

GLOBAL SEABIRD POPULATIONS AND THEIR FOOD CONSUMPTION¹

Michelle Paleczny,^a Vasiliki Karpouzi,^a
Edd Hammill,^b and Daniel Pauly^a

^a*Sea Around Us*, University of British
Columbia, Vancouver, BC, Canada

^bSpatial Community Ecology Laboratory,
Utah State University, Logan, UT

Seabirds share the oceans with us, and they are strongly affected by fisheries both directly (e.g., as by-kills of longline fisheries) and indirectly, because fisheries reduce the abundance of their fish prey below crucial thresholds (Cury et al. 2011). Because they globally consume millions of tonnes of fish and marine invertebrates per year, seabirds play an integral role in the structure, function, and resilience of marine ecosystems. In this, they are similar to marine mammals, for which culling is often proposed, so we will have more fish to catch (Gerber et al. 2009; Morissette et al. 2012), or implemented (Pannoizzo 2013), although at a smaller scale (see Hays 2015).

Because of seabirds' role in the functioning of marine ecosystems, the *Sea Around Us* has taken an early interest in mapping their worldwide distributions, such that they could be considered in global modeling efforts of the sort discussed in Christensen et al. (2009) and chapter 9. The first such product was the preliminary maps of Karpouzi et al. (2007), which came with a database of the estimates of abundance through time and the body sizes and diet compositions of 351 species of "seabirds" (Karpouzi 2005), now incorporated in SeaLifeBase (see www.sealifebase.org).

This database, which was used for a number of contributions on seabirds and their roles in marine ecosystems (Kaschner et al. 2006; Karpouzi and Pauly 2008), was extended by Paleczny (2012), and the number of species covered was reduced to true seabirds (i.e., benthic feeding ducks, scoters, eiders, and mergansers with little potential for overlap with fisheries were not considered further). Moreover, two distribution range maps (breeding and nonbreeding, i.e., foraging ranges) were generated for each of these 324 remaining species (see figure 11.1 for examples) and were then used to generate the global maps in this chapter and other products (Coll et al. 2012; Cheung et al. 2012; Paleczny and Pauly 2011).

SEABIRD BIODIVERSITY AND ECOLOGY

Seabirds are birds that have evolved to forage in the ocean but nest in colonies on islands and coastal cliffs. Brooke (2004) estimated 309 species of seabirds to have a cumulative population of 0.7 billion, and Paleczny (2012) estimated the current global seabird population at 0.77 billion (table 11.1). These populations belong to approximately 324 species (approximate because of recent taxonomic revisions, e.g., Rains et al. 2011), and four orders, Procellariiformes (i.e., petrels, diving petrels, storm petrels, and albatrosses), Charadriiformes (i.e., auks, terns, gulls, and skuas), Sphenisciformes (penguins), and Pelecaniformes (boobies, cormorants, frigatebirds, pelicans, and tropicbirds). Seabirds are unique among avian taxa for their relatively

