

# Chapter 8

## The Transboundary Nature of Seabird Ecology

Patrick G.R. Jodice and Robert M. Suryan

**Abstract** The term ‘seabird’ is generally applied to avian species that forage in the marine environment over open water. Seabirds typically nest in colonies and are long-lived species with low annual reproductive rates. Seabird breeding sites typically occur on islands or along coasts and as such are often at the boundaries of ecological or political zones. During the breeding season, seabirds cross a very distinct terrestrial/marine ecological boundary on a regular basis to forage. Even relatively ‘local’ species cross multiple jurisdictions within a day (e.g., state lands and waters, and federal waters) while pelagic species may transit through international waters on a daily, weekly, or monthly time-frame. Seabird life-histories expose individuals and populations to environmental conditions affecting both terrestrial and marine habitats. The wide-ranging and transboundary nature of seabird ecology also exposes these species to various environmental and anthropogenic forces such as contamination, commercial fisheries and climate forcing that also are transboundary in nature. Therefore, wherever conservation of seabirds or the management of their populations is the goal, consideration must be given to ecosystem dynamics on land and at sea. Because the jurisdiction of agencies does not cross the land-sea boundary in the same manner as the seabirds they are managing, these efforts are facilitated by multi-agency communication and collaboration. By their very nature and by the nature of the systems that they must function within, seabirds embody the complexity of wildlife ecology and conservation in the twenty-first century.

**Keywords** Contaminants • Environmental forcing • Fisheries bycatch • Foraging • Marine conservation

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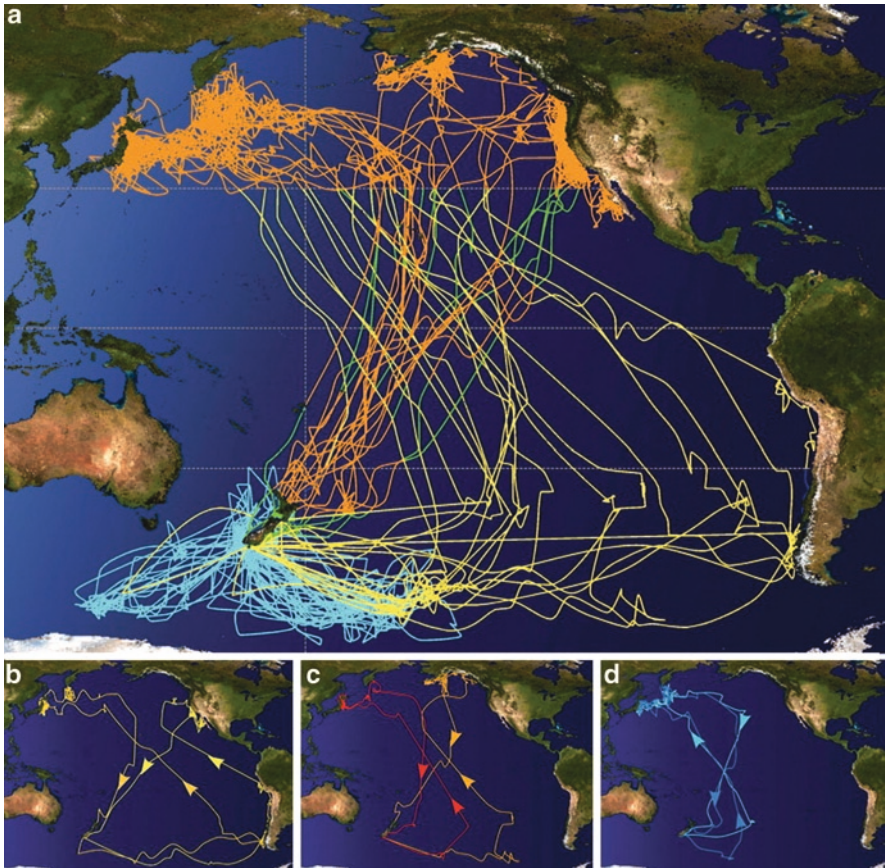
## 8.1 Introduction

In this chapter, we discuss the transboundary nature and multi-scale properties of seabird ecology and life history, considering examples from local to global spatial scales and at daily to decadal temporal scales. The examples we provide will demonstrate that seabirds use multiple spatial scales within relatively brief time frames, cross political boundaries on a regular basis, and thus exemplify transboundary and multi-scale concepts as they relate to wildlife ecology and conservation (Wolf et al. 2006).

Many wildlife species travel substantial distances and cross multiple political and ecological boundaries during migration periods. For example, many songbirds that breed in the Northern Appalachians migrate during the winter to the Southeastern U.S., the Caribbean, or Central and South America; therefore, management and conservation efforts for these species typically consider their winter, summer, and stop-over regions (Chap. 7). The crossing of ecological and political boundaries by wildlife in marine ecosystems also occurs readily, and although the transitions might appear subtle, they are equally striking. For example, gray whales (*Eschrichtius robustus*) and Atlantic bluefin tuna (*Thunnus thynnus*) may traverse entire ocean basins during their annual cycles.

Many seabirds undergo similar large-scale movements during migration. Northern Gannets (*Morus bassanus*) breeding in Atlantic Canada winter as far south as the Atlantic and Gulf coasts of the U.S. (Mowbray 2002). Cory's Shearwaters (*Calonectris diomedea*) breeding in the Mediterranean and on the Azores and Canary Islands winter throughout the South Atlantic, the Eastern Tropical Atlantic, and the Western Indian Oceans (González-Solís et al. 2007). Sooty Shearwaters (*Puffinus griseus*), upon completion of their breeding cycle in New Zealand, traverse the Pacific Ocean from the Southern to the Northern Hemisphere, crossing from the eastern to the western boundary in a figure-eight pattern (Shaffer et al. 2006) (Fig. 8.1). Most recently, the 30,000-km, round-trip migration route of the Arctic Tern (*Sterna paradisaea*) has been mapped using global location sensing units (i.e., geolocators) (Egevang et al. 2010). Seabirds also cross ecological and political boundaries on much shorter and more frequent time scales compared to those observed during migration. During the breeding season, seabirds cross a very distinct terrestrial/marine ecological boundary on a regular basis to forage. Even relatively 'local' species cross multiple jurisdictions within a day (e.g., state lands and waters, and federal waters) while more pelagic species may transit through international waters.

The environmental dynamics of the ecosystems inhabited by seabirds also incorporate large and variable spatial and temporal scales. For example, locally and short-term severe weather may interfere with chick-feeding, decrease chick growth, or increase chick mortality (Konarzewski and Taylor 1989; Velando et al. 1999). In contrast, the onset of an El Niño event may affect food availability and subsequently seabird productivity at the scale of months, while a shift in climate regimes such as the Pacific Decadal Oscillation or the North Atlantic Oscillation may alter foraging and breeding conditions of seabirds for years and affect entire



**Fig. 8.1** Shearwater migrations from breeding colonies in New Zealand. **(a)** Nineteen sooty shearwaters tracked via miniature geolocation (light sensing) tags during breeding (*light blue lines*), post-breeding migration into the Northern Hemisphere (*yellow lines*), and wintering grounds (Northern Hemisphere summer) and southward return migration to the breeding colony (*orange and green lines*). **(b, c, d)** The three *lower panels* show migration paths of breeding pairs, demonstrating that some go to different wintering areas and meet back at the colony the following breeding season, while others go to the same areas – all exhibiting a figure eight migration pattern (From Shaffer et al. 2006)

ocean basins (Chavez et al. 2003; Velarde et al. 2004). Anthropogenic threats to seabirds, such as habitat disturbance at colonies, oil spills, or climate change, also may operate from local and short-term to global and long-term scales. The transboundary nature of seabirds thus differs from that of songbirds (Chap. 7) or even other large marine vertebrates because of their propensity to cross multiple ecological and political boundaries on short and frequent time scales and because they are similarly affected by large-scale anthropogenic events and ecosystem dynamics.

