo Federal Pesquero and entering into force in 2010 (Resolution CFP 15/10, http://www.cfp.gob.ar/ resoluciones/res15-2010-a1.pdf). Other initiatives include the creation in 2004 of one (Monte León) and in 2012 of two marine parks in Santa Cruz province. The Monte León Park (Law No. 25.945) and “Makenke” Park (Law No. 26.817) are located within San Julian Bay. Interestingly, the Penguin Island marine park (Law No. 26.818) lies within waters of the Argentine Continental Shelf and includes several islands. Regarding protection of offshore waters, in 2013 the Senado de la Nación Argentina approved by Law No. 26.875 its first Marine Protected Area -named Banco Namuncurá/Burdwood Bank- located S of Malvinas Islands and E of Staten Island. This protected area aim at preserving, managing and promoting the implementation of the ecosystem approach to fisheries in an area of high environmental sensitivity (http://www.infoleg.gob.ar/infolegInternet/ anexos/ 215000-219999/218102/ norma.htm). Other modern-day initiatives include “Pampa Azul”, a strategic enterprise coordinated by the Ministerio de Ciencia, Tecnología e Innovación Productiva (*Ministery of Science, Technology and Innovation*) that includes inter-Ministerial agencies of

Argentina aimed at conducting research and deepening scientific knowledge as a basis for the conservation and management of natural resources within the Argentine Sea (http://www.mincyt.gob.ar/noticias/la-presidenta-presento-la-iniciativa-pampa-azul-9931). Further, the Ministerio de Ciencia, Tecnología e Innovación Productiva in its National Plan for Science, Technology and Innovation "Argentina Innovadora 2020" included a number of initiatives such as the "Production and Processing of Ocean Resources" which will accompany the initiative described above for the promotion, research and technological development of the exploration and use of Argentine maritime areas.

Despite the progress achieved, there is an important gap in our understanding on the major factors which structure and control the spatial and temporal variability in the composition and structure of avian assemblages in Argentine waters and their relationships with the dynamics of other commercial and semi-commercial fisheries operating within jurisdictional waters as well as those fishing in regional jurisdictions (i.e. the Argentine-Uruguayan Common Fishing Zone). Furthermore, the effects of global or local climate change on species distribution, their phenology and physiology, the cycles, composition, and interactions of communities, and the structure and dynamics of ecosystems are poorly understood in this region of southern South America.

## 5.2. Certification Schemes in Fisheries and the Opportunity to Introduce the Ecosystem Management Approach

Recent Food and Agriculture Organization of the United Nations (FAO) assessments of the perilous state of many of the world´s fisheries resources seems to have stimulated non-governmental organizations (NGOs) and private industry toward environmental labeling (also known as ecolabelling) as a complement to traditional modern-day fisheries management programs (Wessells et al., 2001). This type of certification is sometimes based on third-party auditing of compliance with performance-based sustainable resource management standards developed by non-state actors, such as NGOs, industry sectors, and social groups, though first- and second-party labelling schemes also exists (Wesselles et al., 2001; Potts and Haward, 2007). Further, these certifications are seals of approval given to products that are deemed to have fewer impacts on the environment than functionally or competitively similar products (Wesselles et al., 2001; Potts and Haward, 2007). There are already several national, international, industry-sponsored, NGOs-led and consumer-supplier partnership certification and standards schemes under development in the fisheries sector[16].

In Argentina, one major factor playing a significant role in the implementation of better fishing practices is related to the advent of the *Marine Stewardship Council* (MSC) certification schemes in fisheries, given that one of its components addresses the impact of fishing operations on the ecosystem (e.g. effects on the environment, related species, bycatch). In recent years, several fisheries (freezer trawlers targeting the Patagonian scallop *Zygochlamys patagonica* and Hoki, and coastal ice-trawlers targeting the Argentine anchovy) have been certified under the MSC scheme (http://www.msc.org/track-a-fishery/fisheries-in-

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[16] The range of possible (eco) labels is broad. The focus of claims can range from "not overfished, to no marine mammal bycatch and not over-fished, to no bycatch of any sort and not over-fished, to ecosystem friendly where the entire ecosystem with its complicated food chain is not harmed" (Wessells et al., 2001).

the-program/certified/south-atlantic-indian-ocean). A forth one (freezer longliners and trawlers targeting the Patagonian toothfish) is currently under evaluation. Although these processes are not driven by the Government certainly creates opportunities to develop better fishing practices including in the agendas of fishermen not only target species but also other management issues affecting the marine environment. The certification scheme implemented in two national fisheries offered good examples regarding seabird conservation in fishing fleets. In the first case, the certification process of the Hoki fishery allowed since 2012 the implementation of an outreach program for crew onboard freezer trawlers operating in Southern Patagonia and information sharing with skippers that improved conditions for the implementation of mitigation measures such as bird scaring lines during fishing operations. In relation to this, the Consejo Federal Pesquero has very recently approved the implementation of trials onboard these vessels to examine the operational difficulties of setting bird scaring lines in large (freezer) trawlers, as well as their effectiveness mitigating seabird interactions and incidental mortality (Act CFP No. 03/14, http://cfp.gob.ar/actas/ACTA%20CFP%203-2014.pdf). Another example at a smaller scale can be found in the Anchovy trawl fishery operating in northern Patagonia under a CMS certification scheme since 2011 and where due to the small size of the vessels and reduced crew it was impossible to task observers onboard, therefore no information on bycatch and other fishery related matters was available in this fishery before achieving a certification.

Despite the initiatives referred above had, to a certain extent, improved the context in which data on the ecosystem effect of fisheries is gathered, there is still little knowledge about the effect of other fisheries on marine ecosystems, particularly freezer trawlers fishing for Anchovy in northern Patagonia and ice and freezer trawlers pooled fishing for hake in waters of the Argentine-Uruguayan Common Fishing Zone, among others.

## 5.3. Argentina’s National Plan of Action-Seabirds: Where Are We Today?

In view of the detrimental effects of fishing activities on a number of seabird species, FAO developed in 1999 the International Plan of Action – Seabirds aimed at reducing the incidental catches of seabirds in longline fisheries which was elaborated within the framework of the Code of Conduct for Responsible Fisheries (FAO, 1995). This scenario allowed delineating principles and guidelines to improve the fishing practices and to promote the development of National Plans to reduce this source of mortality in seabirds (FAO, 1999). Subsequently, FAO updated its previous technical document and extended it to include other fisheries such as trawling once the later were identified as a serious threat to top predators including seabirds (FAO, 2009b). In Argentina, the studies on seabird conservation in fisheries, and specifically addressing incidental mortality in fisheries, started in the year 2000 after an agreement signed between the Universidad Nacional de Mar del Plata, the Ministerio de Ambiente and the Consejo Federal Pesquero to perform the first assessment on the levels of seabird mortality associated to longliners via data gathered by on board observers belonging to the INIDEP. Further, the inclusion of other target fleets, interactions between local researchers and Governmental Organizations, and the ratification in 2006 by Law No.

26.107 of the Agreement on the Conservation of Albatrosses and Petrels (ACAP)[17], led in 2007 to a workshop organized by the Secretaría de Ambiente y Desarrollo Sustentable de la Nación and the Subsecretaría de Pesca y Acuicultura de la Secretaría de Agricultura, Ganadería, Pesca y Alimentos on the conservation of pelagic seabirds with the aim of providing a level of coordination to frame future actions relevant to the Agreement's Plan of Action. (http://www. ambiente.gov.ar/ archivos/web/GTRA/file/Libro_taller_ aves.pdf). One of the main outcomes of this workshop was triggering the drafting of a technical document as a basement for the National Plan of Action – Seabirds, which was adopted in 2010 by the Consejo Federal Pesquero (http://www. cfp.gob.ar/resoluciones/res15-2010-a1.pdf). As a follow up regarding the implementation of the Argentine National Plan of Action – Seabirds, the Consejo Federal Pesquero approved the creation of a Group of Technical Advice comprised by representatives of the Government, the Academia and NGOs (by Act CFP No. 06/13). The terms of reference of this multidisciplinary group include (1) the coordination of actions to comply with the PAN-AM, (2) to report such actions to the Consejo Federal Pesquero, (3) assess the needs of updating the PAN-AM, and (4) align the actions of the PAN-AM with international commitments taken by Argentina. Further recommendations after the first review of the National Plan of Action – Seabirds and focusing in the large and complex trawl fleet include (1) the adoption of best fishing practices related to the use and management of fishery discards and offal, (2) the consideration of a range of interactions between seabirds and fisheries (in addition to data gathering on bycatch), and (3) the need for specific legislation regarding best practice mitigation measures onboard trawlers.

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[17] The Agreement for the Conservation of Albatrosses and Petrels (ACAP) is multilateral agreement aimed at improving and maintaining the conservation status of albatrosses and petrels (www.acap.aq).

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*Chapter 4*

# PLASTIC DEBRIS AND SEABIRDS: UPDATING AN OLD STORY

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## ABSTRACT

The importance of ocean pollution, including pollution from plastics, has been recognized for a long time. However, the current generation and disposal of plastic worldwide has no precedent. Plastic litter accounts for 50-80% of waste items stranded on beaches, floating on the ocean surface and lodged in the seabed. Floating plastic debris is usually ingested by marine animals by mistake, or because it resembles their natural food. This plastic intake by animals such as seabirds can produce entanglement, intoxication, internal wounds, digestive tract blockage and ulcers among other conditions. While these damages are important, further concerns have arisen about plastics sorbing potentially hazardous hydrophobic chemicals. These compounds found in the waters where plastics are, can be plastic additives from other degrading plastics such polychlorinated biphenyls (PCBs) or chemicals from other sources like persistant organic pesticides (POPs), both with the capacity of being sorbed by plastics. However, the importance of the ingestion of plastic-derived chemicals present in the natural prey of seabirds through biomagnification, compared with the amount of these chemicals intake via plastic debris is still being studied. The finding of PCBs and POPs in the ingested plastic pellets and plastic fragments, have led to additional research aimed at assessing the relative potential of plastic as a vector of pollutants transport. The results of these studies are until now contradictory, largely because the role of the dilution and cleaning mechanisms of the studied chemicals are under debate. The impact of plastic debris on individuals is well known although it is not entirely clear how plastic ingestion at the individual level could impact the whole population and how this will impact entire ecosystems. For example, one strategy to mitigate damage caused by ingested plastics is to regurgitate them, so the transference of these plastics to chicks is not uncommon while being fed. As most chicks are unable to regurgitate plastic fragments, these accumulate in their stomachs eventually causing death. At present, the implications of chemicals sorbing on the population size of seabirds is unknown. The effectiveness of using seabirds as monitors has increased considerably in recent years. Sampling the stomach contents of beached birds, birds killed accidentally by fishing activities or by examining regurgitated pellets of predators that feed on seabirds can be useful as well. Nonetheless, there are still questions to answer before we can confidently assess the impact of plastic waste on the environment through seabirds. For example: Is there a linear relationship between pollutants sorbed and the surrounding plastic debris? Or do birds reach a point where they become saturated by these chemicals independently of their plastic ingestion? Throughout this chapter we will evaluate the progress made to answer the open questions about the impact of plastic debris on seabirds and discuss the future of seabirds as a group and their use as monitors of plastic pollution to evaluate the health of ecosystems.

## INTRODUCTION

The problem with plastic litter has worsened with time, not only because its production has dramatically increased from 0.5 to 260 millions of tons per year since 1950 [1] but also because recent studies have shown that damages caused by plastics to the environment are bigger than was thought.

When we visit a beach, especially during vacations it is almost inevitable to find large amounts of plastic litter floating in the sea and along the coast. This is due to plastics´ light weight, low production cost, corrosion resistance and malleability, factors that make plastics so popular, that they have substituted other materials like metals and glass. Our plastic dependence is such that globally, we require more than 200 million tons of crude oil for plastic production [2], which represents 8% of the world´s production [3]. To have an example of the vast amount of plastic we use, only in the US, 100 thousand million plastic bags are produced, using 12 million barrels of crude oil. Thus, plastics not only directly pollute the environment *per se* but also indirectly by promoting the need of a more extensive crude oil production and all the negative environmental consequences derived from this activity.

About 0.2 to 3% of plastic production ends up at sea [4], although Thompson [5] states that this amount can reach 10%, which makes plastic the main component of marine debris [6]. Every fishing vessel use plastic fishing gear [7] and a big part of it is lost or discarded into the sea, reason why up to 18% of marine plastic litter is attributed to the fishing industry [2].

On the other hand, aquaculture is also an important source of marine plastic debris [8]. It has been estimated that all this plastic litter represents between 50 and 80% of beach waste, floating on the ocean surface and on the seabed. Tourism is also an important source of plastic waste that ends on the sea or beached [9]. Plastic pollution from land origin is also important because several plastic additives like plasticizers can lixiviate in landfills to water bodies and transported to the sea [10].

Undoubtedly, the most visible effect of plastic waste is the esthetic, which has economic repercussions for countries due to tourism decrease [11]. For example, in 1987 in New Jersey and in 1988 in Long Island, US it was reported the loss of between 121 and 327 millions of user days at the beach and between US$ 1.3 $x10^9$ and US$ 5.4 x $10^9$ from tourism activities mainly due to accumulation of plastic debris in beaches [12].

However, it can be the least of the problems for wildlife. Plastic pollution can have major consequences on the ecosystems like carbon sequestration prevention.

Although precise mechanisms by which plastics get to the sea bed are not available, some feasible hypothesis exists. For example, sediment decantation on pelagic plastic particles and seawater when they accumulate in large quantities [13].

Seabirds are one of the marine taxonomic groups more threatened in the world with around 25% of species under some protection category by the IUCN [14] from which some of them are catalogued as endangered or critically endangered (table 1).

These species directly depend on sea resources for surviving. Seabirds are very sensitive to environmental changes and anthropogenic alterations because they are in the middle and top of trophic chains. Several characteristics: high philopatry to nesting places, longevity, coloniality, relatively easiness to being captured on their breeding grounds and detectable on their feeding place, facilitate that seabird monitoring can be carried out individually or colonially during several years, facilitating comparisons during long periods of time and on large marine areas.