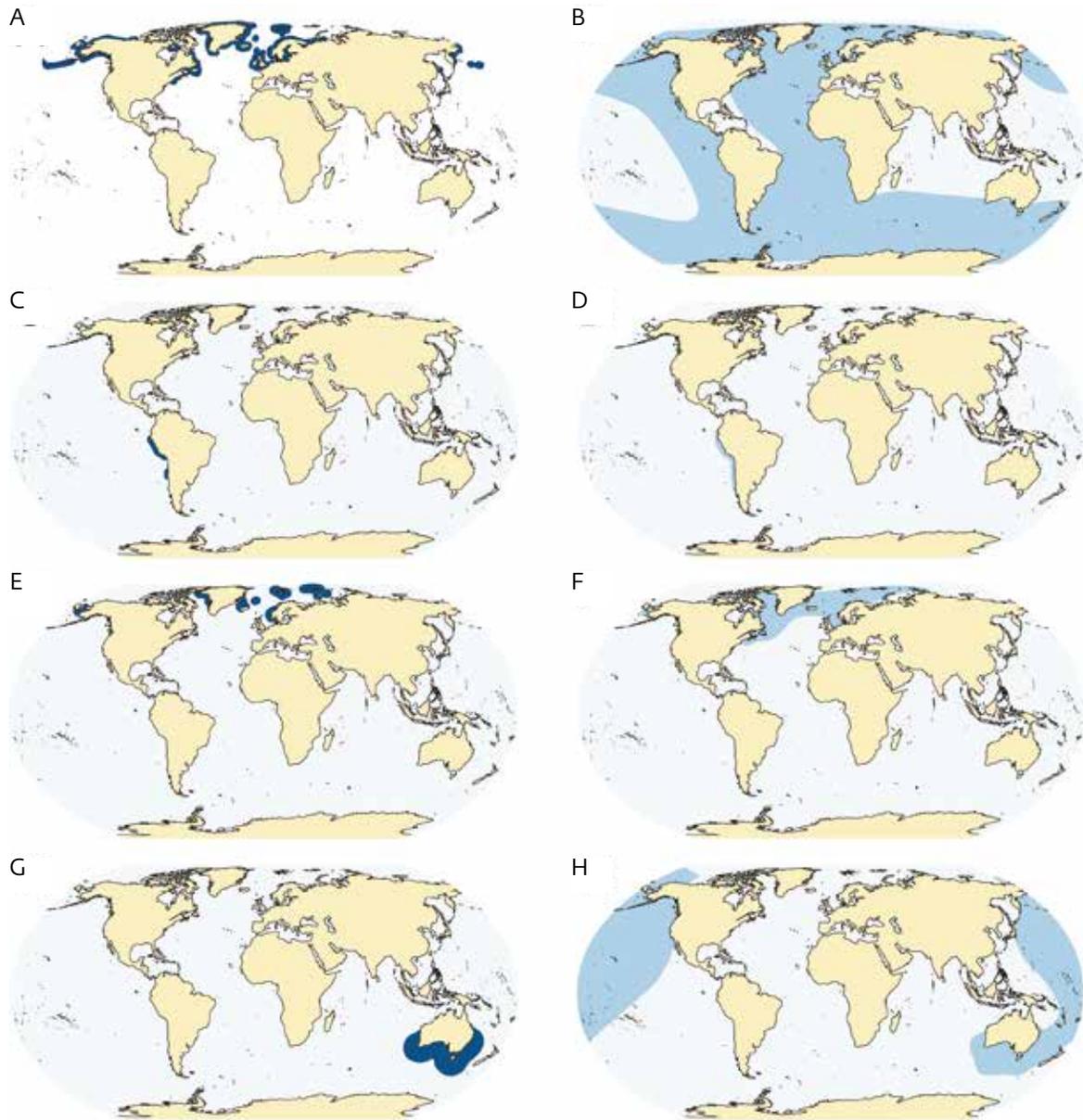


Figure 11.1. Examples of breeding season range (left) and total range (right) for four species of seabirds: (A, B) Arctic tern (*Sterna paradisaea*); (C, D) Peruvian booby (*Sula variegata*); (E, F) dovekie (*Alle alle*); and (G, H) short-tail shearwater (*Ardenna tenuirostris*). The breeding season ranges are estimated based on the maximum observed foraging radius from the colonies, and the foraging ranges are adapted from expert-derived range maps. (Adapted from Egevang et al. 2010; Gaston et al. 1998; Harrison 1987; Poole 2005.)

K-selected life history strategy (i.e., large body size, low population growth rate, and long lifespan) and ability to travel long distances to forage for prey (up to thousands of kilometers per foraging trip in some species). Jointly, the distribution of these 324 species covers the world's oceans, with species richness being highest in productive regions, particularly in the southern hemisphere (figure 11.2). The greater seabird endemism in the southern

hemisphere may be a consequence of spatial isolation between breeding populations, as the distances between islands and continents supporting seabird colonies are greater than in the northern hemisphere.

The main prey of seabirds are krill, fish, and squid, and less commonly benthic crustaceans, other seabirds, marine mammal carrion, and jellyfish (see chapter 10). The relative importance of these diet items varies

Table 11.1. Minimum estimate of seabird population changes, 1950–2010 (from Paleczny 2012).

Family	Numbers (10 ³) in year closest to 1950	Numbers (10 ³) in year closest to 2010	Percentage remaining
Spheniscidae	102,397	65,283	64
Diomedeidae	5,498	5,170	94
Procellariidae	390,382	287,877	74
Hydrobatidae	32,695	46,065	141
Pelecanoididae	60,954	47,933	79
Phaethontidae	228	214	94
Pelecanidae	730	508	70
Phalacrocoracidae	17,945	6,082	34
Fregatidae	1,037	534	52
Sulidae	6,564	6,950	106
Stercorariidae	1,281	1,224	96
Laridae	39,957	34,779	87
Sternidae	139,430	53,797	39
Alcidae	196,787	212,058	108
Total	995,887	768,472	77

between seabird taxa, as well as regionally and seasonally. For example, seabirds may switch diets between breeding and nonbreeding season, with adults commonly provisioning high energy–density prey (e.g., forage fish) to their chicks. Seabirds are also prey in marine and coastal ecosystems, consumed by a variety of marine mammals (e.g., seals, sea lions,

walrus, sea otters, killer whales, polar bears), sharks, coastal birds of prey (e.g., hawks, eagles), and other seabirds (see Hipfner et al. 2012). Seabirds share symbiotic foraging interactions with other marine fauna; for example, temperate foraging auks have mutualistic relationships with marine mammals (e.g., Anderwald et al. 2011), and most tropical sea-

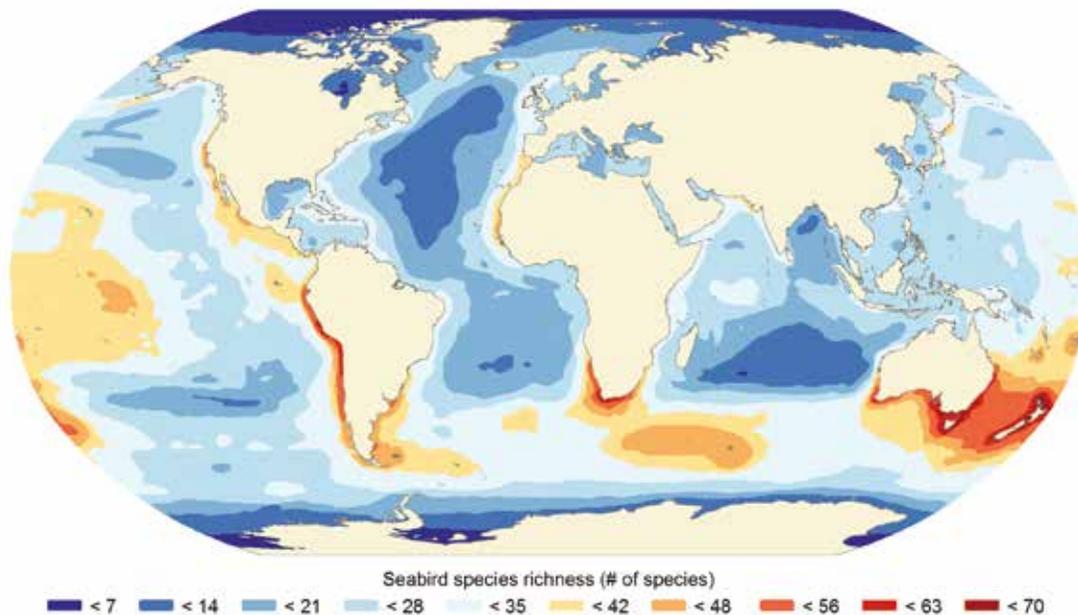


Figure 11.2. Global seabird species richness, as constructed using maps of total range (as in figure 11.1) for each of the world's 324 seabird species.