In the following sections, we provide examples of seabird behavior, ecology, and conservation that exemplify the concepts of both landscape-scale – in this case, referring to large spatial scales on both land and sea – and transboundary patterns and processes. Along with a review of seabird biology and life history, we also review the transboundary and landscape-scale nature of seabird foraging ranges and breeding habitats, and the effects of contaminants, environmental forcing, and fisheries bycatch on seabirds.

## 8.2 Seabirds: Taxa, Life-History Traits, and Foraging Ecology

In the following section, we provide a brief review of key life-history traits that exemplify the landscape-scale nature of seabird ecology. Seabird biology and natural history are also thoroughly reviewed by Furness and Monaghan (1987), Gaston (2004), and Schreiber and Burger (2001).

The term ‘seabird’ is generally applied to species that forage in the marine environment over open water. Typically included are all species from the orders Sphenisciformes (penguins) and Procellariiformes (albatrosses, petrels, storm-petrels, fulmars, and shearwaters), most species from the order Pelecaniformes (pelicans, boobies, frigatebirds, gannets, and cormorants), and some species from the order Charadriiformes (alcids, gulls, terns, skuas, and skimmers; Schreiber and Burger 2001). There are 65 seabird genera and approximately 222 wholly marine and 72 partially marine species (Gaston 2004). Seabirds include some of the most abundant birds on Earth, such as the Wilson’s Storm-petrel (*Oceanites oceanicus*), which may number greater than 10 million individuals (Warham 1990); some of the rarest birds on earth, such as the Chatham Island Petrel (*Pterodroma magentae*) and the Chinese Crested Tern (*Sterna bernsteini*), each of which likely has only 10–20 breeding pairs (BirdLife International 2008); and numerous highly endemic birds such as the Bermuda Petrel (*Pterodroma cahow*) and Black-capped Petrel (*Pterodroma hasitata*), which now breed in only one or a few sites in the West Indies, the Fiji Petrel (*Pterodroma macgillivrayi*), found only near the island of Gau in the South Pacific, and the Christmas Island Frigatebird (*Fregata andrewsi*), which breeds only in that island group.

Seabirds can also be categorized by the marine zones in which they tend to forage. For example, albatrosses (Diomedidae) are considered classic pelagic seabirds because they typically forage away from the coastal zone and over open ocean during both the breeding and non-breeding seasons. In contrast, most gulls (Laridae) and terns (Sternidae) are regarded as nearshore because they tend to forage in coastal waters and winter in coastal zones where they may often be found loafing on beaches. Some seabirds use both nearshore and pelagic zones. For example, many alcids and penguins forage in the nearshore and pelagic zones during both the breeding and non-breeding seasons and only rarely use terrestrial habitat outside of the breeding season. Although these categories present some ambiguities and are not strictly defined, they do provide an immediate and clear transboundary reference in terms of spatial scale.

Approximately 96% of seabird species nest in colonies (Wittenberger and Hunt 1985). Colony size can vary from tens of pairs to over 1 million, and the abundance of nesting birds varies based on attributes such as availability of nesting habitat, proximity of food, or size and proximity of nearby colonies. Seabirds use a wide variety of substrates for nesting habitat (Gaston 2004). The most common nest occurs on open ground. Ledges of cliff faces are also used where they are available. Shearwaters, storm-petrels, diving-petrels, puffins, and tropicbirds commonly use ground burrows or crevices in cliffs. Trees and shrubs are commonly used in tropical areas by Pelecaniformes, gulls, and terns, although one species of alcid, the Marbled Murrelet (*Brachyramphus marmoratus*), specializes in nesting on limbs of old-growth trees in the Pacific Northwest. Nests also can be found on human-made structures. Two examples include Least Terns (*Sternula antillarum*), which commonly nest on rooftops throughout the Southeastern U.S. (Gore and Kinnison 1991; Krogh and Schweitzer 1999) and Black-legged Kittiwakes (*Rissa tridactyla*) which nest on abandoned structures in the U.K. (Coulson 1968) and Alaska (Gill et al. 2002).

Seabirds tend to be long-lived, relatively slowly reproducing species especially at the 'pelagic' end of the spectrum. For example, while some nearshore species such as terns, skimmers, and gulls may breed at 2–4 years of age, pelagic species such as albatrosses and petrels may delay breeding until 10 years or more. Unlike waterfowl and songbirds, seabird clutches tend to be small ( $\leq 5$  eggs). Nearshore species typically have larger clutches compared to pelagic species, most of which lay only one egg. Several species only breed every other year (e.g., albatrosses, frigatebirds; Warham 1990, Nelson 2005) and many seabirds will abandon current nesting attempts, especially when feeding conditions are poor, as a means to increase the probability of surviving to reproduce the following year (Golet et al. 1998). The incubation period of seabirds ranges from a fairly typical 28–30 days in many nearshore species to about 80 days in large seabirds such as Wandering Albatrosses (*Diomedea exulans*) and Northern and Southern Royal Albatrosses (*D. sanfordi* and *D. empomphora*) (Tickell 2000).

Nestling or chick-rearing periods are variable among seabirds and can be extensive. Gulls and terns may fledge in 30 days or less, Brown Pelicans (*Pelecanus occidentalis*) require approximately 75 days, Magnificent Frigatebirds (*Fregata magnificens*) 150–185 days, and Wandering and Royal albatrosses and King Penguins (*Aptenodytes patagonicus*) 240 or more days. In contrast, some seabird chicks depart the nest prior to developing the ability to fly. Many gulls and terns will depart the nest within a few days of hatching, some forming large crèches in intertidal zones. For these species, management during the breeding season thus requires secure nesting areas and secure chick-rearing areas. A unique trait among some alcids (e.g., Common Murres [*Uria aalge*], Ancient Murrelets [*Synthliboramphus antiquus*]) is for chicks to depart the nest prior to gaining flight and to complete the majority of pre-fledge chick-growth at sea, including chicks from the *Synthliboramphus* murrelets which depart the nest within days, as well as other alcids, which depart the nest beginning within 2 weeks after hatching.

Seabirds employ a variety of foraging techniques, forage in a variety of locations, and forage upon a variety of items. The dominant diet item among seabirds is fish, and the type and size taken depends in part on the foraging technique, geographic distribution, size of the bird, and marine habitat. In many northern and mid-latitude areas, fish such as herring, sardines, anchovies, and menhaden (*Clupeiformes*), sand eels (*Ammodytes* spp.), and smelts (*Osmeridae*) are common in diets, while in tropical latitudes flying fish (*Exocoetidae*) may be more common. Invertebrates such as cephalopods (e.g., squid) and zooplankton (e.g., krill) are also important food items, the latter particularly so in high latitude or highly productive regions. Seabirds also use anthropogenic food sources such as offal and discarded bycatch from commercial fisheries, and the availability and distribution of these food sources may alter seabird diets, distributions, and population dynamics (Furness 2003; Garthe et al. 1996).