**Table 1. Seabird species listed as endangered (EN) or critically endangered (CR)**

| Family | *Species* | Common name | Status (trend) |
|---|---|---|---|
| Alcidae | *Brachyramphus marmoratus* | Marbled Murrelet | EN(decreasing) |
| Alcidae | *Synthliboramphus hypoleucus* | Guadalupe Murrelet | EN(decreasing) |
| Fregatidae | *Fregata andrewsi* | Christmas Frigatebird | CR(decreasing) |
| Diomedeidae | *Diomedea sanfordi* | Northern Royal Albatross | EN(decreasing) |
| Diomedeidae | *Phoebetria fusca* | Sooty Albatross | EN(decreasing) |
| Diomedeidae | *Thalassarche carteri* | Indian Yellow-nosed Albatross | EN(decreasing) |
| Diomedeidae | *Thalassarche chlororhynchos* | Atlantic Yellow-nosed Albatross | EN(decreasing) |
| Diomedeidae | *Thalassarche chrysostoma* | Grey-headed Albatross | EN(decreasing) |
| Diomedeidae | *Diomedea amsterdamensis* | Amsterdam Albatross | CR(decreasing) |
| Diomedeidae | *Diomedea dabbenena* | Tristan Albatross | CR(decreasing) |
| Diomedeidae | *Phoebastria irrorata* | Waved Albatross | CR(decreasing) |
| Haematopodidae | *Haematopus chathamensis* | Chatham Oystercatcher | EN(increasing) |
| Hydrobatidae | *Hydrobates homochroa* | Ashy Storm-petrel | EN(decreasing) |
| Hydrobatidae | *Hydrobates macrodactylus* | Guadalupe Storm-petrel | CR(unknown) |
| Laridae | *Larus bulleri* | Black-billed Gull | EN(decreasing) |
| Laridae | *Sterna acuticauda* | Black-bellied Tern | EN(decreasing) |
| Laridae | *Chlidonias albostriatus* | Black-fronted Tern | EN(decreasing) |
| Laridae | *Sternula lorata* | Peruvian Tern | EN(decreasing) |
| Laridae | *Thalasseus bernsteini* | Chinese Crested Tern | CR(decreasing) |
| Phalacrocoracidae | *Phalacrocorax capensis* | Cape Cormorant | EN(decreasing) |
| Phalacrocoracidae | *Phalacrocorax featherstoni* | Pitt Shag | EN(decreasing) |
| Family | *Species* | Common name | Status (trend) |

**Table 1. (Continued)**

| Family | *Species* | Common name | Status (trend) |
|---|---|---|---|
| Phalacrocoracidae | *Phalacrocorax onslowi* | Chatham Shag | EN(decreasing) |
| Procellariidae | *Pelecanoides garnotii* | Peruvian Diving-petrel | EN(decreasing) |
| Procellariidae | *Pterodroma alba* | Phoenix Petrel | EN(decreasing) |
| Procellariidae | *Pterodroma atrata* | Henderson Petrel | EN(decreasing) |
| Procellariidae | *Pterodroma axillaris* | Chatham Petrel | EN(increasing) |
| Procellariidae | *Pterodroma baraui* | Barau's Petrel | EN(decreasing) |
| Procellariidae | *Pterodroma cahow* | Bermuda Petrel | EN(increasing) |
| Procellariidae | *Pterodroma hasitata* | Black-capped Petrel | EN(increasing) |
| Procellariidae | *Pterodroma incerta* | Atlantic Petrel | EN(increasing) |
| Procellariidae | *Pterodroma madeira* | Zino's Petrel | EN(stable) |
| Procellariidae | *Puffinus bannermani* | Bannerman's Shearwater | EN(decreasing) |
| Procellariidae | *Puffinus huttoni* | Hutton's Shearwater | EN(stable) |
| Procellariidae | *Puffinus newelli* | Newell's Shearwater | EN(decreasing) |
| Procellariidae | *Pseudobulweria aterrima* | Mascarene Petrel | CR(decreasing) |
| Procellariidae | *Pseudobulweria becki* | Beck's Petrel | CR(decreasing) |
| Procellariidae | *Pseudobulweria macgillivrayi* | Fiji Petrel | CR(decreasing) |
| Procellariidae | *Pterodroma caribbaea* | Jamaican Petrel | CR(unknown) |
| Procellariidae | *Pterodroma magentae* | Magenta Petrel | CR(increasing) |
| Procellariidae | *Pterodroma phaeopygia* | Galapagos Petrel | CR(decreasing) |
| Procellariidae | *Puffinus auricularis* | Townsend's Shearwater | CR(decreasing) |
| Procellariidae | *Puffinus bryani* | Bryan's Shearwater | CR(decreasing) |
| Procellariidae | *Puffinus mauretanicus* | Balearic Shearwater | CR(decreasing) |
| Sulidae | *Papasula abbotti* | Abbott's Booby | EN(decreasing) |

Seabirds are widely used to monitor atmospheric, edaphic and hydric pollution [15-17], prey pollution (fish, cephalopods and plankton) and to evaluate fishing stocks status e.g. [18, 19, 20] and climate change [21].

Seabirds are also good indicators of marine plastic pollution because several species can ingest plastic particles and reflect plastic pollution burdens of specific areas at different ages during different breeding stages.

However, the damage and consequences this ingestion has on seabirds' populations is unknown and several contradictory results exist even in studies of the same species. Which is undeniable is the fact that seabirds are constantly exposed to plastics and this exposition is continually increasing due to the production and utilization of plastic products by the entire civilized world. On the present chapter we will discuss different ways that marine plastic debris is affecting or could potentially affect seabirds worldwide.

## PLASTICS AND INVASIVE SPECIES

Generally, plastics do not stay in the places where are discarded but are distributed all around the world due to marine currents and winds. Plastics are found even in remote places like the north of Norway [22] and the Arctic and Southern Oceans [23]. The hard plastic surface is used by hitchhiking species to get dispersed to new places [9, 13, 24]. Through this process, organisms like bacteria, polychaete worms, hydroids, mollusks and tunicates, (many of them considered invasive species) can travel long distances in a more efficient way than doing it on ship hulls or ballast entanglement [25]. These species usually do not damage seabirds directly. However, they can do it indirectly in a very severe way by affecting their food availability. For example, floating plastics have been identified as transport vectors of harmful algae species [26] that can bloom and cause big fish mortality, which is the main prey for several seabird species. It has been suggested that even species like cats and rats, which cause great damage to seabird colonies, can survive on the top of regular size plastic debris enough time to reach an island and colonize it [27].

## ENTANGLEMENT

For approximately 50 years now, natural fibers from fishing nets have been substituted by nylon and other synthetic materials. These represent a major danger of marine pollution because due to their lightness, much larger floatable nets can be manufactured, which can persist on the marine environment for long periods of time after they are abandoned, lost or discarded at sea [28]. This has increased the danger for seabirds of being accidentally entangled on gillnets, trawls of monofilament lines when trying to get food.

For example, gillnets are responsible of causing the death of 400 000 seabirds per year [29]. Such kind of nets are practically invisible for diving seabirds and very resistant, thus they are easily entangled while fishing, making seabirds very vulnerable to be predated, die drowned, by starvation or due to the wounds provoked when trying to free themselves.

Those kind of nets can persist on the marine environment for long periods of time after they are abandoned, lost or discarded at sea [28]. A report from Canada´s Food and Agriculture Organization [30], estimates that 10% of static fishing gear is lost annually, which means they can continue “ghost fishing” almost indefinitely [13].

Around 148 seabird species have been identified as prone to be entangled in gillnets. From these, 81 have been registered entanglements. Higher densities of susceptible species are on temperate and sub-polar regions from both hemispheres in comparison with the tropics. The most sensitive species to become net entangled are Sphenisciformes (penguins), Pelicaniformes (pelicans, boobies, gannets, cormorants, frigates and tropic birds) and shore birds (skuas, gulls, terns and auks) [31]. Scavenging seabirds like Herring, Black-backed and Black-headed gulls (*Larus argentatus, Larus marinus* and *Chroicocephalus ridibundus*) have the highest entanglement rate because they usually search for food on landfills or on the trail left by fishing boats, where entangler plastic amounts are higher. Other vulnerable group is that of plungers like Pelicans and Gannets. On the other hand, seabirds that feed through pursuit diving, surface seizing and dipping are generally less prone to be entangled [31]. The majority of entangled seabirds are not able to free themselves thus they usually die. Other items that can entangle seabirds are the six-pack plastic rings although the entanglement frequency is much lower than that from fishing line.

## USE OF PLASTICS AS NESTING MATERIAL

The use of plastic debris as nest material is common in several seabird species (table 2). However, this behaviour causes chicks to ingest it or become entangled, although it is not common [32, 33]. Votier et al. [33], found that the proportion of nests constructed with plastic debris in Gannets (*Morus bassanus*) increased from 49% in the 70´s to 80% in recent years. They suggest that this increase along with other mortality causes can be very important, and these kind of deaths should be prevented because seabirds suffer when they die this way.

**Table 2. Seabird species in which plastic debris have found on nests, chicks or boluses**

| Species | % | Mean | More abundant debris | Color | References |
|---|---|---|---|---|---|
| | | NESTS | | | |
| | 23-34.5 | 0.31 ±0.504 | | | |
| Sula bassana | 97 | | Fishing gear | | [32] |
| *Sula leucogaster* | 3-31<br>58.3 | | Hard plastic (91.2%) | white, black, green | [38, 39] |
| *Morus bassanus* | | 469.91g | Synthetic rope | | [33] |
| *Morus serrator* | 23-35% | 0.31 ±0.504 | Rope (78%) | | [113] |
| *Phalacrocorax auritu* | 37 | | Fishing gears, plastic bags | | [114] |
| | | CHICKS OR FLEDGINGS | | | |
| *Ardenna pacifica* | 21% | 3.2 | Plastic fragments | white and green | [115] |
| *Ardenna tenuirostris* | 100% | 7.6 pieces<br>113mg | user plastic | light in colour | [58] |
| *Calonectris diomedea* | 83.5% | | Nylon lines (55.3%) | white | [59] |
| *Rissa Tridactyla* | 57.2 | | | | [116] |
| *Puffinus carneipes* | 90 | 17.5 | | white | [61] |
| *Puffinus carneipes* | 79 | 2.6±3.6 $cm^3$ | | | [51] |
| *Puffinus pacificus* | 43 | 0.7 ±0.9 $cm^3$ | | | [50] |
| *Puffinus tenuirostris* | 96 | 148.1 mg | User plastics | light color | [63] |
| | | BOLUSES | | | |
| *Phoebastria immutabilis* | 100 | 70.6-17.4 pieces<br>0.58-0.20g | | | [117] |

## PLASTIC INGESTION

Plastic intake by seabirds has been widely documented [34]. At least 44% of seabirds use to ingest plastic [35]. Plastic consumption has been detected in Guillemots, Fulmars, Gulls, Boobies, Albatrosses and Auks (table 3). There are places where the amount of plastic is so big that in some colonies, 90% of birds sampled show evidence of plastic ingestion (table 3). It has been shown that this ingestion is selective and depends amongst other factors on plastic color [36]. This backs up the hypothesis that seabirds can ingest these plastics when mistaken for food like jellyfish. However, Codina-García et al. [37] found in 9 seabird species, a preference for dark plastics over light ones. Moreover, Lavers et al. [38] and Verlis et al. [39] detected a high proportion of black plastics in nests of the Brown Booby (*Sula leucogaster*), which cannot be explained by the confusion hypothesis.

Plastic intake is closely correlated with foraging strategies and diet. Planktivorous seabirds are more prone to mistake plastics with their prey than piscivorous species [40], even though they can feed of planktivorous fish and squid that potentially could have ingested marine plastics. The type of plastic also influences the preference of seabirds. For example, Short-tailed Shearwater (*Puffinus tenuirostris)* prefers hard plastics like rubber and gloves [41, 42]. However, even diving Auks that feed in the water column have been detected to ingest plastics. Provencher et al. [43] found that 11% of sampled Thick-billed Murres (*Uria lomvia*) in the Canadian Arctic had some plastic on their gastrointestinal tract. Interestingly, only user plastic was found on these samples and a seasonal effect on plastic ingestion was detected. Plastic was present on the samples only at the beginning of the breeding season and absent by the end, probably due to plastic consumption in the south while wintering and posterior digestion throughout the breeding season.

**Table 3. Studies in which plastics have been found on seabirds. Only Works where at least 10 birds were sampled are cited. Period from 2008-2014**

| Group | Species | Region | % | More abundant plastic ítem | References |
|---|---|---|---|---|---|
| Alcidae | *Spheniscus magellanicus* | Brazil | | | [1] |
| Alcidae | Uria aalge y U. lomvia | Terranova, Canada | | | [2] |
| Alcidae | *Uria lomvia* | Canadian Artic | 11 | | [3] |
| Diomedeidae | *Phoebastria immutabilis* | North Pacific Ocean | 83.3 | | [4] |
| Diomedeidae | *Phoebastria nigripes* | North Pacific Ocean | 51.7 | | [4] |
| Hydrobatidae | *Oceanodroma leucorhoa* | North east Canada | 48 | | [5] |
| Laridae | *Laruss audouini* | Catalan coast | 13 | | [6] |
| Laridae | *Larus glaucescens* | Island North Seattle | 91.3* | | [7] |
| Laridae | *Larus michahellis* | Catalan coast | 33 | | [6] |
| Laridae | *Rissa tridactylae* | Catalan coast | 50 | | [6] |

**Table 3. (Continued)**

| Group | Species | Region | % | More abundant plastic ítem | References |
|---|---|---|---|---|---|
| Procellariidae | *Ardenna pacifica* | Australia | 21 | | [8] |
| Procellariidae | *Calonectris diomedea* | Catalan coast | 94 | | [6] |
| Procellariidae | *Calonectris diomedea* | Canary Island | 83% | | [16] |
| Procellariidae | *Calonectris diomedea* | Nova Scotia, Canada | 0% | User plastic | [19] |
| Procellariidae | *Calonectris diomedea* | Brasil | 100 | | [21] |
| Procellariidae | *Daption capense* | Brasil | 75 | | [20] |
| Procellariidae | *Fulmarus glacialis* | Eastern North Pacific | 92.5 | | [9] |
| Procellariidae | *Fulmarus glacialis* | Iceland | 79 | | [10] |
| Procellariidae | *Fulmarus glacialis* | North Sea | 95 | | [11] |
| Procellariidae | *Fulmarus glacialis* | California, US | 86.5 | Hard plastic | [22] |
| Procellariidae | *Fulmarus glacialis* | Northern Canada | 84 | | [23] |
| Procellariidae | *Fumarus glacialoides* | Brasil | 33, 79 | | [20, 21] |
| Procellariidae | *Macronectes giganteus* | Brasil | 64.3 | | [20] |
| Procellariidae | *Pachyptila belcheri* | Brasil | 33,3 | | [20] |
| Procellariidae | *Procellaria aequinoctialis* | Brasil | 25, 49 | | [20, 21] |
| Procellariidae | *Procellaria conspicillata* | Brasil | 22 | | 21 |
| Procellariidae | *Puffinus carneipes* | Australia | 79 | | 12 |
| Procellariidae | *Puffinus gravis* | Nova Scotia, Canada | 88% | | 19 |
| Procellariidae | *Puffinus gravis* | Brasil | 7, 89 | | 20, 21 |
| Procellariidae | *Puffinus griseuss* | Nova Scotia, Canada | 72% | | 19 |
| Procellariidae | *Puffinus griseuss* | Brasil | 63.6% | | 20 |
| Procellariidae | *Puffinus mauretanicus* | Catalan coast | 70 | | 6 |
| Procellariidae | *Puffinus pacificus* | Australia | 43 | | 12 |
| Procellariidae | *Puffinus puffinus* | Brasil | 86, 60 | | 20, 21 |
| Procellariidae | *Puffinus tenuirostris* | North Pacific Ocean | | | 13, 17 |
| Procellariidae | *Puffinus tenuirostris* | Australia | 63% | | 14 |
| Procellariidae | *Puffinus yelkouan* | Catalan coast | 70 | | 6 |
| Procellariidae | *Pterodroma solandri* | Australia | | | 18 |
| Procellariidae | *Thalassarche chlororhinchos* | Brasil | 44, 7 | | 20, 21 |
| Procellariidae | *Thalassarche melanophrys* | Brasil | 73, 12 | | 20, 21 |
| Sulidae | *Sula leucogaster* | Islands Timor Sea | 3-31 | | 15 |

[1]Brandão et al. 2011, [2]Bond et al. 2013, [3]Provencher et al. 2010, [4]Gray et al. 2012, [5]Bond and Lavers 2013, [6]Codina-García et al. 2013, [7]Lindborg et al. 2012, [8]Verlis et al. 2013, [9]Avery-Gomm et al. 2012, [10]Kühn and van Franeker 2012, [11]van Franeker et al. 2011, [12]Hutton et al. 2008, [13]Yamashita et al. 2011, [14]Acampora et al. 2014, [15]Lavers et al. 2013, [16]Rodríguez et al. 2012, [17]Tanaka et al. 2013, [18]Bester et al. 2010, [19]Bond et al. 2014, [20]Barbieri 2009, [21]Colabuono et al. 2009, [22]Donelly et al. 2014, [23]Provencher et al. 2009).