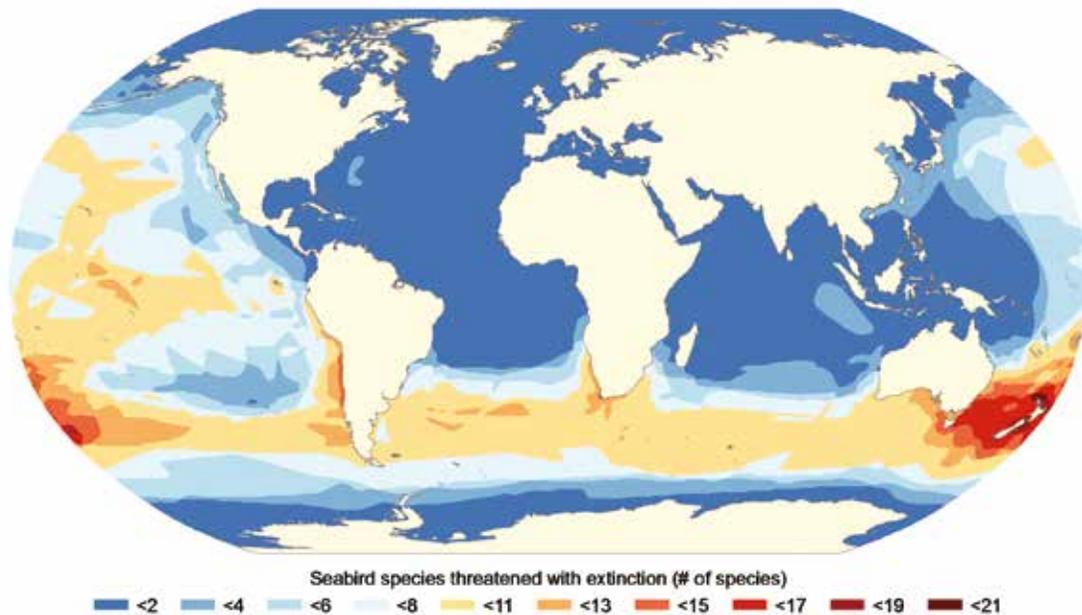


Figure 11.3. Seabird species considered threatened and on the IUCN Red List (IUCN 2012) (i.e., Vulnerable, Endangered, or Critically Endangered). Map constructed using foraging (nonbreeding) season range maps.

birds forage commensally with dolphins and tunas (Ballance and Pitman 1999). Seabirds are also important cross-ecosystem nutrient subsidizers, transporting nutrients via their guano to their breeding colonies, where they play a major role in enriching the productivity and biodiversity of the terrestrial and marine ecosystems surrounding their colonies (Croll et al. 2005). Because of their charismatic nature and accessibility at terrestrial breeding colonies, seabirds provide additional ecosystem services such as opportunities for wildlife interactions and ecotourism (Lewis et al. 2012) and opportunities to monitor change in marine ecosystems (Piatt et al. 2007), including fisheries-induced changes (Einoder 2009).

Seabird populations are threatened by humans, however (figure 11.3). Throughout history, we have depleted seabird populations by hunting seabirds for their feathers, meat, and oil and introducing previously absent predators to colonies (Croxall et al. 1984; Roberts 2007). More recently, in the modern industrial era, humans additionally threaten seabirds through coastal development, pollution, climate change, and fisheries (Croxall et al. 2012) and even through renewed targeted commercial harvesting for food (Grémillet et

al. 2015). Seabird populations are particularly vulnerable to these threats because they have inherently low reproductive output and therefore slow population recovery rates (Russell 1999). Also, they range over large areas, which increases their probability of exposure to spatially heterogeneous anthropogenic threats (Jodice and Suryan 2010).

SEABIRDS AND FISHERIES

Fisheries are one of the greatest modern anthropogenic threats, affecting seabirds in numerous ways, of which the most threatening are as follows: Fisheries deplete the abundance or availability of seabird prey (i.e., forage fish, squid, krill); fishing gear (e.g., longlines, gillnets, and trawl nets) catch and kill seabirds as incidental bycatch; and fisheries deplete the abundance of predatory fish (e.g., tunas) with which many tropical seabirds forage commensally (Furness 2003; Wagner and Boersma 2011; Zydulis et al. 2009). Quantification of overall fisheries-induced seabird mortality is challenging because of a lack of reporting. However, fisheries-induced prey depletion has been associated with seabird breeding failures or population declines in most ecosystems supporting major forage fish