Seabirds forage primarily by surface feeding (e.g., gulls, terns, albatrosses), plunge diving into the top few meters of the water column (e.g., pelicans), pursuit diving (e.g., alcids, penguins, shearwaters, diving-petrels, and cormorants, some of which can access waters as deep as 100–500 m during their pursuit dives), and kleptoparasitism (skuas, jaegers, and frigatebirds). Seabirds may forage individually, in small single- or multi-species flocks, or occasionally in large flocks numbering over 1 million. Surface-feeding seabirds may forage in association with sub-surface foragers such as alcids, penguins, tuna, dolphins, or whales that effectively drive prey toward the surface (Hebshi et al. 2008), and this habit can be common in nutrient poor, oligotrophic waters (Ballance et al. 1997). Seabirds tend to locate prey visually, although some procellariids use olfaction (Nevitt et al. 2008) and some specialized species such as skimmers (*Rynchops* spp.) use tactile senses.

The location of foraging depends to a certain extent on the foraging technique and the accessibility of prey. Seabirds often frequent locations that are characterized by nutrient-rich surface waters such as upwelling zones, fronts and eddies, seamounts, or along the edge of the continental shelf. Ultimately foraging locations are dictated by a combination of habitat features that affect prey availability, including attributes such as ocean and wind circulation patterns, the extent of upwelling and productivity, turbidity, and distance from the breeding site. The spatial scale at which these features operate varies from local to global, and their temporal scale also varies from relatively predictable (e.g., upwelling generated via water currents and associated with a landmass or seamount) to highly ephemeral (e.g., local wind-generated aggregation of surface prey items).

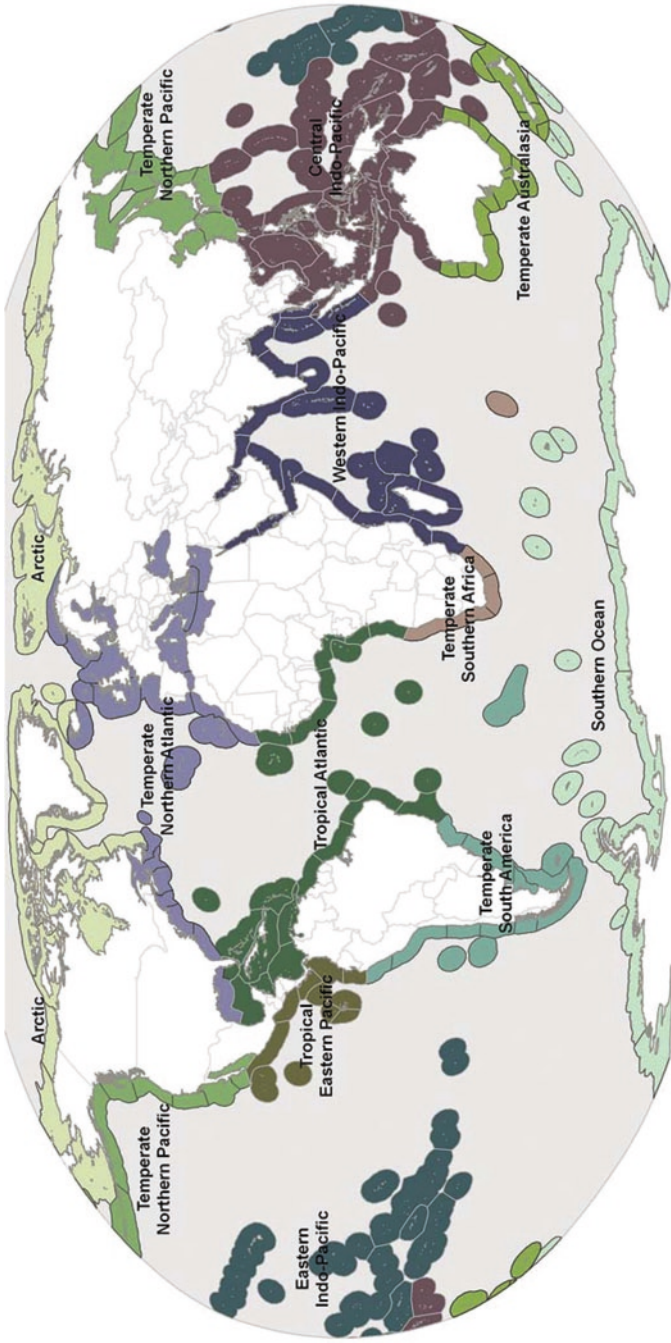
Most seabirds are central-place foragers during the breeding season, returning to land on a regular basis to incubate or feed nestlings. The distance between the foraging area and the breeding site varies over four orders of magnitude across all seabirds. The frequency of food delivered to chicks also varies widely among species and is one of the primary factors that contribute to the transboundary habits of seabirds (i.e., regularly crossing from terrestrial to marine systems). Feeding frequency can vary within and among species based on factors such as distance to the food source, the extent and type of parental care required by the chick, weather,

and chick age. For some species, feeding frequency ('feeds') is best measured on a per hour basis. For example, studies of chick feeding by Brown Pelicans in Mexico and South Carolina revealed that chicks received 1–4 feeds per hour, although the number of feeds decreased with age (Pinson and Drummond 1993; Sachs and Jodice 2009). In other species, feeds are best measured on a per day basis. Jodice et al. (2006) found that at six colonies during 5 years of study chicks of Black-legged Kittiwakes received on average 2–5 feeds per day with adults foraging primarily in nearshore waters (Suryan et al. 2002). Trivelpiece et al. (1987) measured feeding rates in three species of penguins raising chicks at King George Island. Chicks of the more nearshore Adelie Penguin (*Pygoscelis adeliae*) were fed about once per day while those of the more offshore and deep-diving Chinstrap and Gentoo penguins (*P. antarctica* and *P. papua*) received 1.5–2.0 feeds per day. Feeding also occurs less than daily in many pelagic species. For example, many albatrosses and petrels regularly feed chicks at 1–5 day intervals although the gap between feeds extends with chick age (Warham 1990). Very infrequent feedings occur in the King Penguin, which during the winter starvation period may deliver food to chicks only once per 30–90 days (Cherel et al. 1987). The variability associated with these provisioning rates is based in part on life-history traits but also can vary with environmental conditions. This fact becomes important when discussing the concept of ecoregions within the marine environment and the extent to which seabirds traverse both ecoregional and political boundaries.

### 8.3 Seabirds, Boundaries, and Scales

Large-scale conservation planning and the mapping of biological diversity for conservation purposes are more common in terrestrial compared to marine systems (Spalding et al. 2007 and included references). For example, despite the prevalence of marine environments across the globe, these habitats are underrepresented in global reserve networks, comprising less than 0.5% of the earth's surface (Chape et al. 2005). Only within the past 10 years have global classification systems been developed for the marine environment. Longhurst (2007) proposed biogeographical provinces for pelagic waters (approximately ten for each ocean basin). Within this scheme, boundaries are not fixed in space or time but instead can shift based on the temporal changes in physical forcing that regulate phytoplankton distribution. Spalding et al. (2007) developed a biogeographic system for coastal and shelf areas (Fig. 8.2). This hierarchy of 12 realms, 62 provinces, and 232 ecoregions provides a comprehensive and readily available framework for marine conservation planning within the area in which most marine diversity and most threats occur (Spalding et al. 2007; UNEP 2006).

Here we present several aspects of seabird ecology and management that highlight the landscape-scale properties of seabirds.