## DAMAGES CAUSED BY MACROPLASTIC INGESTION

During the mid-eighties and the beginning of nineties, studies stated that plastic ingestion did not severely affect seabirds [44-47]. However, there is also a long list of the negative effects of plastic consumption by seabirds.

Seabirds can ingest as much plastic as to occupy a big part of the stomach and provoke distention. This reduces food storage capacity and induces a fake satiety sensation thus significantly reducing feeding capacity [48].

It is not uncommon that seabirds with plastics in their gizzard, lack food in the proventriculous [44]. For this reason, individuals with high loads of plastic on their tract struggle to accumulate enough energy reservoirs essential for reproduction, molting and survival when adverse conditions are present. They also present a low body condition, characteristics considered as evidence of the damage caused by plastic ingestion [49-51]. However, in some studies this correlation between plastic load and body condition has been absent. Analyses of 9 Procellariiformes in the western Mediterranean from 2003 to 2010 did not show a significant association between body condition and the ingested plastic mass, size or number of items in any of the species [37]. Acampona et al. [41] did not find such correlation either after the necropsy of adults and juveniles of Short-tailed Shearwaters in Australia.

Apart from the more obvious damages of macroplastic ingestion like the obstruction of the digestive tract, which prevent seabirds from absorbing nutrients from food through the intestine [52], some of these plastics have sharp edges that produce cuts and ulcerations from the stomach mucous [42, 53]. Although it is infrequent that these lesions are deadly because seabirds can tolerate similar wounds from prey spines, in some cases they can get infected and therefore decrease their survival odds [53].

It is not easy to show that plastic consumption is responsible for deaths on seabirds because at dying, seabirds sink or are eaten by scavengers. Without a necropsy is very hard to link plastic ingestion with mortality [54] and these are rarely done. However, there are some studies showing that death of some seabirds were due to obstruction of the digestive tract by ingested plastics e.g. [55] and probably it is more common than we know.

The main prey of seabirds, fish, are not free from plastic ingestion themselves. In the North Pacific Central Gyre, approximately 35% of planktivorous fish had plastic pieces in their guts [56]. Moreover, there is a correlation between plastic amounts found in fish and pollution loads [57], which represent an additional source of contamination for seabirds.

## TRANSGENERATIONAL PLASTIC TRANSFER

Several seabirds like petrels, cormorants, skuas, gulls, terns and albatrosses, regurgitate plastics perhaps to mitigate the damage caused by ingested plastics and thus avoiding their accumulation [49] (table 2). However, some species cannot regurgitate. In general, Procellariiformes are incapable of regurgitating plastic, which explains at least partially, the great amount of plastic debris found on this group. Plastic abundance on petrels (*Calonectris diomedea*) in the Mediterranean Sea was higher than that in gull stomachs despite the later ones ingesting higher quantities [37].

Nevertheless, regurgitation as a protection measure against plastic damage increases transference from these particles to chicks [58-60]. This plastic interchange rises because the low discrimination capacity between plastics and prey of young birds [41]. Moreover, similar to Procellariiformes, chicks from several species do not normally regurgitate until they are almost fledged, reason why they can accumulate great amounts of plastic during the time they spend in the nest [61]. Together, these factors provoke chicks to be more vulnerable to plastic litter than adults. Chicks that do not regurgitate ingested plastics, can accumulate them to a degree that directly interfere with digestion, causing a decrease in their feeding frequency provoking a smaller body size when fledging, a lower survival probability and lower fitness [62].

A direct correlation (positive or negative) between the plastic load in chicks and their physical condition measured in body mass exist in several species. For example, Flesh-footed Shearwaters (*Puffinus carneipes*) fledglings with high amounts of ingested plastic had reduced body condition [61]. On the other hand, Spear et al. [50] found that Procelariiformes in good condition had the highest levels of plastic loads, due to their capacity of foraging more in more productive places where plastics are also abundant. These findings suggest that plastic pollution affects differently individuals from dissimilar ages and species although this correlation is not present in other studies [58, 63].

## MICROPLASTICS

In general, plastic particles from 333 µm up to 5 mm are commonly called microplastics although smaller particles of less than 1uµ are also considered in this category though they are harder to detect [64-66]. The most common class of plastics from these micro particles are polyethylene, polypropylene and polystyrene [2, 67]. Microplastics exist in every compartment of the marine environment: oceans and coastlines, at the surface, deep in the ocean and in every latitude [68]. There are two big categories for microplastics: 1) Primary or industry plastics [69], which are commercial micro-particles like scrubbers, precursor pellets and abrasives. These primary pellets are resin granules, disc- or cylindrical shaped, which are used as raw material for industrial use. 2) Secondary or user plastics which are by-products of big plastics like cloth or fishing nets fibers that enter the marine environment via runoff or directly from fishing activities. Within the user plastics, fragments product of environmental degradation (photodegradation and high temperatures) of larger plastics [68, 70] like polyesters from fabrics [71], polyethylene from plastic bags [72] and polystyrene from buoys [73] are included.

Plastics product of degradation are the main source of the majority of microplastics, principally those in the beach environment. For this reason, plastic cleaning from beaches before it weathers down can be highly beneficial for the marine ecosystems apart from the esthetic benefits [2].

Microplastics found in the marine environment can have land and marine based origin sources, although fishing and ship littering account for a big proportion of plastics at open sea [13]. The origin of plastics can be local or remote with their distribution and abundance in the marine environment due to sea surface currents and winds, plastic density, shape, colors and closeness to towns [2, 71], reason why there are some areas with higher concentrations of microplastics than others. The majority of studies have focused mainly on detritus larger than 333µm although much smaller microplastics (<100 µm) exist in the sea. However, sampling them is very hard, affecting the accuracy of their abundance [74].

An important source of microplastic particles are boring isopods. These microorganisms damage polystyrene buoys from piers by making tunnels on these structures and ejecting abundant microplastic particles. These particles are variable and of irregular shape, the majority globular or rectangular lined with fine strands, some of them highly irregular with a mean perimeter-area ratio 200% higher than a similar sized circle [73]. These type of particles can persist in the marine environment and can be consumed or colonized by several species like amphipods, echinoderms, polychaetes, mussels, crustaceans, lobsters, fish, birds, turtles and mammals (reviewed in [75]) because they are very similar to various species of plankton. Another important source of microplastics are biodegradable plastics which are typically composed of synthetic polymers and starches, vegetable oils or specialized chemical products (like TDPA™), designed to fasten degradation times [9, 72]. However, its decomposition is not total since starches from bioplastics disintegrate but a great amount of microscopic fragments remain [76].

Three main effects of microplastics on marine life exist:

1) The spread of non- native species by supplying surfaces for organisms to be attached and float to a new area (sponges, hydroids, bryozoans, mollusks, isopods, barnacles, polychaetes and toxic microalgaes) reviewed in [73].
2) Accumulation in the gastrointestinal tract provoking obstruction and reduced absorption of nutrients.
3) Transport of toxic chemicals (persistent organic compounds and trace metals; see below for details).

Additionally, microplastics have the possibility of being colonized by microorganisms that cause mircoplastics to sink [13, 68] thus having the chance to interact with benthic and pelagic organisms.

It is unknown how often microplastics are ingested by zooplankton and what are the implications of this. Zooplankton plays a key role in marine food webs by acting as primary consumers and juveniles of several commercial species.

Some zooplankton can feed by chemo or mechano receptors to select food [74]. It has been shown that plastic microbeads are ingested along with algaes. This feeding is consequence of indiscriminate feeding spherical preys with similar diameters as micro beds [77-79]. Zooplankton are capable of indiscriminately ingesting microplastics of 1 to 40 µm of diameter by filter-feeding and discard these particles in fecal pellets soon after being ingested. Microplastics can also accumulate on the surface of dead zooplankton and be trapped on the appendages of live copepods, as well as clustered on the alimentary tract [74]. Ingestion of microplastics has been shown in marine organisms like amphipods, lugworms, barnacles, mussels, crustaceans, seabirds and fish. This ingestion can obstruct the gastrointestinal tract, aggregate and block it, avoid food intake by fake satiation and introduce toxic compounds to the blood stream. Another factor that potentially could increase pollution is the large ratio of surface area to volume along with the hydrophobic properties of microplastics, which allows them to be vulnerable to contamination by hydrophobic organic contaminants (HOCs) [75].

Several species of seabirds ingest microplastics mistaking them for prey. Especially surface eating planktivorous like the Little Auk (*Alle alle*), Phalaropes and Storm petrels, which are exposed to the ingestion of plastic pellets. On the other hand, Shearwaters and Albatrosses commonly ingest larger plastics and pellets that are so small for them that they pass unnoticed through the digestive tract and are difficult to detect by the sampling methods to determine plastic ingestion. Plastic pellets of all types were found in petrels, shearwaters and prions in the late 80´s by [49]. Twenty years later the proportion of pellets significantly decreased on the studied species. Nevertheless, the total number of plastics was not different between the studies, this being attributed to the increase of plastic fragments (derived from a user plastic) in the environment.

Nylon fibers from clothes or fishing nets are an important source of microplastic pollution (<1cm). Depending on the places found they can be attributed to domestic sewage or fishing activities. For example, at the Canary Islands, 83.5% of shearwater chicks (*Calonectris diomedea*) had ingested nylon threads from commercial fisheries that were regurgitated by their parents. In Glaucous Winged Gulls (*Larus glaucescens)* films from plastic bags in boluses were the main cause of contamination. This type of microplastic (<1 cm) was found in 12% of the boluses analyzed from 2007 to 2010. Moreover, 2.9% of the boluses were formed from at least 50% plastic. In comparison, diet analyses of this species in 1979 did not find plastics in boluses, which indicate that plastic consumption by G.W. Gulls is increasing [80].

In the North Pacific Ocean, plastics were present in the stomachs of 83% of Laysan Albatrosses (*Phoebastria* immutabillis) and 52% of Black-footed Albatrosses (*Phoebastria nigripes*). Laysan had more plastic fragments than fishing line and Black-footed more line than fragments, which suggests that Black-footed consumes more by-products from the fishing industry than Laysans [81]. It has been found that plastic ingestion is larger in species from lower latitudes apparently because more fragments are available [43].

## USE OF NORTHERN FULMARS AS MONITORS OF SEA PLASTIC CONTAMINATION

Northern Fulmars have been used as monitors for plastic pollution of the North Sea. Data of plastic presence on the Fulmars´ stomachs exist since the 80´s when 91% of the samples had some type of plastic. In the mid-nineties this proportion increased to 97% and in the first half of the twenty first century was down to 95%.

All this data shows that plastic presence on the digestive tracts of Fulmars has not decreased since the year 2000. Moreover, the average mass of plastic per stomach doubled from 0.34g in the 80´s to 0.64g at the end of the 90´s. At present, this mass has stabilized at around 0.28g. Additionally, the proportion of different types of plastics (industry and users plastic) dramatically varied through time: from the late 70´s to the late 2000´s industrial plastic significantly decreased while user plastics increased from the 80´s to the 90´s. During this period of time, the mass of industry plastics halved, while user plastics tripled. Both types of plastic decreased from 1996 to 2005 but no change was detected from 1998 to 2007 [82].

Van Franeker and Meijboon [83] reported that fledgling fulmars had more plastic particles in their stomachs than adults. However, they found out that different age groups can be combined into a single monitoring unit. It remains unknown why chicks present higher plastic mass than adults although some explanations exist, like the one stating that adults decrease plastic load during chicks feeding, although this explanation works only with short-term findings.

Surprisingly, when several locations on the North Sea were analyzed for plastic burden differences between locations, a clear pattern in plastic mass was present despite Fulmars capability of travelling long distances in short periods of time. The highest plastic incidence was found in the English-French Channel, decreasing northwards, with a minimum at the Scottish Islands.

This pattern indicates that shipping and fisheries are the main sources of plastic pollution in the North Sea and that Fulmars normally spend periods of time within an area long enough to accumulate a specific level of plastics in their stomach (providing an excellent tool for a multi-year comparison) for that area. The rate of disappearance of plastics from the stomachs needs to be considered in order to make assumptions about the amount of litter in a specific place. It is estimated that plastic “digestion” happens at about 75% per month, depending on the type of plastics (soft foamed and sheet-like plastics disappear faster). The Ecological Quality Objectives for the North Sea (EcoQO) target for “acceptable ecological quality” has been defined by the 1992 Oslo and Paris Conventions for the protection of the marine environment of the northeast Atlantic (OSPAR) as when less than 10% of fulmars carry more than 0.1g of plastic. However, 58% of Fulmars in the North Sea exceed this level, while 44% of Fulmars in the Faroe Islands (considered a “clean” environment) surpass this limit as well [82].

In the Eastern Northern Pacific, the same protocol of sampling Fulmar carcasses for plastics was carried out by Avery Gomm et al. [84]. They found that 92% of the stomachs had plastics with an average mass of 0.39 g. From this, 96% were user plastics and 4% industrial pre-production pellets. These results are similar to the results from the North Sea by van Franeker et al. [82] and out pass the EcoQO target by an extensive range. From 1969 to 1977, 58% of fulmars had plastic presence (Reviewed in [84]). Robards [85] reported an increase of 26% in the numbers of fulmars with plastic in their stomachs during 1988-1989. The results from 2009-2010 study showed an increase of 8% compared to 1989 and an increase of 34% over the past 40 years.