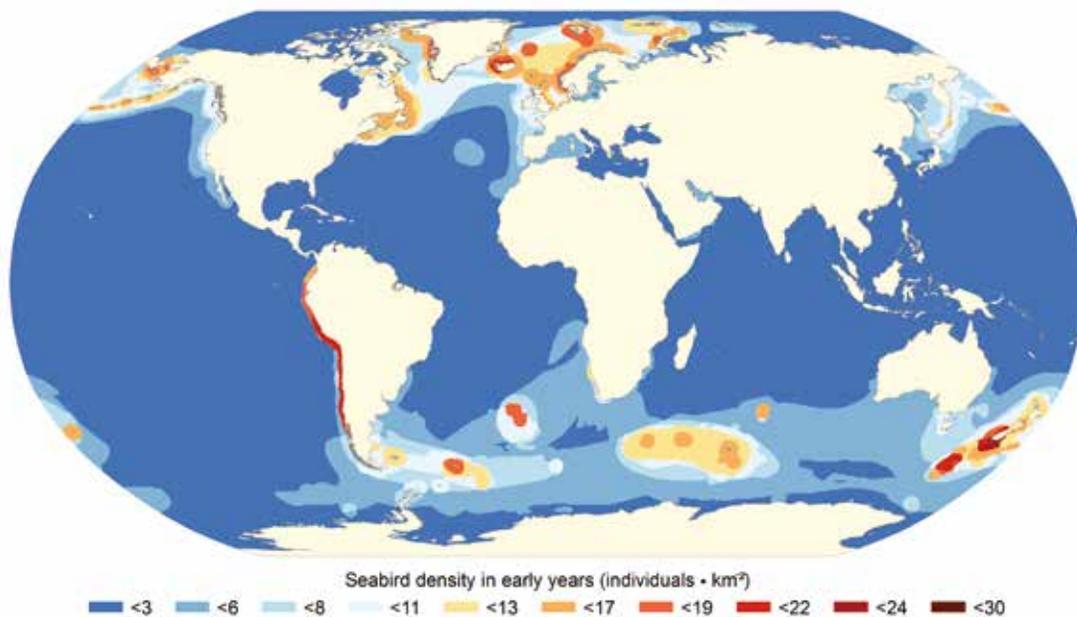


Figure 11.4. Global seabird density in the 1970s and 1980s. This map was constructed using the earliest available population size estimates for each of the world's 324 seabird species, mostly around 1980 (Palczny 2012), converted to density by assuming that a breeding population of 70% of the total population is distributed evenly within the breeding season range for the duration of the breeding season and within the total range for the duration of the nonbreeding season, and a nonbreeding population of 30% of the total population is distributed evenly within the total range for the entire year.

fisheries (Montevecchi 2002), and hundreds of thousands of seabirds per year are reportedly killed as fisheries bycatch (Anderson et al. 2011; Moore and Zydalis 2008).

The effect of these various factors is that current seabird populations are depleted from their historical baseline, with data suggesting that the monitored portion of the global seabird population has declined by approximately 70% between 1950 and 2010 (Palczny et al. 2015), with eleven of the fourteen seabird families experiencing a net decline (table 11.1). Additional but unquantified seabird declines occurred before seabird population monitoring, both before and during the modern industrial era. For example, hunting and introduced predators before population monitoring are estimated to have reduced tropical seabird populations to 1/100–1/1,000 of their historical abundance (Steadman 1997). According to the Red List of the International Union for Conservation of Nature (IUCN), one third of the world's seabird species are considered threatened with extinction and one half are known or suspected to be declining (Croxall et al. 2012).

Seabirds forage during the breeding season, within a few to thousands of kilometers from their breeding colonies, depending on the species. During the nonbreeding season, most seabirds (i.e., 220 of 324 species; Cox 2010) disperse or migrate to occupy larger foraging ranges (example in figure 11.1). The distribution of seabirds at sea generally reflects prey availability at large spatial scales (Shealer 2002). Globally, seabirds reach their highest densities in upwelling areas (i.e., Humboldt Current, Benguela Current, Eastern New Zealand) and in the northern and southern temperate regions (figure 11.4); these are regions that correspond to high ocean productivity (Longhurst et al. 1995).

Global maps of observed seabird population changes (figure 11.5) indicate that seabird density has declined over about 90% of the world's marine surface area, especially in the southern temperate regions, with stable populations observed only in some regions of the northern hemisphere. This pattern resembles the global distribution of seabird species threatened with extinction (figure 11.3).

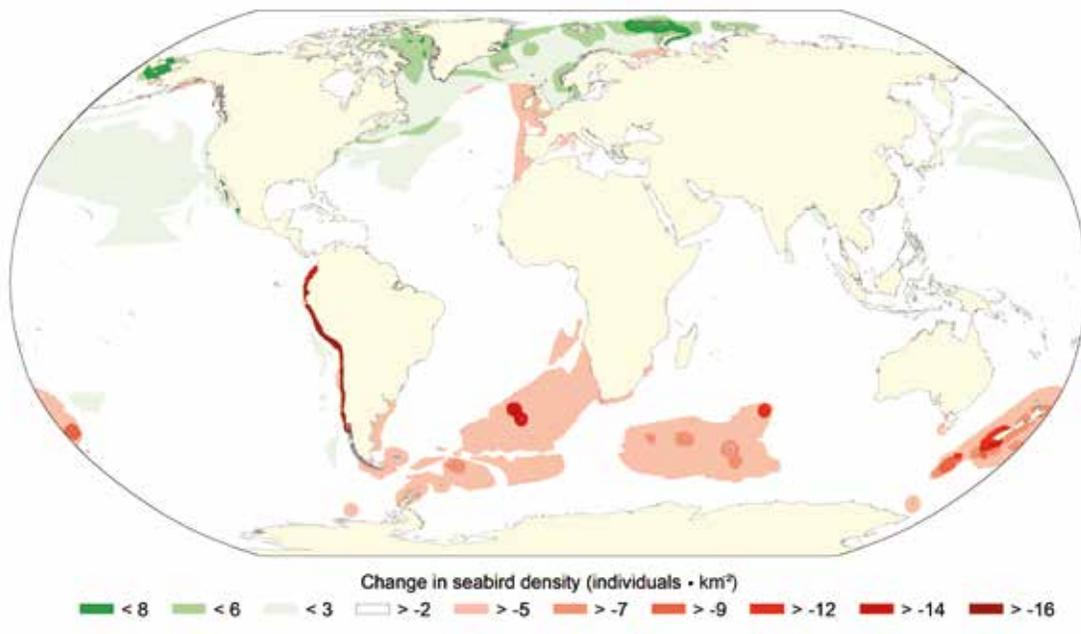


Figure 11.5. Observed change in global seabird density. Map constructed using the difference in density estimated using earliest and latest available population size records for each of the world's 324 seabird species (spanning an average of 16 years, and available for 86% of the global seabird population). The method used for figure 11.4 was used to estimate density.

When interpreting these observed patterns, one needs to consider that the overwhelming majority of initial estimates of seabird population size were made after the 1970s, and therefore population changes before and during the early modern industrial era are not captured by these maps. Thus, the northern hemisphere and the tropics (Roberts 2007) will have a low seabird baseline abundance. Observed increases in seabird populations in parts of the northern hemisphere can reflect population recovery after intense commercial hunting for feathers and oil (Colyer 2000; Grandgeorge et al. 2008), nesting habitat restoration projects (e.g., predator removal; Jones and Kress 2011), or higher availability to seabirds of fisheries discards as food (Kelleher 2005). Furthermore, early unobserved seabird population declines in the northern hemisphere may explain the low seabird density in some productive regions in the northern hemisphere, such as the California and Canary Currents (figure 11.4).