**Fig. 8.2** Final biogeographic framework for coastal and inshore areas: Realms and provinces. Biogeographic realms with ecoregion boundaries outlined; definitions of bioregions in Spalding et al. (2007)



### **8.3.1 Breeding Habitats, Political Boundaries, and Ecological Boundaries**

Seabird breeding sites typically occur on islands or along coasts and as such are often at the boundaries of ecological or political zones and hence influenced by the dynamics of both marine and terrestrial systems. Across the range of seabird species, the consistent use of a site as a nesting location varies from strongly philopatric to highly plastic. In addition, some species have a limited number of nesting sites while others occupy numerous sites. Seabirds that are philopatric and that nest in only one or a few locations can present a substantial conservation challenge. For example, the Short-tailed Albatross (*Phoebastria albatrus*) currently numbers about 2,500 individuals with breeding colonies on only two islands off the coast of Japan. Key threats to this species include the instability of soil, the threat of mortality and habitat loss from an active volcano, and vulnerability to other natural disasters such as typhoons at its main breeding site. Interestingly, the second remote breeding island for this species is currently disputed territory among three Asian nations (BirdLife International 2008), thus adding a different twist to the concept of ‘trans-boundary.’ Nonetheless, the Short-tailed Albatross demonstrates an ‘all eggs in one basket’ situation. In species that rely on a single location for a colony, a goal of conservation planning may be to reduce the risk to a species, perhaps from a stochastic event such as a storm or predator invasion, by developing an alternate nesting site (Miskelly et al. 2009).

Some seabirds, such as the Red-legged Kittiwake (*Rissa brevirostris*), have only a few nesting locations that are widely spaced. Major colonies are located on the Pribilof Islands in the Eastern Bering Sea, Bogoslof Island in the Aleutian chain which lies approximately 350 km south of the Pribilof Islands, Buldir Island which lies 1,000 km west of Bogoslof Island, and the Commander Islands which lie another 700 km west of Buldir Island and are within Russian waters. These few colonies occur in two realms (Arctic and Temperate Northern Pacific), two provinces (Arctic and Cold Temperate Northwest Pacific), and three ecoregions (Eastern Bering Sea, Aleutian Islands, and Kamchatka Shelf) as delineated by Spalding et al. (2007).

Unlike the previous examples, some seabirds are loosely philopatric and tend to move readily among multiple sites from 1 year to the next. This is very common in some beach-nesting terns, where the quality and size of breeding beaches are subject to a high degree of interannual variability due to winter storms and sediment transport. Management of these species, therefore, requires a network of readily available sites that can accommodate thousands of birds from 1 year to the next. For example, along the coast of South Carolina, Royal and Sandwich terns (*Sterna maxima* and *S. sandvicensis*) have nested on nearly a dozen sites over the past 3 decades (Jodice et al. 2007). These sites occur over about 175 km of coastline, and colonies of thousands of birds frequently move among sites in consecutive years. For example, between 1990 and 1991, the nest counts at one colony in South Carolina decreased from 8,200 to 200 while nest counts at another colony increased from 900 to 11,000. Additionally, between 1986 and 2005, six different sites were used only one to four

times each and during that period nest counts ranged from several to nearly 4,000. While the reasons underlying such large-scale and natural relocations are varied and may include both natural and anthropogenic factors (e.g., beach erosion, human disturbance or development), the management message is that a single site cannot support a species having a low degree of colony philopatry.

Seabird breeding ranges also may cross multiple political boundaries. While many species of landbirds breed among multiple nations, seabirds may nest in multiple nations as well as cross these boundaries on a daily or weekly basis as they forage. For example, the West Indian Breeding Seabird Atlas ([www.wicbirds.net](http://www.wicbirds.net)) catalogs breeding locations and population estimates for 25 seabirds on nearly 800 islands spread across 39 countries from Bermuda to the islands off of Northeastern South America. Two wide-ranging species in the region are the Audubon's Shearwater (*Puffinus lherminieri*) and White-tailed Tropicbird (*Phaethon lepturus*). Each nests in over 20 countries throughout the West Indies (Lee 2000a; McGehee 2000) and in 5–6 ecoregions based on Spalding et al. (2007) including the Bermuda, Bahamian, Eastern Caribbean, Greater Antilles, and Southern Caribbean ecoregions. Conservation regulations, enforcement, education, and funding for wildlife management and conservation vary considerably across the region making management efforts spatially inconsistent and temporally variable. Although the need for transboundary conservation efforts in this region has been recognized for over a decade (Gochfeld et al. 1994), such efforts have yet to be fully realized.

Along with variability in the number of nesting sites used by a species and the consistency with which sites are used among years, seabirds also display variability in the types of habitats used for nesting. While most seabirds typically nest on cliffs or plateaus, or in burrows immediately adjacent to their marine foraging habitat, others do not. Seabirds also nest in forests and alpine areas, which are quite distinct from the marine zone. Here we provide four examples of seabirds that nest 'inland' and face management challenges associated specifically with their inland nesting habitat.

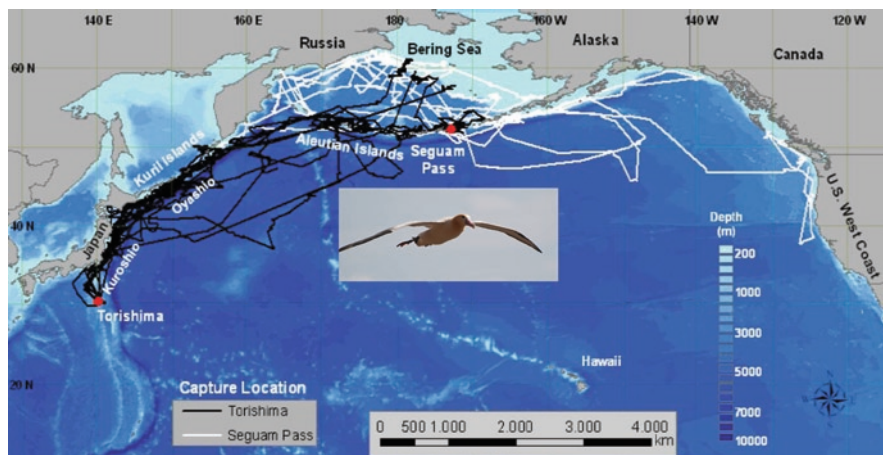
Inland nesting is not uncommon among the petrels and shearwaters, which often nest in burrows or cavities. The Hutton's Shearwater (*Puffinus huttoni*) is endemic to New Zealand and is considered threatened. The species currently nests at only two alpine sites in the Seaward and Inland Kaikoura Mountains at elevations of 1,200–1,800 m (Cuthbert et al. 2001; Cuthbert and Davis 2002). Nesting habitat of Hutton's Shearwater is considered to be endangered and has been lost to introduced nest predators and browsers, the latter of which are responsible for erosion in the alpine nesting areas (BirdLife International 2009a; Cuthbert et al. 2001). Like Hutton's Shearwater, Newell's Shearwater (*Puffinus newels*) is also considered to be endangered. The species is now confined to steeply sloped, forested sites at 160–1,200 m elevation and as far as 14 km inland on Kaua'i, Molokai, and Hawaii in the Hawaiian Islands (Ainley et al. 2001; Day and Cooper 1995). While their bones can be found in caves throughout the island chain, populations of Newell's Shearwaters persist in areas least affected by introduced predators and urbanization (adults collide with power lines while commuting inland) (BirdLife International 2009b). Another highly endangered, inland nesting seabird is the Black-capped Petrel, which nests on forested slopes and cliffs at elevations of 1,500–2,300 m at a limited

number of sites in Haiti and the Dominican Republic, although it nested much more broadly throughout the Caribbean before humans arrived in the region (Lee 2000b). Deforestation for charcoal and small-scale agriculture is the primary factor underlying loss of nesting habitat. Another inland forest-nesting species, the Marbled Murrelet, nests in old-growth forests along the Pacific Northwest coast of North America up to 65 km inland. Nesting habitat has declined due to timber harvesting and fragmentation in coastal forests (Gaston and Jones 1998). Management actions, research, and planning for each of these four species have focused not only on the marine environment but also on issues related to forest management, urbanization, or grazing in the nesting environment and thus have incorporated transboundary and landscape-scale thinking.