Additionally, the ingested plastic mass increased from 0.04 g between 1969 and 1977, to 0.12 g in 1987 and to 0.38 g in 2009-2010 (Reviewed in [83]). Although comparisons between studies need to be done with care because their duration, high levels of plastic found in the eastern North Pacific are comparable with those from the North Sea (long term polluted), indicating that high levels of plastic pollution happen in both regions [83]. The change in the proportion of types of plastics (industrial and users plastic) found in Northern Fulmars in both studies could have several explanations amongst which fragmentation of user plastics, accumulation of these plastics over time and a lower input of industrial pellets into the marine environment [86] are possible.

Fulmars are a very good example of how seabirds can provide information about the health of the environment otherwise impossible to obtain by direct physical measurements (Reviewed in [82]).

## PLASTICS AND TOXIC CHEMICAL COMPOUNDS

Plastic consumption by seabirds implies damage to organisms beyond the physical harm. It has been shown that seabirds can ingest pollutants through the plastics they consume [10, 87]. The amount of pollutants that seabirds can ingest depends on how long ingested plastics have remained at sea [88]. This leads to a positive relationship between pollutant concentration in the organism and plastic loads [89] which indicates that there is transference of pollutants from plastic to seabirds [10, 87]. However, it is unknown if the presence of plastics in the stomachs of seabirds occurs because they mistake them for prey (direct ingestion), or if seabirds acquire them by feeding on prey that had previously consumed plastics debris (indirect ingestion).

The risk posed by plastics to seabirds is determined by plastic abundance and the original material from which they were made. Polypropilene [90] and polyetilene [64] are the most common type of plastics found in the environment. Plastics made of HDPE (high-density polyethylene), LDPE (low-density polyethylene) and PP (polypropylene) represent greater danger of sorption and concentrate more chemicals like polychlorinated biphenyls (PCBs) and polycyclic aromatic hydrocarbons (PAHs) than plastics made of PET (polyethylene terephthalate) and PVC (polyvinyl chloride) [91].

However, the capacity of sorbing metals is not different between different type of plastics [92]. Additionally, during plastic production, usually various substances like phthalates, organotins and Bisphenol A (BPA) are added to increase their durability and corrosion resistance. When these plastics float in the oceans or are beached, suffer a photodegradation process due to the exposition to the sun, which cause polymers to oxidize and break [68, 93, 94] at the same time that additives lixiviate from plastics [95]. This lixiviation effect also occurs when litter is burned in public waste lands [10].

Mato et al. [96] reported that plastic sorption of organic pollutants is approximately two orders of magnitude higher than that in sediments and natural soils. Floating plastics can concentrate pollutants up to 500 times from the water column [97]. Due to their floatability, these plastics can be easily transported by marine currents, converting them in a mean of transport of hydrophobic chemical compounds to remote and pristine places.

During the last 20 years, a broad range of hydrophobic organic pollutants like PCBs an POPs have been found on ingested plastics by seabirds [98]. The presence of plastic derived chemicals like BDE209 and BDE183, congeners of polibrominated diphenyl ethers (PBDEs) applied to plastics as flame retardants, suggests the transference of plastic-derived chemicals to seabirds [87]. Additionally there is a correlation between trace metals concentration on seabirds' feathers like chromium and silver with the amount of plastics ingested [61]. Both results support the idea that the presence of such pollutants is due to plastic ingestion.

Plastics are biochemically inert because they do not disturb the endocrine system due to their large molecular size. Nevertheless, marine plastics carry small molecular size chemicals that can enter the cells, interact with biological molecules and disrupt the endocrine system. These chemicals are divided in two groups: 1) Hydrophobic chemicals that are adsorbed through sea water due to the affinity of these compounds for the hydrophobic surface of plastics. An example of this group is nonyphenol, a very potent endocrine disruptor. 2) Additives of the molecules that form plastics in order to make them malleable or resistant to heat. Some components from this group are PCBs, DDE and PAHs [10]. Plastics may turn toxic when they degrade and release their additives. Both types of chemicals are absorbed by marine fauna [60, 97].

In zooplankton and other marine organisms, these pollutants can act as endocrine disruptors, carcinogenic or toxic substances with impacts in growth, sexual development, fecundity, morbidity and mortality. An analysis of three colonies of Northern Fulmars (*Fulmarus glacialis*) revealed an association between PCBs and dioxin concentrations with thyroid hormones and retinoids [99], while Nost et al. [100] found in Black-legged Kittiwake (*Rissa tridactyla*) chicks and Northern Fulmars, a positive correlation between total thyroxin (TT4) and perfluorinated compounds (PFCs), substances commonly found in plastic pellets. Moreover, in the Wandering Albatross (*Diomedea exulans*), heavy metals like mercury and persistent organic pollutants (POPs) negatively impacted hatching, fledging and reproduction probabilities [101] which drove these researchers to conclude that this population of seabirds is declining as consequence of the increase in mercury and POPs.

In seabirds, damage caused by plastic ingestion increases because they are frequently the top predators on the trophic chain, potentially biomagnifying these compounds [10, 102]. Apart from transporting pollutants in open waters and on the trophic chain, plastics also contribute to persistence of pollutants for longer on the environment. For example, the soils of the Arctic where fulmars reproduce have increased pollutant burdens thus an elimination of plastics from Fulmars is a very likely cause for this increase [103].

Nevertheless, there is still lack of details on the mechanisms of chemical transfers from plastics to organisms. It is unknown how these substances sorb to microplastics in comparison with natural particles like suspended matter, detritus or phytoplankton.

It is also not understood how material properties, additives or weathering will influence sorption pathways of toxic chemicals [104].

Organic pollutants transference from marine plastic fragments to seabirds was shown in Streaked Shearwaters (*Calonectris leucomelas*) and in the Short-tailed Shearwaters. Compounds adsorbed to plastic particles can be released on the digestive system and absorbed by tissues. On seabirds another issue appears to influence adsorption: biomagnification of organic compounds. Especially hydrophobic chemicals with low bio transformation properties like PCBs, which are abundant on seabirds' food. For this reason, when chemicals derived from ingested plastics are studied, the compounds in natural food sources have to be taken into account [10]. To address this issue, Teuten et al. [10], fed Streaked Shearwaters with PCBs contaminated pellets and fish (which bioconcentrate PCBs) during 7 days. Each chick was exposed to around 100 ng of PCBs from the pellets and 15 ng from the fish. PCBs concentration was measured in preen gland oil from the chicks every day. It was found that PCB levels increased up to day 7 while in the control group (fish fed only) this increase in PCBs was not detected. These results indicate that plastic PCBs were transferred to chicks' tissues. To test these findings further, analyses were done with PCBs divided in lower and higher chlorinated congeners because lower chlorinated congeners were abundant in plastic pellets compared to fish. In the plastic feeding chicks, this type of congeners were three times higher from day 0 to 7 while no differences were found in the group fed only with fish. This results show that biomagnification of phenolic compounds in the food chain is not likely because the hydrophilic group makes them easier to metabolize.

Thus, ingestion of plastics in the marine environment is a direct route of pollution for animals high on the trophic chain (e.g. seabirds) but apparently no biomagnification of PCBs exists through this pathway (10). In addition, biomagnification does not play an important role in the transfer of nonylphenols to seabirds at higher trophic levels [96], which suggest that direct ingestion of pellets is the most common way by which these pollutants transfer.

PBDEs are less biomagnified than PCBs thus their exposure from prey ingestion could potentially be less and the direct influence from PBDEs in microplastics clearer seen. To answer this question, Tanaka et al. [87] measured PBDEs from fatty tissues and ingested plastics of Short-Tailed Shearwaters. Two PBDEs congeners were not found in the prey but were adsorbed to the plastics from the sea, demonstrating the input of these compounds to seabirds tissues through plastics [87].

Industry plastic pellets can accumulate trace metals in high concentrations, which is counterintuitive due to pellet composition, morphology and surface area (hydrophobic and small areas). This accumulation of metals is not simply adherence or entrapment to the solid material, it is metal sorption due to the oxidization of microplastics´ surface [2]. Lab experiments showed that pellets can accumulate metals from the water column or surface microlayer. Mechanisms seem to be varied and complex, though adsorption of metals apparently will increase as the plastic ages and its polarity, surface and porosity rise causing organic matter to attach to it thus favouring metal sorption.

Although the role of pellets as metals reservoirs is low on beaches and estuaries, these habitats hold the largest amount of microplastics. Pellets can transport metals to open sea waters where they can act as an important source of metals to the biota that ingests those [105].

## CONCLUSION

It is estimated that in the Northern Pacific Ocean 970,000 items by sq km are present with a mass of 30,169 g/km$^2$ [106] which represent 3 and 7 times the previous historic record for this region [107].

However, Cózar et al. [66] did not find the amounts of plastic predicted by rates of production and input. They estimated floating particles to be between 7,000 to 35,000 tons from a world survey of floating plastics on the seas, quantities much lower than expected. Additionally, they found a gap in the distribution of plastics smaller than 1mm and a predominance of 1-5 mm plastics. These findings are surprising and strongly suggest a loss of plastics from the oceans´ surface. Cózar et al. [65] proposed four explanations for plastic sinks: shore deposition, nano-fragmentation, biofouling and ingestion.

Despite the unexpected low amounts of plastic reported by Cózar et al. [65] evidence exist about seabirds showing a tendency of increased plastic ingestion. Fledglings with plastic on their gastrointestinal tract increased in Australia from 2005 [51] to 2011 [61]. The number and weight of plastics found in Northern Fulmars and the plastic prevalence has increased in the last 40 years [84]. Although Ryan [108] compared the amount of ingested plastics in five Procellariids between 1980 and from 1999 to 2006 in the South Atlantic Ocean and found that the number of ingested plastic particles was not different, but the type of plastic was. Apparently user plastics are much more abundant nowadays than industrial plastics, which indicates that the main source of plastics in the sea is fragmentation of bigger plastics from marine and terrestrial origin [66, 82, 84, 109].

The most sensitive species to be affected by microplastics are surface-feeding petrels, shearwaters and albatrosses (adults and chicks) with 90% of samples indicating some form of microplastic ingestion. The quantity of plastics is lower as the latitudes increase and more fragments than pellets are observed. For these reasons, seabirds are good and susceptible monitors of marine plastics [108]. Procellariiformes cannot regurgitate plastics due to a constriction between the gizzard and the proventriculus [80], which explains the large quantities of plastic on their digestive system. These plastics can leach toxic pollutants that enter into their tissues and cause physiological damages (e.g. endocrine disruption) apart from the physical ones (e.g. obstruction). Seabirds are exposed to microplastic ingestion by two sources: 1) Direct ingestion while foraging and 2) Through their prey that have already ingested microplastics (again directly or indirectly through their own diet). This is very important because it is known that in several ocean regions, fish with microplastics were more than half of the world ocean´s total fish biomass [110].

The damage that seabirds suffer due to plastic ingestion is scarce. The direct damage by plastic obstruction in the digestive tract can only be verified through a necropsy, which is hard to accomplish because usually corpses sink or are eaten by predators or scavengers.

Moreover, there is not a protocol to routinely carry out necropsies of seabirds found at beaches or at sea. Damage caused by pollution ingestion through ingested plastics is even less clear. Evidence of this damage is mainly from lab experiments in which similar concentrations of plastics found in nature are given to seabirds [10].

Findings of damage by plastic pollution in nature are basically anecdotic [9] or derived from correlative data. There are not studies about direct effects of plastic pollutants on natural seabird’s populations [111] which can only be accomplished by carrying out long term studies.

Although studies to understand the magnitude of the damages caused by plastic pollution and the processes by which they affect organisms started some decades ago, there is still a lack of basic knowledge about these processes. For example, PCBs that are not present on the prey of seabirds have been found in their gastrointestinal tract, suggesting transference from chemical products derived from ingested plastics to seabird tissues [87]. However, it is unknown how plastic additives like plasticizers interact with sorbed chemicals by plastics [91].

For example, metals and pesticides toxicity have been shown in several studies but the evidence about bioavailability and effects of metal pollutants ingested through plastics is almost inexistent [57]. In addition, it is not known if ingestion of non-polluted plastics have adverse effects on vital seabird factors like mortality or reproductive success [104] or the effect of plastic ingestion on chicks and fledglings and consequently on population viability [51]. These complex pathways call for the need of starting research programs and risk assessments focused on ecologically relevant issues.

Plastics capacity of sorbing pollutants depends on their type and size. Availability of pollutants in the plastics differs depending of the pollutant amounts present on the environment, of the time plastics have been in contact with them and the disintegration degree provoked by photo-degradation. For this reason knowing the damages that each plastic compound produce on seabirds is not enough, it is necessary to know how seabirds are affected by all the pollutants together sensu [91].

An overwhelming evidence about seabirds being good bioindicators of sea plastic litter in a specific place exist [84, 108]. This information should be taken in a consistent way in order to be used to take decisions about environmental issues like plastic prohibition, production and the way it is discarded (from boats, fisheries and cities). For example, apart from the direct evaluation of plastic consumption, the assessment of nest composition of some seabirds like Gannets could provide a very useful index about the prevalence of fishing gear waste in order to evaluate the risk of entanglement of other species in the marine environment [112].

## Future Needs

It is necessary to quantify in a more precise way the type and amount of plastic that seabirds ingest in order to estimate in a more trustable way the danger that each plastic type represents to them. A method that appears to be promising is the identification of chemical products that characterize different type of pellets using gas chromatography-mass spectroscopy and use these profiles as indicators of the presence of each type of plastic [90].

There are contradictory findings on the effects of plastic on seabirds' health and condition, about color preference, pollutants transported by plastics, etc. This is due mainly to sampling differences and focus on diverse variables like age or reproductive status of adults [49].

It is needed then to establish an international consensus and adopt a standardized method that allows making temporal and spatial comparisons in a more trustable way.

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*Chapter 5*

# URBAN HYMNS: HOW URBAN ENVIRONMENTS AFFECT BIRD POPULATIONS AND AVIAN SINGING BEHAVIOR

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## ABSTRACT

Recently, humans have altered and created entirely new environments to which animals have either adapted or been extirpated. Urban environments are one of the most extreme examples of how humans have changed previous habitats. Urban environments present massive challenges for birds living in these spaces and the impacts can be seen on all aspects of their behavior including how they communicate with one another. Here, I review how birds, have adapted their singing behavior for life in urban areas. First, I examine how birds' diets in urban areas differ from their diets in other environments and the implications of these differences for birds' song quality and production. I also briefly examine some of the effects that urban environments have on the ecology of avian species, which can affect avian singing behavior. I will then review some of the differences between urban and other environments and relate these differences to the birds' singing behavior. Finally, I conclude that urban environments can dramatically affect avian ecology and communication and I suggest that this may ultimately affect evolution in urban bird populations.