On the other hand, observed seabird declines in the southern hemisphere may best be explained by the southward expansion of fisheries since the 1970s (Swartz et al. 2010), within a period of increasing seabird popu-

lation monitoring. Major fisheries-related threats in the southern hemisphere include bycatch by pelagic longlines (Anderson et al. 2011) and competition with the purse seine fisheries for Peruvian anchoveta (*Engraulis ringens*) and other forage fish fisheries in the Humboldt Current (see contributions in Pauly and Tsukayama 1987; Pikitch et al. 2014). There is also considerable evidence that climate change is contributing to widespread seabird population changes in the Antarctic (Croxford et al. 2002), notably affecting penguins (Forcada and Trathan 2009).

Mapping global seabird density and changes therein is inevitably limited by assumptions about seabird distribution, because plotting direct seabird observations is not possible at the global scale or over decades. Although these maps do account for the difference in seabird density (and hence prey consumption) between breeding and foraging areas, it is probable that they underestimate the importance of some foraging hotspots (e.g., shelf edges, frontal zones). However, it is impossible to accurately predict the locations of these foraging hotspots for all seabird species, given that the spatial distribution of

Table 11.2. Estimated food consumption per seabird family (t/year·10³) of 5 prey types in early and recent years. Annual consumption per family was calculated as the average contribution of diet items (based on all available diet data per species) to the estimated annual food intake per species (calculated using breeding and nonbreeding season duration and daily food intake as a function of the mean individuals in each species; Karpouzi 2005). The underlying data are maintained by and available from the *Sea Around Us*.

Order	Family	Estimated annual food consumption (t/year·10 ³) in early years/ in recent years					
		Krill, plankton	Other fish	Forage fish	Squid	Other ^a	Total
Charadrii- formes	Stercorariidae (skuas)	5/5	47/47	52/52	0/0	69/69	173/173
	Laridae (gulls)	419/389	1,394/1,295	2,070/ 1,923	167/155	867/805	4,917/4,567
	Sternidae (terns)	508/191	3,331/1,253	1,297/488	468/176	458/172	6,062/2,280
	Alcidae (auks)	2,906/ 2,494	3,869/ 3,320	7,389/ 6,341	479/411	202/174	14,845/ 12,740
Pelecani- formes	Pelecanidae (pelicans)	0/0	78/63	172/139	0/0	0/0	250/202
	Phaethontidae (tropicbirds)	0/0	11/10	6/6	3/3	0/0	20/19
	Sulidae (boobies)	0/0	467/560	564/677	50/60	1/1	1,082/1,298
	Phalacrocoracidae (cormorants)	6/2	1,888/680	1,172/422	34/12	68/25	3,168/1,141
	Fregatidae (frigatebirds)	1/1	91/48	65/34	40/21	0/0	197/104
Procellarii- formes	Procellariidae (petrels)	10,402/ 7,421	8,082/ 5,765	651/464	5,597/3,993	4,371/3,118	29,103/ 20,761
	Hydrobatidae (storm petrels)	199/270	202/274	8/11	49/67	19/26	477/648
	Diomedidae (albatrosses)	158/142	684/614	36/32	715/641	158/142	1,751/1,571
	Pelecanoididae (diving petrels)	2,403/ 1,899	96/76	19/15	0/0	41/33	2,559/2,023
Sphenisci- formes	Spheniscidae (penguins)	20,788/ 14,474	13,558/ 9,440	1,869/1,301	2,528/1,760	551/384	39,294/ 27,359
Total		37,795/ 27,288	33,798/ 23,445	15,370/ 11,905	10,130/ 7,299	6,805/ 4,948	103,898/ 74,886

^aIncludes benthic crustaceans, other seabirds.

seabird foraging, especially at smaller spatial scales, varies seasonally and interannually (Weimerskirch 2007). Thus, the present maps were constructed using robust estimates of per species density, suitable for assessing large-scale patterns in seabird density and changes therein, but not more.

GLOBAL PREY CONSUMPTION BY SEABIRDS

The global consumption of prey by seabirds is estimated to have declined from approx-

imately 104 million t/year in the 1970s and 1980s (figure 11.6) to 75 million t/year in 1990s and 2000s (see also table 11.2). Our modern estimate of global prey consumption is comparable to a previous but less detailed estimate of 70 million t/year (Brooke 2004), which it thus confirms. For comparison, it is estimated that the global marine mammal population consumes 168 million t/year (Kaschner et al. 2006).

The order of importance of prey types was consistent between early and recent years.