### 8.3.2 *Ranges of Seabirds: from Bays to Oceans*

Like many birds, seabirds often cross ecoregional and political boundaries during post-breeding dispersal and migration. For example, many nearshore species common to the southeastern U.S., such as Royal Terns and Brown Pelicans, migrate across multiple state boundaries during the non-breeding season, although they typically remain within the region. In contrast, other seabirds engage in extensive post-breeding dispersal. The Great and Magnificent Frigatebirds (*Fregata minor* and *F. magnificens*), for example, travel 1,400–4,400 km from their breeding sites and continue to make foraging trips of many hundreds of kilometers once they relocate (Weimerskirch et al. 2006). Short-tailed Albatrosses breeding on Torishima Island off the coast of Japan disperse over 10,000 km to the Bering Sea off Alaska and Russia, with some crossing to the opposite side of the Pacific Ocean (Fig. 8.3; Suryan et al. 2006). Likewise, other species of albatrosses in the Southern Hemisphere are well known for their global circumnavigations in a region where ocean crossings are unimpeded by land masses (Croxall et al. 2005). In the Western Atlantic, the Great Shearwater (*Puffinus gravis*) breeds in the South Atlantic but disperses to the Bay of Fundy (<http://www.tristandc.com/wildgreatshearwater.php>).

Within the breeding season, both pelagic and nearshore species of seabirds frequently range over extensive areas and cross multiple habitats and political jurisdictions. In fact, many species do not commonly forage close to their colonies due to what is referred to as ‘Ashmole’s halo’ (Birt et al. 1987), a zone around the colony that tends to be depleted of prey due to its proximity to the colony (Ashmole 1963, 1971). Typically the size of the halo shows a direct relationship with colony size although recent modeling efforts suggest that the halo effect may be undetectable for small colonies or for colonies of far-ranging pelagic species (Gaston et al. 2007). Nonetheless, this general pattern means that natural resource managers responsible for seabird colonies should consider not only ecological and management-related issues on and near the colony, but depending on the size and location of the colony, managers also may need to consider vast areas of marine habitat in which seabirds may forage even while rearing chicks. These areas are often in international



**Fig. 8.3** Post-breeding migration paths of 14 satellite tracked short-tailed albatrosses. Albatrosses were tagged at their breeding colony on Torishima, Japan, and at-sea near Segum Pass, Alaska. These results demonstrated that juvenile albatrosses (<1 year old; white lines) were ranging much farther than adults, which was later confirmed by additional tracking studies (From Suryan et al. 2006)

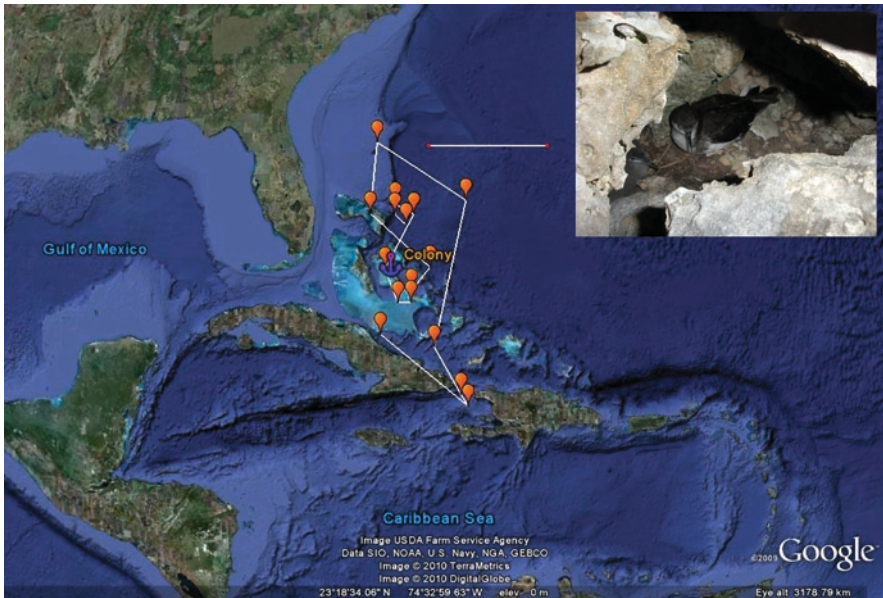
waters or in waters controlled by other governments or other wildlife or fisheries management agencies. Several examples of foraging ranges of breeding seabirds across four orders of magnitude (less than 10 km to more than 1,000 km) serve to demonstrate the need to address multiple spatial scales when considering conservation and management actions for this suite of species.

The Little Tern (*Sternula albifrons*) is a small (less than 60 g) seabird that breeds along coasts and inland waterways of temperate and tropical Europe and Asia. This species is declining in Europe, particularly in the U.K. where populations have declined by about 30% since the mid-1980s. Despite its small size, this species may cover 10–27 linear km during 1–2 h of foraging and regularly travels 2–3 km offshore during the breeding season, covering areas of 6–50 km<sup>2</sup> (Perrow et al. 2006). In the Southeastern U.S., the similarly-sized Least Tern, also considered to be a nearshore species, may be found up to 10 km offshore during the breeding season. Hence, even relatively small, inshore species may use offshore areas.

Many breeding seabirds have foraging ranges on the order of 20–100 km and hence forage not just locally but throughout a region. Adams et al. (2004) found that, on average, breeding Cassin's Auklets (*Ptychoramphus aleuticus*) at two colonies in California foraged within 30 km of their colonies and that colony-based foraging areas covered 500–1,200 km<sup>2</sup>. Hatch et al. (2000) used satellite tags to track movement patterns of Common and Thick-billed Murres (*Uria lomvia*) from two colonies in the Gulf of Alaska and two colonies in the Chukchi Sea. They found that both species, when attending chicks, regularly foraged 50–80 km from colony sites and that foraging ranges of the two species at the same colonies overlapped considerably. However, the foraging ranges of both murre species differed

considerably when examined at two colonies separated by about 50 km. Garthe et al. (2007) used GPS loggers to examine foraging ranges of Northern Gannets breeding on Funk Island, approximately 60 km northeast of Newfoundland. They found that gannets raising chicks regularly flew at speeds of 30–40 km/h to forage 32–70 km from the colony. However, other studies of Northern Gannets have revealed broader foraging ranges. Hamer et al. (2001) used satellite tags to track gannets rearing chicks at one colony in Southeast Scotland and another in Southeast Ireland. Individuals from the colony in Ireland foraged 14–238 km from the colony and covered an area of 45,000 km<sup>2</sup>. In comparison, birds from the colony in Scotland foraged 39–540 km from the colony covering an area greater than 200,000 km<sup>2</sup>. These last two studies demonstrate that foraging ranges of the same species may differ among colonies, and therefore management and conservation efforts also may require data from multiple locations.