## INTRODUCTION

Humans are having an unprecedented effect on ecosystems and biodiversity worldwide. We have moved species around the world to create new species assemblages. We have also modified habitats to create new environments, which present entirely new challenges to

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wildlife. Therefore, the effects of urban environments on birds are becoming more important because of the larger areas that they cover and their increasing intensity (Grimm et al. 2008). On a global scale, urban environments can be defined as having a high density of human created structures in comparison to surrounding areas and also higher human populations (Adams and Lindsey 2011). Locally, urban environments are typified by the substrate being buried under concrete or other materials and modification or removal of natural vegetation. Some species have benefited from the intensification of urban environments, while others have been extirpated from these areas. Some authors implicate the increase and intensification of urban environments as being negative for biodiversity (e.g., Peterson et al. 2007) although there is little information about the changes in community structure attributed to urban environments. At broad geographic scales, areas of highest human population density are also associated with high species diversity (Hunter and Yonzon 1993, Balmford et al. 2001, Evans and Gaston 2005, Vazquez and Gaston 2006, Pautasso 2007). However, this is not to suggest that urbanization is good for biodiversity, but rather that areas of highest human population density tend to occur in areas of greatest productivity and so have high levels of biodiversity (Evans and Gaston 2005, Pautasso 2007). Moreover, urbanization is implicated in reducing vertebrate diversity (Cam et al. 2000, McKinney 2008) meaning that increasing urbanization may present a challenge for maintaining vertebrate biodiversity. Therefore, species assemblages in urban environments may vary tremendously among different taxa and in relation to how urban areas are managed. However, it is also possible that if managed properly, urban areas (and especially green spaces) can maintain high biodiversity levels (e.g., Kotze et al. 2011).

Ecologists began studying urban ecology in the 1970s (Sukopp et al. 2008, McDonnell 2011), but our interest has grown in the past decade as it has become clearer that urbanization is intensifying and that it has dramatic effects on wildlife (Marzluff et al. 2008, Gaston 2010, Niemelä et al. 2011, Gil and Brumm 2014a). Birds are among the most obvious and successful classes of vertebrates and so they have attracted much of this attention (e.g., Gil and Brumm 2014a). Moreover, the ease with which birds can be studied and manipulated lends them to ecological research. One of the most conspicuous behaviors of birds is their tendency to vocalize. Therefore, the difference in bird song between urban and other environments has received much research interest (e.g., Potvin et al. 2014).

Here, it is my intention to review some of the important effects that living in urban environments may have on bird populations and their singing behavior. First, I will examine why birds sing and then briefly explore the effects that urbanization has on bird populations. I will then review the links between the singing behavior of birds and their diets and specifically their energetic reserves (which is the most well understood nutritional driver of singing behavior). However, it is not only nutrition and energetic state that affects avian singing behavior. Urban environments differ in many other ways from other habitats. One of the most significant areas of difference between urban environments and other environments are the various forms of pollution and contamination that pervade urban environments. Therefore, I will consider three of the most important forms of pollution for singing behavior of birds: (1) environmental contamination, (2) noise pollution, and (3) light pollution. Finally, I conclude not only that urban environments affect the singing behavior of birds, but also that urban environments may drive change in animal phenotypes, which will ultimately drive adaptation and speciation.

## WHY DO BIRDS SING?

All bird species produce vocalizations, but these vocalizations can be arbitrarily split into two types: (i) songs and (ii) calls. While all bird species produce calls, singing is the province of a single avian taxon, the oscine passerines. Oscine passerines have developed a number of morphological adaptations, which other avian groups lack, such as complex syrinxes and specialized memory and motor regions in the brain. These adaptations are devoted to song learning and production and allow oscine passerines to sing (Catchpole and Slater 2008). Traditional definitions of song emphasize the length and complexity of these vocalizations, which are produced by predominantly males during the breeding season (Catchpole and Slater 2008). Typically, bird songs consist of a series of repeated syllables that form a longer vocalization that may typically last a few seconds, but in some species lasts much longer. However, there are many exceptions to these statements about song. For example, it is well known that in the tropics males and females of many species sing (often in concert) and throughout the year (Stutchbury and Morton 2001). The singing activity of many temperate passerines is often concentrated into bursts (30-90 min) at dawn (the dawn chorus) and to a lesser extent in the evening (the dusk chorus). The tendency to vocalize at these times may allow birds to manage their mass in response to the environmental factors such as predation risk, temperature, and time of day (McNamara et al. 1987; Houston and McNamara 1987; Hutchinson et al. 1993; Hutchinson and McNamara 2000).

Birdsong is a sexually selected trait that has two functions: (1) mate attraction and stimulation and (2) resource defense from conspecific rivals (normally of the same sex). However, there are subtle differences in song depending on how it is used. When males sing to attract or stimulate a mate they tend produce structurally more complex and varied songs than when they are singing to defend resources (Catchpole and Slater 2008). Male song quality is an important component of his attractiveness to females. For example, male sedge warblers (*Acrocephalus schoenobaenus*) that had larger song repertoires (i.e. that sang a higher number of distinct song types) elicited greater numbers of copulation displays from females and paired earlier than males with smaller repertoires (Catchpole et al. 1984).

Male song may also serve to exclude rivals from their territory and guard resources. For example, experiments show male songbirds that were temporarily unable to sing, were unable to exclude rivals from their territories and were displaced by other males (Peek 1972, Smith 1979, McDonald 1989). Moreover, unoccupied nightingale (*Luscinia luscinia*) territories from which male song was broadcast remained unclaimed for longer than territories without broadcast songs (Görensson et al. 1974). Finally, different characteristics of male song displays have been shown to predict attack on a conspecific rival (Searcy et al. 2006, Vehrencamp et al. 2007, Ballentyne et al. 2008, Baker et al. 2012, Barnett et al. 2014). Individual’s song displays may thus communicate information about the sender’s phenotypic quality as well as their motivation to defend their resources to receivers.

## URBAN ENVIRONMENTS AND BIRD POPULATIONS

Urban environments are often considered to be less stressful for animals because of reduced predation and increased food availability (Ditchkoff et al. 2006). However, this assumption does not bear closer analysis. Rather, it is likely that urban environments are just different from other environments and promote the evolution of specific traits. For example, while birds of prey may be less abundant in urban environments, feral and domestic cats (*Felis catus*) may be present in extremely high densities, which can have a devastating effect on bird populations (Loss et al. 2013). Urban environments may also have fewer resources for native bird species to exploit. For example, it is often the case that native food plants are removed and replaced with exotic species, which may be unsuitable for native birds (McKinney 2002). Although this results in urban plant communities being more diverse than surrounding communities, this increased diversity is the result of increased abundances of exotic plants, which native birds cannot exploit (McKinney 2002, Luck and Smallbone 2010). Moreover, native birds do prefer native plants to exotic plants in urban habitats (Daniels and Kirkpatrick 2006) although the reason for this preference is unclear. One possibility is that exotic plants might support fewer insect species (Rosenberg et al. 1987) and so may provide less food for insectivorous birds. Native bird species may also be poorly adapted to exploit the flowers and seeds of exotic plants making exotics unsuitable as food plants (McKinney 2002). Therefore, urban environments may present highly novel environments for the preexisting animal species, which they are poorly adapted to exploit.

The challenges that urban environments present to pre-existing species assemblages means that creating urban environments results in new species assemblages compared to surrounding non-urban areas (Chamberlain et al. 2009, Grant et al. 2011, Kotze et al. 2011, Swan et al. 2011). This may be especially evident in North and South America, Australia, New Zealand, Madagascar, and on oceanic islands throughout the world. Often species that are successful in urban environments are able to live commensally with humans and can exploit urban environments (e.g., pigeons [*Columba livia*], house sparrows [*Passer domesticus*], and European starlings [*Sturnus vulgaris*]). Populations of these species can become very dense in urban areas and may act as source populations for their wider distributions. For example, house sparrows live commensally with humans because they have year round access to grain and other human derived food sources. Therefore, sparrows are no longer a migratory species and have become year-round residents throughout their natural range. This relation with humans is thought to have begun between 400,000 and 10,000 years ago in the Middle East (Anderson 2006). The relationship between humans and sparrows has also resulted in sparrows having a distribution that is much wider than their natural range. This shows that intimate commensal relationships can change the behavior of birds and ultimately may also affect their morphology.

When comparisons are made between urban and surrounding rural areas, urban areas are often found to have lower levels of avian species diversity (Sanderström et al. 2006). However, this view ignores the fact that environments are not dichotomous (being either rural or urban), but rather the intensity of urbanization runs along a continuum. Studies that have assessed bird communities along this continuum have found that the most species rich communities occur in areas of intermediate urban intensity (Blair 1996, McKinney 2002, Tratalos et al. 2007). One hypothesis for this higher biodiversity at intermediate urban intensities is that these environments may have higher levels of environmental heterogeneity, which can support a greater number of species (Blair 1996). Other ideas focus on the increased availability of resources in moderately intense environments, but that competition becomes more intense in highly urban environments which reduces diversity (Shanahan et al. 2014).

## URBANIZATION AND BIRDS' DIET QUALITY

There are a number of ways in which urban environments can differ from non-urban environments (both directly and indirectly) (Clucas & Marzluff 2011). From a dietary perspective, one of the most important ways that the diets of urban bird populations differ from other populations is the provision of supplementary food (Amrhein 2014). Supplementary feeding of urban birds is both widespread and promotes the survival of birds over winter periods when there may be little other food available. For example, 48 per cent of urban households in the United Kingdom (Evans et al. 2009) provide food for birds, which can increase their winter survival and lead to larger population sizes (Chace and Walsh 2006). However, this supplementary food may be of poorer quality and inadequate for raising nestlings (Chamberlain et al. 2009). Moreover, increased population densities may promote disease transmission, predation, and increase the incidence of exotic species (at the expense of native species) (Chace and Walsh 2006, Chamberlain et al. 2009, Clucas and Marzluff 2011). Therefore, supplementary feeding can have both positive and negative effects on urban populations, the net effect of which are difficult to calculate.

At an individual level, there is little doubt that provision of supplementary food increases reproductive success in birds. For example, Robb et al. (2008) reviewed previous studies that had examined the effects of food supplementation on reproductive success in birds. They found that out of 59 studies, 58 % of them showed that the providing supplementary food advanced birds' laying dates. They also found that food supplementation leads to an increase in clutch size, hatching success, chick growth rate, and fledgling success in between 44 % to 64 % of studies (Robb et al. 2008). However, food supplementation can also have unforeseen effects on the offspring of parents that have been fed. In one study, adult song sparrows (*Melospiza melodia*) that were fed supplemental food had larger clutch sizes, but the male offspring of these clutches had smaller repertoire sizes than males from clutches that had not been supplemented (Zanette et al. 2009). Therefore, it is difficult to assess the overall impacts of differences in diet between urban and non-urban bird populations and the concomitant impacts on bird behavior. However, it is unlikely that without supplementary feeding, urban environments could sustain bird communities at their present populations.

## THE LINK BETWEEN DIET, ENERGY, AND BIRD SONG

Sexual selection theory predicts that birds that are of higher phenotypic quality should produce higher quality song displays than birds of lower quality (Andersson 1994). One mechanism for this might be that increased food consumption is converted to body fat, which may also increase bird's Darwinian fitness (Barnett et al. *submitted*). Song displays are energetically costly to produce (Hasselquist and Bensch 2008) so males with greater energy reserves should produce higher quality song displays (Barnett and Briskie 2007). The most well studied manner in which the effects of diet quality and quantity have on bird song has been by providing birds with supplementary food and examining the effect this has on male singing behavior. By increasing food availability, birds increase their song output and quality because possibly because they have greater energy reserves (Searcy 1979, Davies and Lundberg 1984, Gottlander 1987, Reid 1987, Strain and Mumme 1988, Alatalo et al. 1990, Cuthill and McDonald 1990, Lucas et al. 1999, Thomas 1999, Godfrey and Bryant 2000, Thomas and Cuthill 2002, Berg et al. 2005, Barnett and Briskie 2007, Grava et al. 2009, Barnett and Briskie 2011, Ritschard and Brumm 2012; but see Mace 1989, Enoksson 1990). However, few of these studies have established whether food supplementation leads to increased mass or fat reserves in birds. One of the few studies to do this was Barnett and Briskie (2007) who studied the effect of a short-term food supplement on the singing behavior of a New Zealand population of silvereyes (*Zosterops lateralis*). They found that when birds had access to supplementary food, they increased their song output and quality during the dawn chorus (Figure 1). They also examined the effects of the short-term food supplements on birds' masses and fat reserves and found that birds gained more mass and fat on days when they had access to supplementary food (Barnett and Briskie 2007). However, this study examined only the effect of short-term supplementation.

The effects of longer-term food supplementation may have unforeseen consequences on bird behavior. In territorial birds, supplementary feed might affect the territorial behavior of males on territories near feeding points. This is because birds attracted to feeding points might pass through the territories of males nearby the feeders. Therefore, male territory holders near feeding sites may increase their singing in an attempt to reduce the amount of male trespassing. For example, male great tits (*Parus major*) that were on territories with food supplements gave more vigorous responses to stuffed mounts than did males on other territories (Ydenberg 1984). However, we also need to be cautious with regards to how we view the effects of food supplementation, which is almost universally assumed to be positive. For example, male song sparrows (*Melospiza melodia*) hatching from parents that had access to supplemental food had smaller repertoire sizes than males from clutches that had not been supplemented (Zanette et al. 2009). Therefore, the long-term consequences of supplemental feeding are far from clear and require more research.

The provision of birds with supplementary foods increases energy availability to urban living birds, but these food supplements may change the diets of urban birds from those of non-urban populations of birds in many other ways. For example, the diets of rural populations of house finches (*Carpodacus mexicanus*) (Budyaev 2014) consist of predominantly small and soft grass seeds and supplemented by insects. In urban areas, birds often have access to supplementary food, which can contain high amounts of hard-shelled sunflower seeds. Therefore, the difference between these diets has caused urban populations of house finches to have longer and harder bills that are better at breaking open the sunflower seeds compared with birds from other areas (Budyaev 2014). This change in bill structure is likely to have altered the ability of house finches to produce buzz and trill components of song, which are important for intra-sexual competition in this species (Mennill et al. 2006). Therefore, the changes in bill morphology that are caused by urbanization are likely to cause many different effects although the changes are complicated by the among population variation in bill morphology between urban areas (Budyaev and Hill 2000).

There are also other abiotic effects such as the urban heat island effect (Parlow 2011) that might affect birds' energy management and thus their singing behavior. Theoretical and empirical studies show that birds use excess energetic reserves to sing during the dawn and dusk chorus and throughout the day (McNamara et al. 1987, Houston and McNamara 1987, Hutchinson et al. 1993, Hutchinson and McNamara 2000, Thomas 1999, Thomas and Cuthill 2002, Barnett and Briskie 2007, Barnett and Briskie 2011). Therefore, higher ambient temperatures in urban areas may reduce male songbirds' energetic requirements per day meaning that they do not need to carry as much body fat or be as large to ensure their overnight survival (e.g., Liker et al. 2008). An intriguing possibility is birds living in urban areas could have different mass regulation strategies from non urban birds, which could also affect their song displays. Moreover, such a possibility would complicate the relationship between the quality of urban habitats and the ability to infer anything about this from bird's phenotypes and behavior.