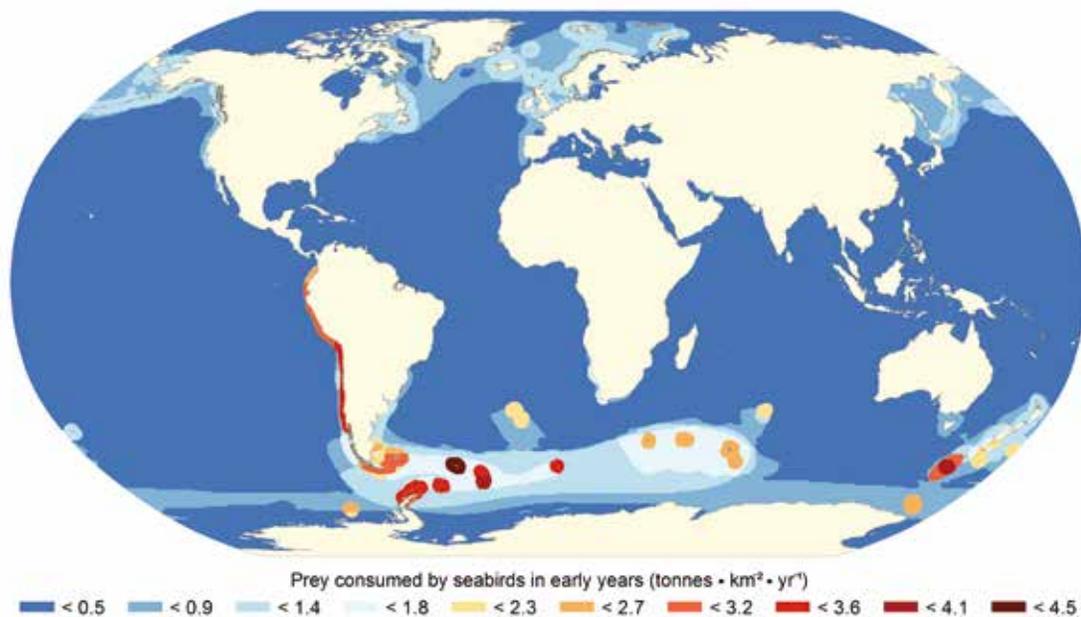


Figure 11.6. Annual food consumption by the global seabird population around the late 1970s and early 1980s. Map constructed using per species estimates of breeding and nonbreeding season density (from figure 11.5), multiplied by the daily food intake, estimated separately for the breeding and nonbreeding seasons.

Ordered from highest to lowest contribution to overall biomass, prey consumed were krill, fish, squid, and other diet items (table 11.2). Forage fish, an important commercial fish group, were estimated to make up 15%–16% (by mass) of all food consumed by seabirds and 31%–34% of the fish consumed by seabirds. It is important to note that although forage fish constitute a small percentage of the global food consumption by seabirds, they are of particular importance to the productivity of seabirds in upwelling ecosystems around the world (Cury et al. 2011).

Seabird prey consumption was historically highest in the temperate and upwelling regions, especially the Humboldt Current off Peru (figure 11.6) and where they declined most severely, mirroring the spatial distribution of global seabird population changes in figure 11.5.

It is important when interpreting these global estimates of prey consumption to be aware that food composition data are often biased toward the breeding season diet of seabirds, which may cause overestimation of the importance of fish in the diets of seabirds. On the other hand, calculating the relative

contribution of diet items using fixed diet compositions does not account for the long-term change in seabird diets that has been observed in some seabirds as a result of long-term ecosystem changes, such as a decline in the trophic level of some species (Becker and Beissinger 2006).

The primary production required (PPR) to support seabirds changed from $0.79 \cdot 10^9$ t/year in the 1970s and 1980s to $0.63 \cdot 10^9$ t/year in the 1990s and 2000s, both estimates corresponding to approximately 1% of annual marine primary production. This is far less than the annual marine PPR to support marine fisheries, estimated at 8% by Pauly and Christensen (1995). Moreover, this estimate, being based on officially reported catch data (and not reconstructed total catches), probably underestimated the PPR of fisheries. This could make the actual PPR of seabirds' food consumption one order of magnitude smaller than that of fisheries catches. Such a result was to be expected: Although seabirds and marine fisheries take roughly similar amounts of biomass from the world's oceans, seabirds target much lower trophic levels than most fisheries.

CONCLUSIONS

This chapter demonstrates the spatial distribution of seabird density and food consumption, and their observed changes. Thus, it points to the potential effects of seabird decline on the marine ecosystems in which seabirds have strong effects on energy and nutrient fluxes. This summary of observed global seabird changes highlights the global importance of ecosystem-based management to protect seabirds and highlights key areas for seabird conservation, such as the temperate and upwelling regions of the southern hemisphere. Also, the spatially ubiquitous nature of global seabird decline lends support to the call for a large-scale approach to seabird conservation (Croxall et al. 2012; Jodice and Suryan 2010), and precautionary management in data-poor situations, an approach recommended for managing wildlife with uncertain population trends and uncertain or uncontrollable threats (Lauck et al. 1998). Marine no-take zones are a key large-scale and precautionary approach to seabird conservation and population recovery (Pichegru

et al. 2010), protecting seabirds from direct and indirect fisheries-related threats and allowing sufficient prey to increase seabird productivity and in turn buffer additional mortality caused by other growing threats (e.g., pollution, coastal development, climate change).