At a larger scale are the pelagic species that may depart the nest for multiple days at a time and forage throughout or travel across ocean basins. This is especially common in the order Procellariiformes. For example, one of us (PGRJ) along with several colleagues documented a single Audubon's Shearwater (200 g) that was rearing a chick in the Northern Bahamas to have traveled over 1,000 km during a 1-week foraging trip, covering waters from the Charleston Bump to Cuba (Fig. 8.4).



**Fig. 8.4** Locations of an Audubon's Shearwater determined via global location sensor during 1 week in June 2008. The path distance for this bird was ca. 3,000 km and the linear distance from the northernmost to southernmost point was ca. 1,200 km. This individual was tagged at the Long Cay colony, Bahamas, and was rearing a chick (unpublished data collected by P. Jodice, W. Mackin, R. Phillips, and J. Arnold)

The larger Black-capped Petrel breeds primarily in Haiti and the Dominican Republic but is commonly observed near the shelf break off of Cape Hatteras, North Carolina, during the breeding season, a distance of about 2,000 km from Haiti (Lee 2000b). One of the more extreme cases of long-distance foraging during chick-rearing occurs in the Wandering Albatross. During a single foraging trip, this species may travel 900 km per day and up to 15,000 km during the entire foraging trip, and may range from colony sites on South Georgia Island over 2,000 km north to waters off the coast of Brazil (Jouventin and Weimerskirch 1990; Prince et al. 1992).

These examples demonstrate that even nearshore seabirds can range over a substantial area on a daily basis while pelagic species may cover thousands of kilometers or more during a single foraging trip. These extensive movements have important implications for seabird management and conservation because individual birds traversing that large of an area can encounter an array of environmental conditions and anthropogenic activities, some of which may pose threats to their survival. Advances in tracking technology allow biologists to now consider, for example, how a bycatch threat or the presence of a marine protected area thousands of kilometers distant from a colony may affect seabird ecology (Hyrenbach et al. 2006; Prince et al. 1992).

### ***8.3.3 The Transboundary Nature of Contaminants for Seabirds***

Seabirds have often been used as biosentinels for contaminants, pollution, and other chemical stressors in the marine and coastal environment (Braune et al. 2001; Vander Pol and Becker 2007). Their position at the apex of trophic webs exposes them to biomagnification effects of contaminants. Strong site fidelity to breeding and foraging areas exposes them to persistent point-source contaminants, and wide-ranging foraging habits expose them to spatially diverse contaminant sources and politically inconsistent regulatory policies in both marine and terrestrial environments (Burger and Gochfeld 2002). Here we describe the transboundary nature by which seabirds encounter contaminants.

Nearshore species are exposed to contaminants during the breeding season in much the same way as a raptor or songbird. A parent forages within a relatively local area while provisioning itself and its chicks and acquires some contaminants from their prey. For example, Wenzel et al. (1996) examined the distribution of five trace elements in nestling Black-legged Kittiwakes in the North Sea and attributed elevated concentrations to local food sources. Becker (1989) and Becker et al. (1991) also attributed mercury contamination in eggs of nearshore Common Terns within the Elbe estuary to local sources of mercury. The transboundary nature of contaminants for nearshore seabirds often arises because the contaminants of concern, although produced at a single point source, are either transported across ecosystem boundaries (e.g., from agricultural to marine systems) or obtained as birds forage in agricultural or urban systems (Cifuentes et al. 2003).

Pelagic seabirds provide examples of transboundary contamination at extensive spatial scales. Breeding adults, in particular, may regularly travel a significant

distance from an uncontaminated breeding site to a contaminated site to forage. For example, Finkelstein et al. (2006) examined organochlorine and mercury contamination in the Black-footed Albatross (*Phoebastria nigripes*) and Laysan Albatross (*Phoebastria immutabilis*), two sympatrically breeding species in the Northwestern Hawaiian Islands. Contamination levels were about 400% higher in Black-footed Albatrosses compared to Laysan Albatrosses despite similarities in diets, breeding behavior, and nesting locations. The difference in contaminant loads was attributed to a difference in foraging locations between the two species. Black-footed Albatross were foraging northeast of the Islands toward and along the west coast of North America where contamination history is strong, while Laysan Albatrosses were foraging north and west of the Hawaiian Islands in areas without a strong contamination history. While this example clearly demonstrates the transboundary nature of contamination for both species, it also demonstrates that species that breed sympatrically may be exposed differentially to contamination depending on the location and extent of the foraging range. Therefore, not only can it be difficult to predict contamination effects on pelagic seabirds due to their extensive foraging habits, but it cannot be assumed that the intensity or type of contamination will be consistent among species breeding in a single location due to the variability that may occur in foraging ranges.

Both pelagic and nearshore seabirds also may be exposed to contaminants that are being transported. For example, seabirds may forage relatively locally in an area that does not contain a contaminant source, but oceanic and atmospheric currents may move contaminants across boundaries and hence affect seabirds. Ricca et al. (2008) found elevated levels of contaminants in a suite of seabirds from the Aleutian Islands that were nesting and foraging in locations that were not associated with point sources of contamination. The species sampled represented multiple trophic positions and the authors suggested that the contaminants were being transported from the Western Pacific through oceanic and atmospheric processes.

Another potential mechanism for contaminant transport considers the transboundary nature of seabirds foraging upon discarded bycatch from commercial fishing vessels. Many seabirds attend commercial fishing vessels where they scavenge for discarded bycatch (Furness et al. 1988; Garthe and Hüppop 1994). In many cases the discarded bycatch items are demersal (bottom-dwelling) fish while the seabirds themselves are surface feeders (Walter and Becker 1997; Wickliffe and Jodice *in press*). Demersal prey often contain higher levels of contaminants such as mercury due to biomagnification and bioavailability in deeper waters (Monteiro et al. 1996). As these demersal fish are brought to the surface and hence made available to seabirds during the discarding process, any contaminants they may contain are effectively transported across depth boundaries. For example, Arcos et al. (2002) suggested that levels of mercury in Audouin's Gulls (*Larus audouinii*) that foraged upon discarded benthic prey were elevated compared to levels in Common Terns that did not forage upon discarded prey.

Oil spills also represent a transboundary contamination source for marine wildlife. Seabirds are exposed to oil primarily through direct contact and contamination of their prey base. Effects may be lethal or sublethal, occur proximate to or distant

from seabird colonies, and be persistent. For example, the *Exxon Valdez* oil spill in Northern Prince William Sound (PWS), Alaska, created a sudden and severe point source of contamination. Ultimately the oil spread 750 km to the southwest and eventually contaminated more than 2,000 km of shoreline (Peterson et al. 2003). Approximately 878,000 seabirds were breeding at colonies within the ultimate path of the spill and many colonies experienced direct and immediate oiling (Piatt et al. 1990). Pigeon Guillemot (*Cephus columba*) colonies on the Naked Islands in Central PWS about 35 km from the spill were directly in the path of the prevailing currents and were oiled within 3–4 days of the spill. In contrast, seabird colonies 300–400 km from the spill site in lower Cook Inlet and at the mouth of the Gulf of Alaska in the Barren Islands group did not originally appear to be in the direct path of the spill but were oiled within 3 weeks. Hence the oil spilled in Northern PWS acted as a proximate and somewhat predictable source of contamination at colonies in Central PWS but also acted as a distant and somewhat less predictable source of contamination at colonies elsewhere.