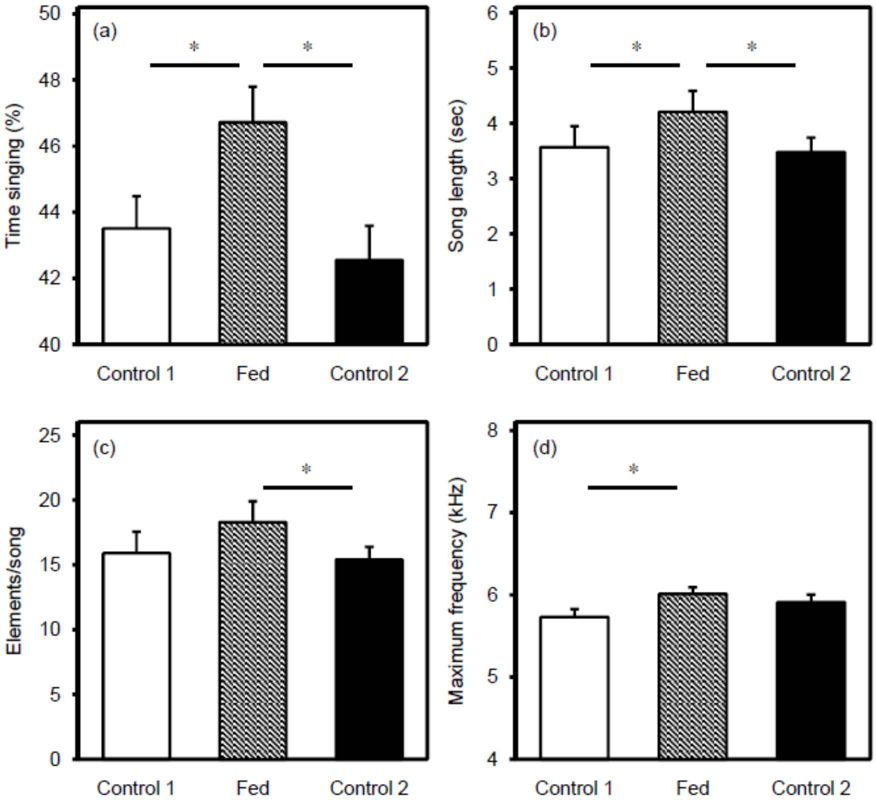

Figure 1. The mean percentage (+ SE) of time that male silvereyes sang over the three consecutive days of the experiment during their dawn chorus song displays (a). This increase in the percentage of time singing may was likely the result of birds increasing the lengths of each song that they sang (b) which they achieved by increasing the number of elements that they included into each song (c). The birds also sang songs with higher maximal frequencies on the fed days compared with songs on the first control day (d), which indicates that in addition to being structurally more complex, their songs were also higher quality. The asterisks indicate significant differences (i.e. $P < 0.05$, Sheffe's test) between comparisons (redrawn from Barnett and Briskie 2007).

Here, I have focused mainly on the effect that supplementary feeding has on avian singing behavior in urban areas. Despite our reasonable knowledge of the effects of supplementary feeding on avian singing behavior, most food supplementation studies have taken place in non-urban environments. Moreover, the diets of urban bird populations may vary in many other ways from non-urban bird populations. For example, the types of insects and plants on which birds feed may vary substantially between urban and other areas (McKinney 2008, Luck and Smallbone 2010). This may cause differences in the developmental conditions of nestlings raised in urban environments compared with other environments. Thus, there is a need for further studies of the energetic and behavioral effects of food supplementation on birds in urban contexts.

## THE EFFECTS OF THE URBAN ENVIRONMENT ON AVIAN SINGING BEHAVIOR

Living in urban environments can have many other positive and negative effects on bird populations in addition to state-based effects. Some of these effects include increased harassment, persecution and disturbance from humans, the effects of cars and roads, habitat destruction and fragmentation, differences in climate, and many forms of pollution (e.g., light, noise, pesticides), all or some of which may affect birds (Clucas and Marzluff 2011). Urban environments can affect avian communication systems at many points from sound production through to perception of the song by other birds (Figure 2). First, urban environments affect an individual's (sender's) ability to produce songs. Second, urban environments affect the propagation of sound through space. Finally, intrinsic and extrinsic elements of urban environments may affect the ability of receivers to perceive the vocalizations of the signallers (Rosenthal and Stuart-Fox 2012). Therefore, when considering the effects of urbanization on bird song, it is important to correctly identify what aspect of the communication system is being affected.

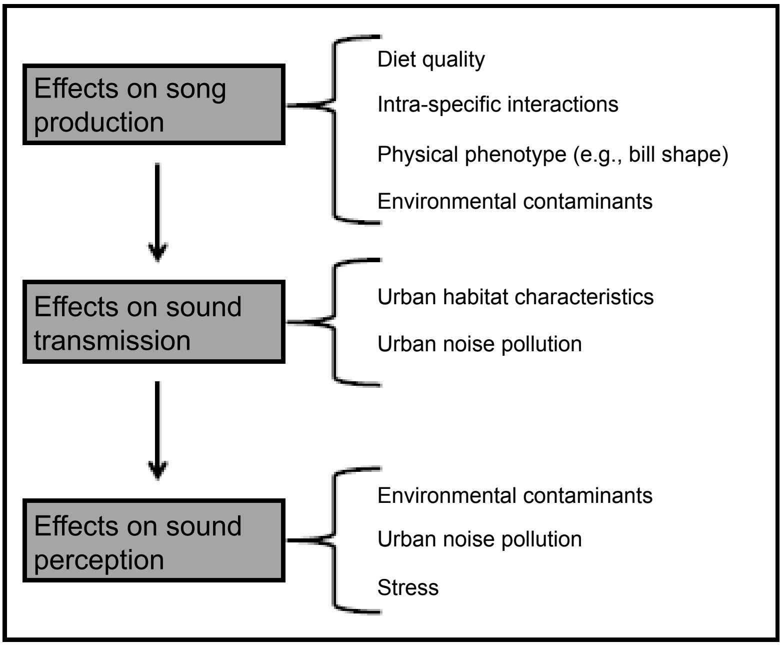

Figure 2. The effects of various factors of living in urban environments at different stages of the communication pathway (song production, propagation, and perception).

Here, I briefly discuss three important impacts that urban environments can have on avian singing behavior. These three factors are forms of contamination or pollution, which either directly influence the individual's phenotypes or affect the environmental quality. The first is the effect that contaminants such as heavy metals and pesticide residues might have on birds. The other two are forms of environmental pollution (i.e. light and noise pollution) that affect the birds as well as the signaling environment.

## CHEMICAL AND METALLIC CONTAMINATION

Urban areas are often more contaminated than other areas (Parlow 2011). Contamination of the environment by chemical pollution can affect the development and expression of acoustic signals in birds via their impact on gene expression, endocrine function, and a range of other cellular processes. Although our knowledge of the effects that chemical pollutants have on free-living birds is scant, we have limited understanding of the effects of pollutants on the singing behavior of birds. For example, great tits (*Parus major*) living in areas with greater metal pollution have smaller song repertoires and sing less than individuals from populations with less metal pollution (Gorissen et al. 2005). Similar results have been found in other passerines and comparisons between oscine and sub-oscine passerines suggest that the differences in song quality may be due the effects of metal pollutants on memory formation in nestlings during song learning (Hallinger et al. 2010).

The most well studied class of contaminants and their effects on animal health are the effects of endocrine disrupting chemicals (EDCs) (Bonier 2012). Endocrine disruptors are exogenous chemicals that interfere with normal hormonal functioning and can cause lethal and sub-lethal effects in animals. Despite our increasing knowledge of the effects of EDCs in relation to animal health, they are poorly understood in relation to their effects on avian singing behavior. In one study, male European starlings (*Sturnus vulgaris*) exposed to higher levels of EDCs (which mimic estrogen) had more complex songs and larger higher vocal centers (HVC) of their brains (Markman et al. 2008) than males with lower levels of exposure. However, the males that had higher exposure to EDCs also had poorer immune systems. Females also preferred to mate with the males with higher levels of EDC exposure. Therefore, the EDCs are likely to destabilize the positive relationship between male song output and phenotypic quality. Although this is a single study, it suggests that EDCs can affect the behavior of animals in complex ways, but that the ultimate effect on populations may be negative (Markman et al. 2008). In time, there will likely be an increase in our knowledge of the effects of chemical pollutants on avian singing behavior as well as birds' wider behavioral and physical phenotypes. However, until we know more, we should assume a precautionary approach and assume that pollutants are unlikely to be positive for avian song production or animal health.

## LIGHT POLLUTION

Photoperiod (the length of daylight) is an important environmental cue that birds use to synchronize various periodic behaviors including reproduction (Rosenthal and Stuart-Fox

2012, Williams 2012). For example, changed exposure to light from artificial sources can affect the production of melatonin, which is an important hormone in reproduction, protection against oxidative stress, and metabolism in birds (Navara and Nelson 2007). Moreover, increased artificial light has been shown to advance the timing of reproductive physiology of blackbirds (*Turdus merula*) by about a month (Dominoni et al. 2013). However, we do not have a full understanding of the effects of elevated light levels on the behavior of birds in urban environments.

One aspect of singing behavior that has been studied in urban populations is the start time of the dawn chorus song display (Spoelstra and Visser 2014). Birds have been shown to start singing earlier in the morning in areas with higher levels of artificial light (Kempenears et al. 2010). However, the effect was not equal across species. Species that begin singing earlier in the morning were more greatly affected by urban light pollution than species that started singing later in the morning. This stronger effect in early singing species was most likely the result of earlier singing species having larger eyes and therefore, being more sensitive to increases in ambient light (Thomas et al. 2002). This result suggests that light pollution in urban environments is a significant driver of behavioral changes in urban bird populations and they may change the phenotypes and behavior of birds (Dominoni et al. 2013).

## NOISE POLLUTION

Urban environments provide challenges for birds and other animals that use acoustic signals to communicate. Moreover, there are a number of ways that urban environments can affect singing behavior of birds. For example, urban environments are physically different to non-urban habitats. In intensely urban areas, the environment may consist of many buildings, which present many hard flat surfaces, which are efficient at reflecting sound waves and there is often little vegetation to diffuse sound (Rosenthal and Stuart-Fox 2012). Therefore, acoustic signals may propagate further in urban areas than they do in non-urban areas. However, the main way urban environments affect avian singing behavior acoustically is through the amount of background noise in the environment.

Urban environments are noisy and this noise often comes from traffic or industrial activities. Recent research shows that birds living in urban environments have a large reduction in the transmission distances of their songs (Nemeth and Brumm 2010). This reduction of transmission may lead to birds controlling smaller territories, high population densities, and higher numbers of territorial intrusions and aggressive interactions between males (Gil and Brumm 2014b). Birds have a number of responses to urban noise including increasing their song amplitude, shifting the frequency of songs, changing of the duration of songs, and singing at different times of the day.

Perhaps the most obvious reaction for singing birds in noisy environments is to increase their song loudness. This increase in song amplitude in response to increased background noise is called the Lombard effect (Brumm and Zollinger 2011) and has been demonstrated a number of times. For example, nightingales (*Luscinia megarhynchos*) exposed to high levels of traffic noise increase their song amplitude by up to 14 dB, which represents more than a five-fold increase in vocal pressure (Brumm 2004). Therefore, given the costs of singing (Hasselquist and Bensch 2008), increasing song loudness may significantly increase the cost of singing for urban birds. However, there are doubts as to how effective increasing song loudness is in making their songs stand out among the urban cacophony (Brumm 2009).

A second response birds make to their songs in urban environments is to shift their singing frequencies. Frequency shifts have been reported in a number of species including great tits (Slabbekoorn and Peet 2003, Slabbekoorn and den Boer-Visser 2006, Salaberria and Gil 2010), song sparrows (Wood and Yezerinac 2006), house finches (Fernández-Juracic et al. 2005, Bermudez-Cuamatzin et al. 2009), silvereyes (Potvin et al. 2011), and blackbirds (Nemeth et al. 2013). The most common form of frequency shift is for birds to increase the minimum frequency possibly because urban noise tends to be lower frequency and may mask the low frequency song components. Therefore, frequency shifts at low frequencies may reduce the masking effects of noise (Pohl et al. 2012).

A third way in which birds alter their singing behavior may be to change the song duration or the time of day at which they sing. For example, many species of birds have been found to sing shorter songs in urban areas because intermittent song production increases the probability that a song will be detected during a window of silence (Slabbekoorn and den Boer-Visser 2006, Nemeth and Brumm 2010, Verzijden et al. 2010). However, such a strategy requires birds to wait for windows of silence and sing at these times. If birds are unable to wait, an alternative strategy is for birds to increase the length of their singing bouts in order to increase the probability of encountering a window of silence (Francis et al. 2011). Some bird species can even change their singing behavior in relation to human behavior patterns. For example, serins (*Serinus serinus*) produce longer song bouts on noisier weekdays than on weekends (Diaz et al. 2011). This indicates that this behavior is under facultative control and that birds can quickly change their singing behavior to match their environment (see Arroyo-Solis et al. 2013 also). Birds may also shift their singing emphasis to a different part of the day where there is less competition with urban noise. For example, after controlling for differences in ambient lighting levels, it has been found that European robins, great tits, blue tits, and blackbirds begin singing earlier in areas with high amounts of daytime noise (Bergen and Abs 1997, Fuller et al. 2007).

Finally, it is possible that birds may change the contents of their songs in urban areas compared with non-urban populations. However, there are few data that specifically address whether birds change their song contents in response to living in urban areas. One aspect that might be affected is song learning as young birds often learn songs from neighbors. If urban populations of birds are fragmented, nestlings may hear fewer conspecific song types as they develop, which might lead to impoverished song repertoires (e.g., Laiolo and Tella 2005, Laiolo and Tella 2007). Information theory also predicts that as environments become noisier, the amount of redundancy (i.e. increased repetition and reduced complexity) built into songs should increase, which has been confirmed in a number of studies (Brumm and Slater 2006, Diaz et al. 2011). Moreover, urban environments may select for particular types of song elements, which was confirmed in a recent study. This study assessed the songs and calls of different populations of silvereyes throughout Australia and found that the songs of urban populations of silvereyes converged on specific note types (Potvin et al. 2014). This raises the possibility that urban environments may shape the evolution of song by selecting for specific qualities of song components. This has many implications for the adaptation and evolution of urban bird populations and may ultimately promote evolutionary divergence of urban and non-urban bird populations along different evolutionary paths.