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REFERENCES

- Anderson, O. R. J., C. J. Small, J. P. Croxall, E. K. Dunn, B. J. Sullivan, O. Yates, and A. Black. 2011. Global seabird bycatch in longline fisheries. *Endangered Species Research* 14: 91–106.
- Anderwald, P., P. G. H. Evans, L. Gygax, and A. R. Hoelzel. 2011. Role of feeding strategies in seabird–minke whale associations. *Marine Ecology Progress Series* 424: 219–227.
- Ballance, L. T., and R. L. Pitman. 1999. Foraging ecology of tropical seabirds. Pp. 2057–2071 in N. J. Adams and R. H. Slotow (eds.), *Proceedings from the 22nd International Ornithology Congress, Johannesburg*.
- Becker, B. H., and S. R. Beissinger. 2006. Centennial decline in the trophic level of an endangered seabird after fisheries decline. *Conservation Biology* 20: 470–479.
- Brooke, M. L. D. 2004. The food consumption of the world's seabirds. *Proceedings of the Royal Society of London. Series B: Biological Sciences* 271(suppl 4): S246–S248.
- Cheung, W. W. L., D. Zeller, M. L. D. Palomares, D. Al-Abdulrazzak, L. Brotz, V. W. Y. Lam, M. Paleczny, and D. Pauly. 2012. *A preliminary assessment of climate change impacts on marine ecosystems and fisheries of the Arabian Gulf*. A Report to the Climate Change Research Group/LLC.
- Christensen, V., C. J. Walters, R. Ahrens, J. Alder, J. Buszowski, L. B. Christensen, W. W. L. Cheung, J. Dunne, R. Froese, V. Karpouzi, K. Kaschner, K. Kearney, S. Lai, V. Lam, M. L. D. Palomares, A. Peters-Mason, C. Piroddi, J. L. Sarmiento, J. Steenbeek, U. R. Sumaila, R. Watson, D. Zeller, and D. Pauly. 2009. Database-driven models of the world's Large Marine Ecosystems. *Ecological Modelling* 220: 1984–1996.
- Coll, M., C. Piroddi, C. Albouy, F. Ben Rais Lasram, W. W. L. Cheung, V. Christensen, V. S. Karpouzi, F. Guilhaumon, D. Mouillot, M. Paleczny, M. L. D. Palomares, D. Pauly, J. Steenbeek, P. Trujillo, and R. Watson. 2012. The Mediterranean Sea under siege: spatial overlap between marine biodiversity, cumulative threats and marine reserves. *Global Ecology and Biogeography* 21(4): 465–480.
- Colyer, R. J. M. 2000. Feathered women and persecuted birds: the struggle against the plumage trade c. 1860–1922. *Rural History* 11: 57–73.
- Cox, G. W. 2010. *Bird Migration and Global Change*. Island Press, Washington, DC.
- Croll, D. A., J. L. Maron, J. A. Estes, E. M. Danner, and G. V. Byrd. 2005. Introduced predators transform subarctic islands from grassland to tundra. *Science* 307: 1959–1961.
- Croxall, J. P., S. H. M. Butchart, B. Lascelles, A. J. Stattersfield, B. Sullivan, A. Symes, and P. Taylor. 2012. Seabird conservation status, threats and priority actions: a global assessment. *Bird Conservation International* 22: 1–34.
- Croxall, J. P., P. G. H. Evans, and E. A. Schreiber (eds.). 1984. *Status and Conservation of the World's Seabirds*. Paston Press, Cambridge, England.
- Croxall, J., P. Trathan, and E. Murphy. 2002. Environmental change and Antarctic seabird populations. *Science* 297: 1510–1514.
- Cury, P. M., I. L. Boyd, S. Bonhommeau, T. Anker-Nilssen, R. J. M. Crawford, R. W. Furness, J. A. Mills, E. J. Murphy, H. Osterblom, M. Paleczny, J. F. Piatt, J.-P. Roux, L. Shannon, and W. J. Sydeman. 2011. Global seabird response to forage fish depletion: one-third for the birds. *Science* 334: 1703–1706.
- Egevang, C., I. J. Stenhouse, R. A. Phillips, A. Petersen, J. W. Fox, J. R. D. Silk. 2010. Tracking of Arctic terns *Sterna paradisaea* reveals longest animal migration. *Proceedings of the National Academy of Sciences of the United States of America* 107: 2078–2081.
- Einoder, L. D. 2009. A review of the use of seabirds as indicators in fisheries and ecosystem management. *Fisheries Research* 95: 6–13.
- Forcada, J., and P. N. Trathan. 2009. Penguin responses to climate change in the Southern Ocean. *Global Change Biology* 15(7): 1618–1630.
- Furness, R. W. 2003. Impacts of fisheries on seabird communities. *Scientia Marina* 67: 33–45.

- Gaston, A. J., I. L. Jones, and I. Lewington. 1998. *The Auks: Alcidae*. Oxford University Press, Oxford, England.
- Gerber, L., L. Morissette, K. Kaschner, and D. Pauly. 2009. Should whales be culled to increase fishery yields? *Science* 323: 880–881.
- Grandgeorge, M., S. Wanless, T. Dunn, E. Timothy, M. Maumy, G. Beaugrand, and D. Gremillet. 2008. Resilience of the British and Irish seabird community in the twentieth century. *Aquatic Biology* 4(2): 187–199.
- Grémillet, D., C. Peron, P. Provost, and A. Lescroel. 2015. Adult and juvenile European seabirds at risk from marine plundering off West Africa. *Biological Conservation* 182: 143–147.
- Harrison, P. 1987. *Seabirds of the World: A Photographic Guide*. Princeton University Press, Princeton, NJ.
- Hays, B. 2015. *Corps of Engineers to cull Oregon cormorants preying on endangered salmon*. Available at http://www.upi.com/Science_News/2015/02/09/Corps-of-Engineers-to-cull-Oregon-cormorants-preying-on-endangered-salmon/4501423520633/. Accessed April 19, 2015.
- Hipfner, M. J., L. K. Blight, R. W. Lowe, S. I. Wilhelm, G. J. Robertson, R. T. Barrett, T. Anker-Nilssen, and T. P. Good. 2012. Unintended consequences: how the recovery of sea eagle *Haliaeetus* spp. populations in the northern hemisphere is affecting seabirds. *Marine Ornithology* 40: 39–52.
- IUCN. 2012. International Union for Conservation of Nature Red List of Threatened Species, Version 2012.2: www.iucnredlist.org.
- Jodice, P. G. R., and R. M. Suryan. 2010. The transboundary nature of seabird ecology. Pp. 139–165 in S. C. Trombulak and R. F. Baldwin (eds.), *Landscape-Scale Conservation Planning*. Springer, Amsterdam, the Netherlands.
- Jones, H. P., and S. W. Kress. 2011. A review of the world's active seabird restoration projects. *The Journal of Wildlife Management* 76: 2–9.
- Karpouzi, V. 2005. *Modelling and mapping trophic overlap between fisheries and the world's seabirds*. Department of Zoology, University of British Columbia, Vancouver, BC.
- Karpouzi, V. S., and D. Pauly. 2008. A framework for evaluating national seabird conservation efforts. Pp. 62–70 in J. Alder and D. Pauly (eds.), *A comparative assessment of biodiversity, fisheries and aquaculture in 53 countries' Exclusive Economic Zones*. Fisheries Centre Research Reports 16(7), University of British Columbia, Vancouver, Canada.
- Karpouzi, V. S., R. Watson, and D. Pauly. 2007. Modelling and mapping resource overlap between fisheries and seabirds on a global scale: a preliminary assessment. *Marine Ecology Progress Series* 343: 87–99.
- Kaschner, K., V. Karpouzi, R. Watson, and D. Pauly. 2006. Forage fish consumption by marine mammals and seabirds. Pp. 33–46 in J. Alder and D. Pauly (eds.), *On the multiple uses of forage fish: from ecosystems to markets*. Fisheries Centre Research Reports 14(3), University of British Columbia, Vancouver, Canada.
- Kelleher, K. 2005. *Discards in the world's marine fisheries. An update*. FAO Fisheries Technical Paper No. 470, Food and Agriculture Organization, Rome.
- Lauck, T., C. W. Clark, M. Mangel, and G. R. Munro. 1998. Implementing the precautionary principle in fisheries management through marine reserves. *Ecological Applications* 8: S72–S78.
- Lewis, S., J. Turpie, and P. Ryan. 2012. Are African penguins worth saving? The ecotourism value of the Boulders Beach colony. *African Journal of Marine Science* 1–8.
- Longhurst, A., S. Sathyendranath, T. Platt, and C. Caverhill. 1995. An estimate of global primary production in the ocean from satellite radiometer data. *Journal of Plankton Research* 17: 1245–1271.
- Montevecchi, W. A. 2002. Interactions between fisheries and seabirds. Pp. 527–557 in E. A. Schreiber and J. S. Burger (eds.), *Biology of Marine Birds*. CRC Press, Boca Raton, FL.
- Moore, J. E., and R. Zydalis. 2008. Quantifying seabird bycatch: where do we go from here? *Animal Conservation* 11: 257–259.
- Morissette, L., V. Christensen, and D. Pauly. 2012. Marine mammal impacts in exploited