Seabirds also may be exposed to oil indirectly at the foraging grounds when they ingest prey (e.g., fish) that have been exposed to oil, and these effects may be quite persistent over time (Jewett et al. 2002). For example, Yellow-legged Gulls (*Larus michahellis*) experienced changes in plasma biochemistry and elevated levels of polycyclic aromatic hydrocarbons that were consistent with the ingestion of fuel oil 17 months after the *Prestige* oil spill occurred off the coast of Spain (Alonso-Alvarez et al. 2007a, b). Similarly, adult Pigeon Guillemots in PWS, which forage on fish and benthic invertebrates, showed elevated levels of CYP1A, a detoxification enzyme associated with exposure to oil, 9 years post-spill (Golet et al. 2002). These examples demonstrate that seabirds may be affected by oil both at and away from the colony, and that these effects can span temporal scales of months to years.

The abundance of plastics in the marine environment has become well-documented and presents another type of transboundary contaminant source for seabirds. Seabirds ingest plastic while foraging, and plastics also are brought back to the nest and ingested by chicks. Robards et al. (1995) and Blight and Burger (1997) noted plastic was very common in 11 species of seabirds from an area in the Eastern North Pacific where both regionally breeding species (e.g., Tufted Puffins [*Fratercula cirrhata*] and Rhinoceros Auklets [*Cerorhinca monocerata*]) and species from the West and South Pacific foraged (e.g. Black-footed Albatross and Sooty Shearwater). Similarly, eight species of shearwaters, albatross, and petrels captured incidentally in drift-net fisheries or gathered from beached-bird surveys off the coast of Brazil frequently had plastics in their systems (Colabuono et al. 2009). Young et al. (2009) found that Laysan Albatrosses nesting on Kure Atoll spent more time foraging within the range of the ‘Western Pacific garbage patch’ compared to Laysan Albatrosses nesting on Oahu, and they also found a higher incidence of plastics in boluses regurgitated from chicks at Kure Atoll colony.

As with contaminants, plastics may be transported to pristine colony sites. Morishige et al. (2007) examined the amount and type of plastic debris on beaches of the Hawaiian Islands NWR. In a 16-year assessment, they found over 52,000



pieces of plastic washed up on the beaches of some of the most remote uninhabited atolls on the planet. Interestingly, they also found a positive correlation between deposition rates and the occurrence of El Niño events, suggesting that the amount of plastic appearing on these remote beaches may vary as changes in wind patterns cause a shift in ocean currents.

These examples demonstrate that seabirds are exposed to contaminants at a wide range of spatial and temporal scales, and that relatively pristine systems can accumulate contaminants. Based on their abundance and global distribution, seabirds also represent a significant biovector of nutrients and contaminants from the ocean to the land. Blais et al. (2005) clearly demonstrated that Arctic ponds subjected to deposition of seabird guano had 10, 25, and 60 times the level of hexachlorobenzene, mercury, and DDT, respectively, compared to ponds that were not exposed to seabird guano. Therefore, not only does seabird guano stimulate productivity via the addition of nutrients, it also provides a transport mechanism for industrial and agricultural pollutants in high-latitude systems where these contaminants are not native (Blais et al. 2005).

### ***8.3.4 Environmental Variability/Climate Forcing***

Seabirds are strongly affected by environmental variables, including climate forcing, operating at multiple temporal and spatial scales. This may range from a localized storm event that causes nest loss at one colony to a hemispheric shift in weather patterns or ocean currents that affect the entire breeding range of a species. Furthermore, climate conditions affecting prey availability on the foraging grounds may reduce chick survival thousands of kilometers away. Environmental variables such as these affect seabirds at various spatial and temporal scales, and changes in seabird populations will likely play a role in restructuring coastal ecosystems.

Seabird life histories expose individuals and populations to environmental conditions affecting both terrestrial and marine habitats. Environmental effects on terrestrial nesting or resting habitat (excluding anthropogenic habitat alteration or predator introductions for this discussion) can be unique for seabirds at times, but in general are mostly similar to those affecting other terrestrial organisms, including severe weather events that generally have localized, short-term consequences. Changes in the marine environment, however, often have the most dramatic, widespread, or longest-lasting consequences to seabird populations. The fluid and dynamic nature of marine systems, however, requires seabirds to adapt to environmental fluctuations in ways drastically different than wholly terrestrial species. This is particularly true during the breeding season when most seabird species are constrained to central-place foraging from their terrestrial nesting habitat yet are required to constantly adapt to their marine foraging habitat, which is in constant three-dimensional motion via horizontal currents and vertical mixing that affects the distribution of prey, themselves often highly mobile organisms.

A dominant force driving horizontal currents and vertical mixing are ocean-atmosphere interactions. Atmospheric winds and temperature affect ocean currents, mixing, and the distribution of seabird prey both locally on time scales of hours or days and regionally on time scales of years to decades. Not surprisingly, these ocean-atmosphere interactions are often themselves transboundary in nature. For example, changes in wind patterns over the equatorial region (e.g., El Niño-Southern Oscillation) affect currents, temperature, and prey availability (i.e., distribution and abundance) thousands of kilometers away in the North and South Pacific and beyond (including terrestrial habitats over the Americas and Asia; Black et al. 2009; Chavez et al. 1999, 2003).

One of the most clear and dramatic examples of ocean-atmosphere interaction and transboundary connections affecting seabird populations is that of Cassin's Auklets breeding in the California Current System off the west coasts of Canada and the U.S. During the 2005 breeding season, Sydeman et al. (2006) reported that unusual atmospheric blocking in the Gulf of Alaska caused the jet stream, which affects coastal winds, to shift southward and cause anomalously warm sea-surface temperatures and unfavorable conditions for auklet prey (zooplankton) in the Northern California Current but not further south. Northern colonies of auklets off Canada and Central California experienced unprecedented (within a 35-year time series) reproductive failure and colony abandonment. In contrast, the abundance of auklet and their prey to the south, off Southern California, was anomalously high. Other examples of changes in ocean conditions affecting seabird prey availability, and hence reproductive success or population abundance, include cool water temperature delaying the inshore migration of key forage fish prey for the Common Murre off Newfoundland (Davoren and Montevecchi 2003), and the opposing effects of cold ocean temperatures benefitting planktivorous seabirds and warm ocean temperatures benefitting piscivorous seabirds in Tauyskaya Bay, Russia (Kitaysky and Golubova 2000).

Several well-documented climate signals that affect terrestrial and marine ecosystems over entire ocean basins have profound effects on seabird populations. In fact, seabirds often provide early warning signs of these large-scale climate changes, even though the actual physical drivers are thousands of kilometers away. One example is the El Niño-Southern Oscillation, which results from changes in atmospheric pressure over the South Pacific and Indian Oceans. Changes in pressure affect equatorial winds (and therefore ocean currents), ocean mixed-layer depth, overall productivity, and consequently food for seabirds. While the extent of El Niño is global, the effects are strongest in the equatorial Pacific. The 1982–1983 El Niño, one of the strongest recorded, resulted in the death of millions of seabirds in the equatorial Pacific due to starvation and also affected reproductive success of some species globally (Schreiber and Schreiber 1989). El Niño events occur relatively frequently, every 2–7 years; however, they are generally short-lived, lasting a year or less. Other well-documented, longer-lasting climate forcing that affect seabirds in the North Atlantic and North Pacific Oceans include the North Atlantic Oscillation, the Pacific Decadal Oscillation, and the Arctic Oscillation. These climate oscillations switch between alternate states lasting

decades and, like El Niño, affect entire ecosystems from zooplankton to seabirds at ocean-basin scales. Effects of these oscillations have been shown to influence seabirds and their prey in the North Atlantic (Aebischer et al. 1990) and North Pacific (Anderson and Piatt 1999), sometimes alternating effects between these two regions (Irons et al. 2008). The effects can also vary by species, and studies in the North Atlantic demonstrate that these broader scale (hemispheric) climate shifts can have great effects on wider ranging species (i.e., more broadly dispersive or migratory during the non-breeding season) but have little or no effect on more locally residing species (Frederiksen et al. 2004).