## CONCLUSION

In this review, I examined the effects that urban environments can have on bird populations. I then focused on the effects of urban environments on avian singing behavior and specifically the effects of supplementary food because supplementary feeding is very common in urban areas (Evans et al. 2009) and it is among the most well understood nutritional drivers of avian singing behavior (Barnett and Briskie 2007). Finally, I highlighted the effects of three aspects of urban environments on avian singing behavior. From this, it is clear that urban environments significantly affect the ecology and singing behavior of birds. However, it is difficult to ascribe whether the net effect of urban life is positive or negative for birds. Perhaps the fairest assessment is that urban environments impose a unique set of selective pressures on birds and can have many positive and negative effects on bird populations and their singing behavior. However, without food supplementation, intensely urban environments would likely be very hostile environments for birds. Environmentally imposed changes on song displays may also affect female mate preferences and so could affect the evolution of urban bird populations and lead to divergence between urban populations and other populations of birds. However, there has been very little study on the effects of urban environments on female preferences and mate choice and is an area that will hopefully see much increased research activity.

Urban environments present a unique opportunity to researchers because they are entirely new environments and may influence the evolution of populations that make their homes in these areas. By documenting the relative evolutionary trajectories of different populations over time we have another excellent opportunity to observe evolution in action. However, urban environments also allow us to learn how to mediate the extent of human impacts on biodiversity, which is one of the major environmental problems facing humanity. As our knowledge of the effects of urban environments on birds increases, our attention should shift to preserving and increasing biodiversity in urban and other areas where human impacts are acutely felt. This is imperative because human impacts are unlikely to subside in the near future meaning that we need to find ways to make urban areas more ecologically sustainable.

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*Chapter 6*

# ECOLOGY AND CONSERVATION OF THE SOCOTRA CORMORANT (*PHALACROCORAX NIGROGULARIS*) IN THE EASTERN ARABIAN GULF

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## ABSTRACT

Socotra Cormorants (*Phalacrocorax nigrogularis*) are regionally endemic, vulnerable seabirds limited to the Arabian Gulf and Sea of Oman regions. Global populations have undergone catastrophic declines, with several major colonies gone completely extinct in the central western Arabian Gulf. Major threats include breeding habitat loss due to oil exploitation, disturbance at breeding colonies, fisheries by catch and occasional hunting. Six of 12 large colonies have become extinct in the United Arab Emirates. Colonies in the western Gulf seemingly have suffered considerably, with much lower numbers compared to historic records. In comparison, the single colony on Siniya Island, Umm Al Quwain, in the eastern Arabian Gulf is arguably the largest in the UAE and possibly the entire Gulf with an increasing population of about 35,000 breeding pairs. Breeding studies indicate variable reproductive success possibly linked with habitat features, weather, diet and impact of predators. Planted trees on the island provide protection from soaring temperatures early in the breeding season and improve breeding performance. The island hosts native Red Foxes (*Vulpes vulpes*) and feral cats (*Felis catus*) that have a negative impact on the breeding performance. Additionally, ample evidence exists of conflict with fishermen. Many birds die annually to fishermen's nets or lines and fishermen generally perceive them to be competitors. Diet studies indicate that fish taken by cormorants have almost no overlap with commercially important species. The island is subjected to periodic disturbance by fishermen collecting sea grass from lagoons. Additionally, the island is littered with a wide range of plastic and other debris. Current trends in the population could be offset if any or all of the threats continue to increase. Conservation and management of this population must focus on removing

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plastics, eliminating disturbance during breeding seasons, engaging local fishermen to reduce by-catch mortality, protecting coastal areas to safeguard foraging sites, and creating awareness.

## INTRODUCTION

The Socotra Cormorant is a regionally endemic, seabird that is undergoing rapid population declines and is currently categorized as Vulnerable (BirdLife International 2012, Jennings 2010). The global breeding population has been estimated to be about 110,000 pairs (BirdLife International 2012, Jennings 2010). This is considerably less than historic numbers and seven colonies have already become extinct in the United Arab Emirates (Jennings 2010, Table 1), some of which had large populations in the 1970s (e.g. Zarka Island, up to 250,000 breeding pairs). One colony, Ras Al Aysh, became extinct due to construction work that connected the island to the mainland, allowing ground predators to invade the colony and decimate it (Jennings 2010).

**Table 1. Breeding colonies of Socotra Cormorants that have become extinct (from Jennings 2010)**

| Island name | Status |
|---|---|
| Sir Abu Nair | population unknown, extinct since 1987 |
| Arzana | population unknown, extinct since 1982 |
| Dalma | 2500 in 1975, extinct since 1976 |
| Qarnayn | 500 in 1988, extinct since 1989 |
| Zirku | 50,000-250,000 before 1978, extinct since 1981 |
| Naita | population unknown, extinct since 1994 |
| Ras Al Aysh | population size unknown, extinct since construction provided access to mainland predators |

**Table 2. Breeding populations (breeding pairs) of Socotra Cormorants in UAE estimated in the 1990s and between 2011-2013 (UAQ - Umm Al Quwain Emirate, AD - Abu Dhabi Emirate)**

| Island name | 1995-1996[a] | 2011-2013[b] |
|---|---|---|
| Siniya - UAQ | 15,500 | 35,000[b] |
| Daiyyina - AD | 9000 | |
| Gagha - AD | 6000 | |
| Hayl - AD | 3000 | |
| RasGhurab - AD | 3000 | |
| Rufayq - AD | 2000 | |
| North Yasat - AD | 2100 | |
| JabalDhanna - AD | 300 | |
| Umm Qasr/Gasha - AD | 150 | |
| Salahah - AD | 80 | |
| All AD sites | | 15,000[c] |
| Total | 41,130 | 50,000 |

[a] Jennings, 2010 (with data covering 1995-1996).

[b] Muzaffar, 2013 (with data covering 2011-2013).

[c] EAD 2012, 2013 (with data covering 2011-2012 and pooled for all sites).

The most recent estimates of populations of breeding Socotra Cormorants within the UAE are from between 2011-2013 (Table 2). The Environment Agency Abu Dhabi has estimated around 12,000 pairs in about 3-6 island colonies in the Abu Dhabi Emirate (EAD 2012, 2013). The largest colony in UAE is Siniya Island in Umm Al Quwain Emirate, with an estimated breeding population of 28,000-35,000 pairs (Muzaffar 2013). Monitoring by EAD suggests that most populations in Abu Dhabi are undergoing declines and several have disappeared since the last estimates from the 1990s (Jennings 2010, Table 2). Thus, a conservative estimate of the breeding populations in UAE at present is 50,000 breeding pairs (Table 2, Muzaffar 2013, EAD 2012, 2013).

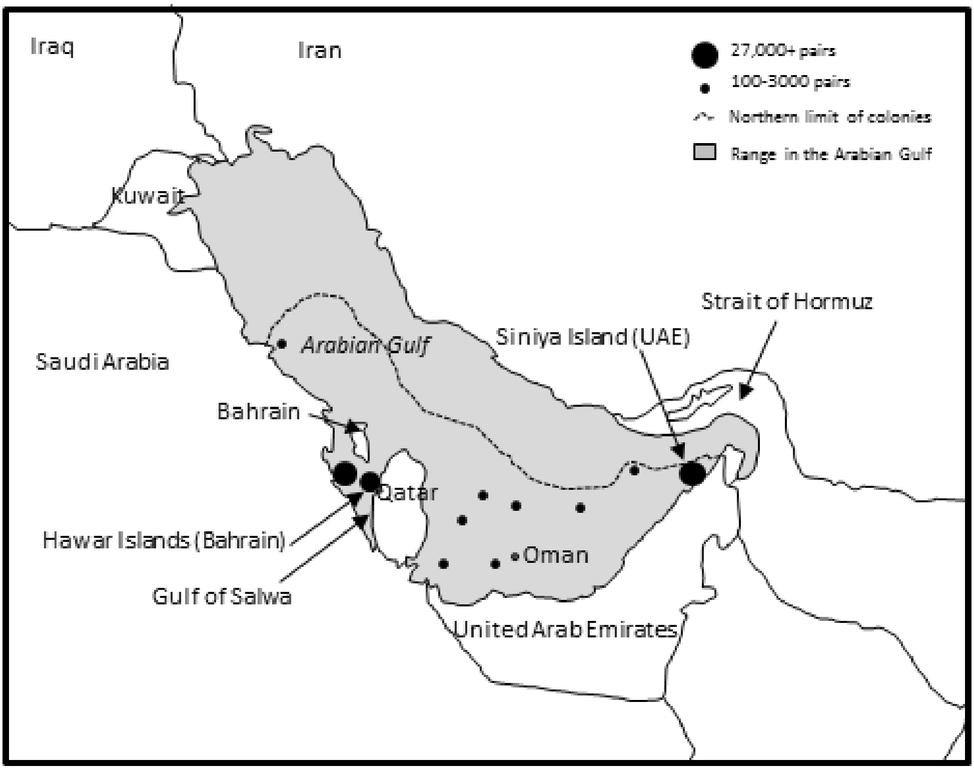

Figure 1. Distribution of extant colonies of Socotra Cormorants and the concentrations of breeding birds in the Arabian Gulf.

The Hawar Island complex located in the Gulf of Salwa (western Arabian Gulf, on the southwest of Qatar but territory of Bahrain) hosted a population of about 27,000 pairs in 2005/2006 (Jennings 2010, Figure 1). Several Saudi Arabian coastal islands in the Gulf of Salwa hosted between 30,000-40,000 pairs in 2005/2006 (Jennings 2010). Thus, within the Arabian Gulf the largest breeding concentrations occur within the Gulf of Salwa and the eastern Arabian Gulf, northern UAE waters (the single colony in Siniya Island, Umm Al Quwain) (Figure 1). Birds outside of the Arabian Gulf breed on islands in the Sea of Oman along the Omani coastline totaling to about 15,000 breeding pairs or less (estimated in 2002, Jennings 2010). These subpopulations are considered separate from the Arabian Gulf population although no studies have specifically examined mixing between the subpopulations. Assuming that some of the historic counts may include double counting, switching between colonies, etc., (see Jennings 2010), it has been conservatively estimated that the global breeding population has declined by 80,000 pairs since the 1960s (BirdLife Inernational 2012).

The UAE federal Law #24 (1999) explicitly prohibits the hunting, trapping, collection of eggs or damaging of nests of Socotra Cormorants. In the past, the species was hunted for food (eggs, chicks and adult birds) although this practice has almost disappeared (Jennings 2010). Recent survey work by Environment Agency Abu Dhabi and Emirates Marine Environmental Group independently verified that egg collection continues on some Abu Dhabi colonies (Wilson 2012). Introduction of feral cats and the presence of other native predators (such as Red Foxes) could pose substantial threats to breeding colonies (Jennings 2010; Muzaffar et al., 2013). Incidental by-catch in fishing nets or lines, disturbance on the colonies (from recreational activities) and oil pollution are also considered to be important threats to the species (Muzaffar et al., 2013).

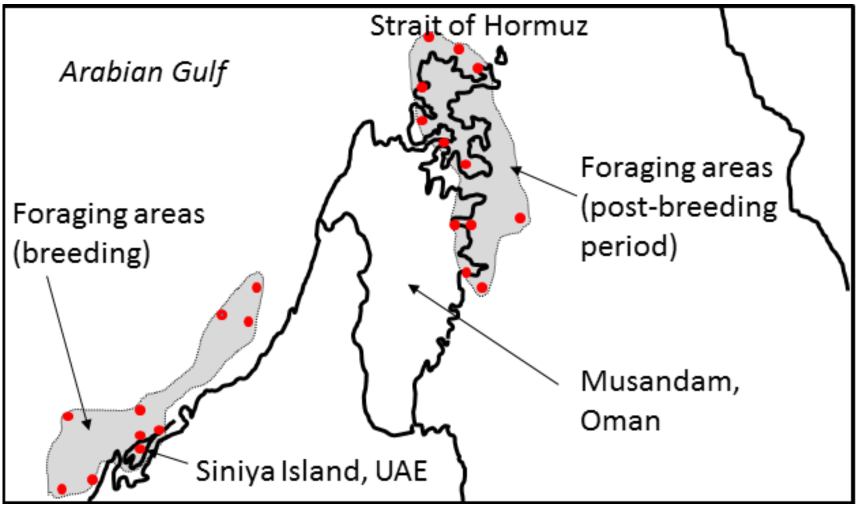

Figure 2. Foraging areas of a single Socotra Cormorant over a 10-day period in November (breeding season) and a 10-day period in December (post-breeding period), 2013 (redrawn from Muzaffar 2014).

## BREEDING BIOLOGY

Previous information on biology of the species has largely been inferred from surveys or monitoring activities (Johnsgard 1993; Nelson 2005). There are few published systematic studies on the ecology and breeding biology of the species (Muzaffar et al., 2012, 2013), although data may be available in unpublished reports (see Jennings 2010). Socotra Cormorants breed between August to March in the Arabian Gulf (Symens et al., 1993; Muzaffar et al., 2012) although breeding could occur in the warmer summer months of June through to October along the Omani coast (Nelson 2005). Details of timing of breeding and complete breeding season are provided here from ongoing studies on Siniya Island, Umm Al Quwain, UAE and compared with information from other colonies when available.

## Timing of Breeding, Nest Site Characteristics and Productivity

Socotra cormorants generally nest on islands with sandy or loose gravel substrate to allow construction of a bowl shaped nest (Jennings 2010) of gravel, compact sand and residual debris (Muzaffar 2013). On Siniya Island, nesting occurred on sandy-gravel substrates either under trees (planted in the 1980s) or in open areas with scattered *Haloxylon/Arthorocnemum* shrub complex (Muzaffar et al., 2012). Nests had a mean external diameter of 72.20 ± 6.06 cm, a mean internal diameter of 36.20 ± 3.56 cm and a mean depth of 14.80 ± 0.44 cm (mean ± standard deviation). Mean distances between nests was 81.10 ± 5.30 cm with central part of the colony having higher densities compared to the periphery (Muzaffar 2013). Egg laying occurred between 13-16 September in 2011 and between 20-25 September in 2012 (Table 3, Muzaffar 2013). First chicks were seen in early to late October in each breeding season and incubation period was estimated to be between 24 and 27 days. Incubation period reported from the Hawar Island complex (Bahrain) was 21 days (Pilcher et al., 2003).