- ecosystems: would large-scale culling benefit fisheries? *PLoS ONE* 7(9): e43966.
- Paleczny, M. 2012. *An analysis of temporal and spatial patterns in global seabird abundance during the modern industrial era, 1950–2010, and the relationship between global seabird decline and marine fisheries catch*. MSc thesis, Department of Zoology, University of British Columbia, Vancouver.
- Paleczny, M., E. Hammill, V. Karpouzi, and D. Pauly. 2015. Population trend of the world's monitored seabirds, 1950–2010. *PLoS ONE* 10(6): e0129342.
- Paleczny, M., and D. Pauly. 2011. Seabirds in Canadian marine ecoregions: distribution and abundance. Pp. 41–46 in W. W. L. Cheung, D. Zeller, and D. Pauly. *Projected species shifts due to climate change in the Canadian Marine Ecoregions*. A report of the Sea Around Us Project to Environment Canada.
- Pannoizzo, L. 2013. *The Devil and the Deep Blue Sea: An Investigation into the Scapegoating of Canada's Grey Seal*. Fernwood Publishing, Black Point, Nova Scotia.
- Pauly, D., and V. Christensen. 1995. Primary production required to sustain global fisheries. *Nature* 374: 255–257.
- Pauly, D., and I. Tsukayama (eds.). 1987. *The Peruvian anchoveta and its upwelling ecosystem: three decades of change*. ICLARM Studies and Reviews 15.
- Piatt, J., W. Sydeman, and F. Wiese. 2007. Introduction: a modern role for seabirds as indicators. *Marine Ecology Progress Series* 352: 199–204.
- Pichegru, D., D. Grémillet, R. J. M. Crawford, and P. G. Ryan. 2010. Marine no-take zone rapidly benefits endangered penguin. *Biology Letters* 6(4): 498–501.
- Pikitch, E. K., K. J. Rountos, T. E. Essington, C. Santora, D. Pauly, R. Watson, U. R. Sumaila, P. D. Boersma, I. L. Boyd, D. O. Conover, P. Cury, S. S. Heppell, E. D. Houde, M. Mangel, É. Plagányi, K. Sainsbury, R. S. Steneck, T. M. Geers, N. Gownaris, and S. B. Munch. 2014. The global contribution of forage fish to marine fisheries and ecosystems. *Fish and Fisheries* 15: 43–64.
- Poole, A. (ed.). 2005. *The Birds of North America Online*. Available at <http://bna.birds.cornell.edu/BNA/>. Cornell Laboratory of Ornithology, Ithaca, NY.
- Rains, D., H. Weimerskirch, and T. M. Burg. 2011. Piecing together the global population puzzle of the wandering albatrosses: genetic analysis of the Amsterdam albatross *Diomedea amsterdamensis*. *Avian Biology* 42: 69–79.
- Roberts, C. 2007. *The Unnatural History of the Sea*. Island Press, Washington, DC.
- Russell, R. W. 1999. Comparative demography and life history tactics of seabirds: implications for conservation and marine monitoring. *American Fisheries Society Symposium* 23: 51–76.
- Shealer, D. 2002. Foraging behavior and food of seabirds. Pp. 137–177 in E. A. Schreiber and J. S. Burger (eds.), *Biology of Marine Birds*. CRC Press, Boca Raton, FL.
- Steadman, D. W. 1997. Extinctions of Polynesian birds: reciprocal impacts of birds and people. Pp. 51–79 in P. V. Kirch and T. L. Hunt (eds.), *Historical Ecology in the Pacific Islands*. Yale University Press, New Haven, CT.
- Swartz, W., E. Sala, S. Tracey, R. Watson, and D. Pauly. 2010. The spatial expansion and ecological footprint of fisheries (1950 to present). *PLoS ONE* 5(12): e15143.
- Wagner, E. L., and P. D. Boersma. 2011. Effects of fisheries on seabird community ecology. *Reviews in Fisheries Science* 19: 157–167.
- Weimerskirch, H. 2007. Are seabirds foraging for unpredictable resources? *Deep Sea Research Part II: Topical Studies in Oceanography* 54: 211–223.
- Zydelis, R., J. Bellebaum, H. Österblom, M. Vete-maa, B. Schirmeister, A. Stipniece, M. Dagys, M. van Eerden, and S. Garthe. 2009. Bycatch in gillnet fisheries: an overlooked threat to waterbird populations. *Biological Conservation* 142: 1269–1281.

NOTE

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