In addition to these cyclical climate patterns, linearly changing or non-periodic trends also affect seabird populations through a wide variety of mechanisms. One potential mechanism is warming trends that affect wind patterns over the ocean, which, in turn, affect currents, water column mixing, and seabird food supply. For example, Bakun (1990) postulated that greenhouse gas-induced warming could, by warming coastal land masses more than water masses, create greater pressure differences between land and sea and thereby intensify coastal winds and water column mixing, with potentially dramatic effects on marine ecosystems (Bakun and Weeks 2004). In the California Current System off Western North America, long-term ocean warming has affected the community composition and abundance of seabirds in offshore waters (Veit et al. 1996, 1997), with an overall decline in numbers resulting from fewer cold-water associated pursuit-diving seabirds despite the increase in warm-water associated near-surface feeding species (Hyrenbach and Veit 2003). In the Northern California Current, warming ocean temperatures were correlated with declines in reproductive success of Tufted Puffins, a cold-water associated pursuit-diving seabird (Gjerdrum et al. 2003). More extreme, anomalous weather events may occur if climate change occurs, which may affect seabird species as well (Frederiksen et al. 2008). Likewise, changes in sea-level rise of even one meter could greatly impact seabird breeding habitat on low-lying beaches, atolls, and rocks (Baker et al. 2006) and in coastal estuarine habitat (Daniels et al. 1993).

### ***8.3.5 Seabirds and Commercial Fisheries: Efforts to Reduce Bycatch Mortality***

Seabirds provide many examples of research, management, conservation, and policy actions that require transboundary efforts for success and implementation (e.g., Wolf et al. 2006). Here we briefly examine the case of seabird mortality that occurs as bycatch within commercial fisheries.

Procellariids (albatrosses, petrels, and shearwaters) are the epitome of ocean wanderers, regularly traversing ocean basins within breeding seasons or crossing hemispheres and circumnavigating the globe during the non-breeding seasons (Croxall et al. 2005; Felicísimo et al. 2008; Fernández et al. 2001). Albatrosses (Diomedidae), which range over long distances and often forage opportunistically,

are particularly prone to incidental mortality in industrial longline fishing operations. Birds are most often hooked when longlines are being deployed and baited hooks are accessible at the surface near the vessel. Due in large part to this bycatch mortality, the Diomedidae are now one of the most endangered families of birds with 19 of 21 species on the International Union for the Conservation of Nature Red List (Croxall et al. 2005). Not only might individual albatrosses forage within the exclusive economic zones (200 nautical mile limit) of different nations, but also within international, high-seas regions outside national jurisdictions where vessels from many nations fish unregulated at times.

While this conservation challenge is far from solved, significant progress has been made during the past decade. Researchers have worked with the fishing industry to develop methods to prevent seabirds from attacking baited hooks while being deployed near the vessel. These include streamer lines that scare birds away from the baited hooks when they are near the water surface and additional weight added to lines that causes them to sink more rapidly (Dietrich et al. 2008; Melvin et al. 2001; Robertson et al. 2006).

Because methodologies for various fisheries are so diverse, no one solution works in all situations; therefore, it is important that a 'toolbox' of options are available to the fishing industry (Melvin and Parrish 2001). For example, national governments and regional fishery management organizations have enacted, through binding agreements such as ACAP (Agreement on the Conservation of Albatrosses and Petrels) and CCAMLR (Convention on the Conservation of Antarctic Marine Living Resources), (1) regulations on the discharge of fish bycatch and fish waste that attracts birds to fishing vessels, (2) area or seasonal closures, and (3) regulations that limit vessels to fishing only at night when some seabird species are less active. Night-setting, however, can increase the undesirable bycatch of other marine life, including sharks, thereby having unintended ecological consequences. Non-governmental organizations, such as BirdLife International, also have initiated multinational, grassroots programs (e.g., Save the Albatross Campaign) to work with fishers to implement measures proven to reduce seabird bycatch across a range of fisheries from local and artisanal to regional and industrial.

## 8.4 Lessons Learned

Throughout this chapter we have provided numerous examples of the transboundary nature of seabird ecology. In a basic sense, seabirds exemplify the transboundary concept because they require both terrestrial and marine habitats. Therefore, wherever conservation of seabirds or the management of their populations is the goal, consideration must be given to ecosystem dynamics on land and at sea. Because the jurisdiction of agencies does not cross the land-sea boundary in the same manner as the seabirds they are managing, these efforts are facilitated by multi-agency communication and collaboration.

From coastal species to ocean wanderers, seabirds traverse ecological and political boundaries on a regular basis and with a frequency and magnitude that is relatively unique among wildlife. Research and the technology underlying these efforts have evolved over the decades to address this unique aspect of seabird ecology as has the thinking of scientists. Many of the examples provided above have benefitted from an interdisciplinary approach to research that includes team members with expertise not just in wildlife but from a wide range of other disciplines, including chemists who understand contaminant transport, fisheries biologists who understand population dynamics of seabird prey, oceanographers and atmospheric scientists who understand ocean circulation and wind patterns, and engineers who can design microelectronic devices that allow the movements of individuals to be tracked across ocean basins for years at a time. Addressing complex ecological questions and improving our understanding of the complex systems we study are benefited by collaborative, cross-disciplinary research teams including such expertise as seabird biologists, fisheries biologists, and oceanographers.

Many seabirds live in remote places that are difficult for researchers to access. As such, knowledge of even basic distributions and status can be lacking, although the need for such data can be critical when attempting to understand seabird ecology and how changes to the land or sea environment might affect a species or site. Therefore, basic inventories of the occurrence and distribution of seabirds both at sea and at breeding sites continue to be important undertakings. For example, a recent inventory of breeding seabirds in the Caribbean makes available, for the first time, a comprehensive, island-by-island review of seabird occurrence in that region (Bradley and Norton 2009).

Seabirds exemplify a suite of wildlife that, throughout their daily, seasonal, and annual cycles, cross multiple ecological and political boundaries. The examples we have provided demonstrate that research, management, conservation, and policy efforts focused on these species often include a transboundary approach and often consider natural and anthropogenic stressors in marine and terrestrial systems that function at multiple scales in both time and three-dimensional space. Many other examples of the ecoregional and transboundary nature of seabird ecology exist that we did not cover here, including eradicating and preventing the reintroduction of exotic predators on terrestrial breeding areas (Keitt et al. 2002; VanderWerf et al. 2007) and managing direct competition for prey species between seabirds and humans via commercial fisheries extraction (Wanless et al. 2007). These and all of the examples we have discussed demonstrate that, by their very nature and by the nature of the systems that they must function within, seabirds embody the complexity of wildlife ecology and conservation in the twenty-first century.

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