**Table 3. Breeding data of Socotra Cormorants on Siniya Island, Umm Al Quwain, UAE**

| | 2011/2012 | 2012/2013 |
|---|---|---|
| Laying date | 13-16 Sept | 20-25 Sept |
| Incubation period | | 24-27 days |
| First chicks | 11 Oct | 14-22 Oct |
| Clutch size | 2.43 ± 0.04 | 2.66 ± 0.03 |
| Hatching success | 49.71 ± 5.85 | 81.76 ± 4.86 |
| Fledging success | 61.59 ± 5.83 | 82.0 ± 4.47 |
| Reproductive success (%) | 32.74 ± 5.34 | 72.09 ± 5.37 |

Density of nests was 0.92 (range 0.48-1.32) nests/m$^2$ (Muzaffar et al., 2012; Muzaffar 2013). Islands in Bahrain had densities of 0.64 and 1.55 nests/ m$^2$ (Jennings 2010) suggesting similarities between colonies from the western and the eastern Arabian Gulf. On Siniya Island, densities of nests were significantly higher in shaded areas compared to open areas (Muzaffar et al., 2012, Table 3). Eggs were elongate, ovoid and egg volume (48.02 ± 4.99cm$^3$, mean ± standard deviation, n = 133) was significantly larger in shaded areas compared to open areas (Muzaffar et al., 2012). Clutch size ranged from 1-11 eggs/nest (one case of 11) although the mean was 2.43 ± 0.04 eggs/nest, with typical clutch sizes being 2-3 eggs/nest. Jennings (2010) reported a mean clutch size of 2 eggs/nest based on colonies in the western Arabian Gulf, with a range of 1-4 eggs/nest, suggesting slightly smaller clutch sizes compared to the eastern Arabian Gulf.

On Siniya Island, hatching success was 58.7% in 2011/2012, with significantly higher hatching success occurring in shaded nests (65.1%) (Muzaffar et al., 2012). Fledging success, was 65.6% and did not vary between shaded and unshaded areas. In comparison, reproductive performance was higher during the 2012/2013 breeding season when all nests were in unshaded areas (Table 3), with 81.7% hatching success and 82.0% fledging success (Muzaffar 2013). Thus, the differences in breeding performance between years could be attributed to factors other than site characteristics, including possible variations in food availability and predation (Muzaffar 2013). Observed overall hatching success of 58.7-81.7%

and fledging success of 65.6-82.0% in 2011-2013 breeding seasons on Siniyaisland were comparable to the ranges observed in other Phalacrocoracidae (hatching success 25-80%, fledging success 22-95%, Nelson 2005). Similar data on the reproductive success on the species has not been reported elsewhere (Jennings 2010).

## Behavior

On Siniya Island, adults incubated eggs between 5-7 hours a day after which the incubating adult switched with its returning partner (Muzaffar 2013). Once chicks hatch, feeding rates were about 2-3 meals/day. Chicks are completely altricial (lack feathers and have unopened eyes) at birth and are highly prone to mortality from overheating and dehydration (Gubiani et al., 2012). By 10-20 days, chicks have a complete coating of white, downy feather. During this time, chicks form ‘creches’ near their nest site (but often outside the nest) with one or more adults guarding the chicks. Chicks older than 20 days begin to wander out of nest sites forming larger creches. As the chicks grow older, they grow a second coating of downy feather and are seen to increasingly form creches outside the nest sites.

Older chicks (> 30 days old), with growing primary feathers with brown edges, form large creches that are usually unassociated with nest sites (Gubiani et al., 2012). Number of individuals in these fledging creches is in the order of thousands. During this time, large chicks undergo a period of starvation as the parents reduce their provisioning of fish. Chicks may exhibit heterocannibalism during this period, whereby chicks of different age classes may feed opportunistically on newly hatched chicks (Jennings 2010; Gubiani et al., 2012).

## Diet and Foraging

Adult Socotra cormorants feed on a variety of fish and there could be marked inter-year variation in the diet (Muzaffar 2013). In the 2011/2012 breeding season, the diet was almost entirely (> 90%) Sailfin Flying fish (*Parexocoetus mento*) during the early part of the season (before November). As the chicks became larger, the diet was switched to include other fish, including Blue-stripe Sardine (*Herklostychthyes quadrimaculatus*) (41.5%) and Pink-eared Emperor (*Lethrinus lentjan*) (26.8%), while the Sailfin Flying fish declined in abundance (28%) (Muzaffar 2013). In contrast, the diet in 2012/2013 was different from 20112012 with most of the diet consisting almost entirely of Anchovies (*Encrasicholina* spp.) throughout the season. Halfbeaks (*Hyporamphus*), scads (*Selar crumenopthalmus*) also formed very minor components of the diet in both years (Muzaffar 2013). It appears that the species is highly adaptable and feeds opportunistically on abundant fish species. Limited studies from elsewhere (reported in Jennings 2010) suggest that Sardines (*Sardinella* sp.), scads (*S. crumenophthalmus* and *Atule mate*), Silverside (*Atherino morphuslacunosus*), Spotted Half-beak (*Hemiramphus far*) and Streaked Rabbit-fish (*Siganus javus*) formed part of the diet in the Hawar Islands colony in Bahrain, although proportions were not reported. The species listed in diet do not overlap with those reported from the Siniya Island study although some were from the same families (pelagic species in the Hemiramphidae, Clupeidae, or Carangidae). Thus, different colonies may have different diets drawing on available local fish resources although the major fish groups targeted could be similar.

Satellite telemetry using back-pack platform transmitter terminals (PTTs) and GPS loggers, indicate that Socotra Cormorants forage distances ranging from 10-70 km during the breeding season on Siniya Island (Muzaffar 2014). Post breeding dispersal of breeding birds suggested dispersal westwards towards Abu Dhabi waters or dispersal north along the UAE shoreline out through the Strait of Hormuz and around the Musandam peninsula of Oman (Figure 2).

## NATURAL AND ANTHROPOGENIC THREATS

### Foxes and Feral Cats

Natural and introduced predators may have substantial effects on breeding seabird populations (Lavers et al., 2010; Mudler et al., 2012). Socotra cormorants have been reportedly impacted by introduced feral cats on some islands in the western Arabian Gulf (e.g. Jennings 2010) although details are limited. On Siniya Island, Muzaffar et al. (2013) conducted a systematic study examining predation related mortality in breeding birds in 2011/2012. Approximately 2000 Socotra Cormorants were being hunted by the existing Red Fox (*Vulpes vulpes*) and feral cat population. Using a population modeling approach, Muzaffar et al. (2013) estimated that breeding could be detrimentally affecting Socotra Cormorants on Siniya Island. Feral cats are especially adaptive and can survive and expand their populations relatively easily. Red Foxes also horde eggs (Muzaffar, unpublished data), further reducing reproductive performance (Muzaffar et al., 2013).

### Tick Parasitism

The soft tick (*Ornithodoros muesebecki*) has been reported from seabird colonies in the Arabian Gulf (Hoogstraalet al., 1970) including Siniya Island (Muzaffar 2013). Soft ticks lay eggs in the substrate (usually sand) that hatch into larvae. These transform successively through seven nymph stages before becoming adults. Thus, their life cycles are complex and may periodically experience outbreaks. High tick abundance can cause breeding failures due to chick mortality and colony abandonment (Duffy 1983; Fear and Gill, 1997). This aspect of the biology of ticks has not been studied and needs further investigation. Furthermore, ticks are vectors for bacteria and viruses which usually do not have direct effects on the hosts due to co-adaptation. However, they may be of health significance to wildlife managers, scientists or other workers on colonies. *Ornithodoros muesebecki* is a vector for *Coxiella burnetii*, the causative agent of Q-fever. Socotra Cormorants often roost or rest on oil rigs in Abu Dhabi and ticks from them tested positive for Q-fever (Sovennand et al., 2011). Workers on oil rigs have also reported fevers and rashes associated with tick bites, demonstrating health effects of the particular strains of *C. burnetii* present on seabird colonies (Sovennand et al., 2011).

### Plastic Debris and Fisheries-related Mortality

Siniya Island suffers from accumulation of plastic and other debris originating from the Arabian Gulf (Benjamin et al., 2013). Large deposits of plastic bottles, buoys, fishing lines, fishing nets, appliances and used car-batteries remain scattered all over the island. Littering in the Arabian Gulf is not well controlled and with the annual movement of 46,000 vessels (of varying origin), attempts to control this by government agencies have failed. The effects on breeding seabirds have not been measured although leaching of chemicals and compaction of plastic seems to be obvious possibilities.

Fishing line entanglement is a widely recognized source of mortality in many seabirds (Schreiber and Burger 2002) including Socotra Cormorants (Muzaffar et al., 2013). On 2011, approximately 40 dead birds were recorded with fishing line or fishing hooks imbedded in their skin or feet. Since observed mortality on the colony is expected to be much lower than actual mortality (e.g. birds that died at sea), it can be assumed that a substantial portion of the breeding birds die annually due to entanglement in gear.

## POSSIBLE EASTWARD RANGE SHIFT

The Siniya Island colony apparently has substantial unoccupied habitat suitable for breeding (Muzaffar et al., 2012). Few Umm Al Quwain Municipality staff members may be present on the island to prevent trespassing. Fishermen are permitted to collect seagrass from lagoons, but this activity is controlled. Aside from these, landings on the island by people are restricted, making disturbance on the colony minimal. In comparison, colonies in the western Arabian Gulf experience significant disturbance from recreational activities (picnics etc.), egg collection, road construction in areas allocated for island resorts (e.g. North Yasat, Abu Dhabi) or for oil extraction (e.g. Zirku, Abu Dhabi, currently extinct) (Jennings 2010, Wilson 2012). Provided food supplies remain abundant, the Siniya Island colony has the potential to expand over the available habitat resulting in growth of the population (Schreiber and Burger 2002; Muzaffar et al., 2013). Socotra Cormorants do not exhibit rigid site fidelity and readily switch between colonies or locations within colonies (Jennings 2010; Muzaffar 2013; Salim Javed, EAD, pers. comm.). Socotra Cormorants also forage widely over the Arabian Gulf during the non-breeding period. Ongoing studies on Siniya Island has shown an increasing trend in the breeding population, and it may be hypothesized that birds unable to find adequate nesting habitat may be shifting gradually to this less disturbed area. Further studies need to be done to ascertain if the increasing trend is indeed due to a shift in breeding range or local population increase. In any case, both the Gulf of Salwa region and Siniya Island remain areas of high concentration of breeding birds and are of high conservation priority for the species.

## CONSERVATION NEEDS AND RECOMMENDATIONS

Conservation of a species entails a combination of approaches to facilitate preservation or restoration of their habitat and populations (Mudler et al., 2012). Since Socotra Cormorants are Vulnerable and global populations are still declining, there is a need to undertake conservation action. Four areas may be identified for conservation purposes: (i) conservation of breeding colonies; (ii) conservation of roosting areas; (iii) conservation of foraging areas; and (iv) public awareness.

## (i) Conservation at Breeding Colonies

The breeding colonies are widely distributed in the Arabian Gulf. All colonies in UAE could be brought under protection, recognizing the provisions of UAE Federal Law #24 (1999) which explicitly prohibits hunting adults, collecting eggs or chicks or harming the habitat. Evidence of egg collection in Abu Dhabi islands (Wilson 2012) in spite of this law suggests difficulties with implementation. Identification of each of the remaining colonies in the UAE as protected and maintaining presence of coast guard or other authorities, with specific instructions or advisories to check boats in the area for dead cormorants could minimize these practices. There is also a need to better understand breeding biology and improve management of threats in all breeding colonies. The Siniya Island colony is threatened by introduced feral cats (Muzaffar et al., 2013). These must be trapped and removed from the island. Other colonies in UAE with feral cat problems (e.g. see Jennings 2010) can also be treated similarly. Red Foxes pose a different kind of challenge (Muzaffar et al., 2013). Although they are capable of reducing reproductive success, their impact needs to be determined more quantitatively and management measures (e.g., relocation) may be implemented to improve chances of survival of breeding birds and chicks on Siniya Island. Conservation measures often must be implemented to ensure the survival of the more threatened species. For example, Arctic foxes (*Vulpes lagopus*) are controlled on islands in North America with sensitive seabirds populations given that species is not-threatened whereas some of the seabird species are (Lavers et al., 2010). Similarly, Red Foxes are considered Least Concern (IUCN 2012) and have a widespread distribution on the Arabian Peninsula, whereas the Socotra Cormorant is Vulnerable (BirdLife Internation 2012). Management options must consider the extent of the threat from foxes using scientifically sound methods before such steps are taken (Muzaffar et al., 2013). Efforts must also be made to clean-up the debris on colonies and engage the sea traffic to reduce pollution in the Arabian Gulf. This step must engage all states sharing the Arabian Gulf and will have the broader effect of reducing pollution in the region.

## (ii) Conservation of Roosting Areas

Many islands and cliffs are used by Socotra Cormorants for roosting and resting in the post-breeding period (Jennings 2010, Muzaffar 2014). These islands are often far away from the breeding colonies making them important for conservation. A portion of the birds of Siniya Island moved north along the shoreline and remain in the Musandam region, roosting on cliffs during the non-breeding period (Muzaffar 2014). Others dispersed westwards towards Abu Dhabi, presumably roosting in areas near some of the breeding colonies in the region. It is important to identify where birds disperse after breeding (either through satellite telemetry or banding studies to better identify these areas. Since some of the roosting areas are already known (Jennings 2010, Wilson 2012, Muzaffar 2014), efforts must be made to bring these areas under protection.

### (iii) Conservation of Foraging Areas

Preliminary data shows that Socotra Cormorants breeding on Siniya Island forage either northeastwards or westwards during the breeding seasons covering distances up to 10-70 km (Muzaffar 2014). These areas are close to the coast and are likely linked with shoals of migratory fish that have variable seasonal abundance (Jennings 2010, Wilson 2012). Thus, conservation efforts must ensure that areas close to the coast are protected, particularly when cormorants are foraging. With increasing vessel activity, there may be continuous disturbance on foraging areas. Formulation of guidelines targeting the behavior of recreational or fishing vessels when approaching large concentrations of foraging cormorants could be an important first step. Furthermore, studies need to identify the types of fishing gear that are most detrimental to cormorants and gradually reduce or eliminate their use.

### (iv) Creation of Awareness

The Socotra Cormorant is regarded as a threat to fisheries throughout the region. However, diet analyses indicate that Socotra Cormorants target fish that are not species targeted in the commercial fisheries in UAE (Benjamin et al., 2012; Muzaffar 2013). Thus, the fear of competition between cormorants and fisheries is misplaced. The role of the Socotra Cormorant in the Arabian Gulf needs to be studied and their impact as components of the ecosystem needs to be clarified. As foragers of small pelagic fish, overfishing and reduction of cormorant numbers could be a major long-term concern to the greater Arabian Gulf ecosystem. Creating awareness in this regard as well as ensuring that local fishermen are aware of the laws associated with hunting cormorants is of paramount importance to the future of the species in the region. The UAE government is committed to protecting natural resources and maintaining habitat for wildlife (EAD 2012, 2013). All of the above proposals are in line with this commitment and may help to protect not only the Socotra Cormorant, but many other species that co-exist in the Arabian Gulf.

## CONCLUSION

Socotra Cormorants occur in significant breeding concentrations in the western and eastern Arabian Gulf and despite declines since the 1960s, breeding populations could be safeguarded from further declines through careful conservation intervention. Conservation and management of these populations must focus on removing plastic and other debris, eliminating disturbance during breeding seasons, controlling invasive predators, engaging local fishermen to reduce by-catch mortality, protecting coastal areas to safeguard foraging sites, and creating awareness.

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