CHAPTER 1

Introduction to the World's Seabirds

Past Knowledge and New Revelations

I remember, at a recent international conference, a seasoned researcher receiving a medal celebrating her distinguished career in seabird research. Her cheeks had the sheen of a farmer's, well-polished and apple-red from exposure to the Scottish wind. She recounted how she had sat atop the islet of Ailsa Craig during her earlier doctoral studies and wondered where the gannets, nesting on that granite lump in the Firth of Clyde, went when they flew beyond the horizon. She had no idea, and nor then did anyone else.

But now, increasingly, they do. Modern electronics are revolutionising our knowledge of the activities of seabirds at sea. Just as mobile phones were unknown 50 years ago and the early clumsy 'bricks' clutched by Gordon Gekko in Wall Street now seem laughable compared to the latest iPhone, so it is with the electronic devices that scientists attach to seabirds. They have become smaller and more sophisticated, and opened up the watery world of seabirds to our fascinated gaze.

Seabirds can be seen in so many circumstances, all of which raise questions. Think of the father and his small son about to start eating their fish and chips on the sea wall at St Ives in Cornwall. Suddenly a Herring Gull swoops and snatches a helping of chips for its tea. The small boy is scared, the father is resigned but curious. Does that gull making its living entirely from pirating holidaymakers?[1] And what does it substitute for chips outside of the holiday season when the esplanade is empty?*

The next day the pair join a local fisherman and head offshore to catch mackerel. Catching mackerel on a handline of colourful flies may not be the most sophisticated angling, but what a thrill for a ten-year-old. The thrill is only compounded when a group of Northern Gannets surrounds the fishing smack and begins to plunge into the water. At the moment of impact, the black tips of their wings are stretched so far back as to extend beyond the tip of the tail. The birds are obviously becoming as streamlined as possible. Not only does this reduce the risk of bodily damage but it also enables them to increase the depth they reach. But do they catch the mackerel on the downward plunge or on the subsequent ascent (the latter, it turns out), and what depth do they reach? How does that depth compare to the depth a penguin attains on a dive lasting some ten times longer?

In the west of Ireland, hard-core birdwatchers barely sleep through a September night. A deep depression, the residue of a Caribbean hurricane, is passing through, rattling the windows of their hut. They will be up at dawn and quickly positioned at the cliff edge, telescopes trained on the horizon. They like nothing better than Joseph Conrad's "westerly weather . . . full of flying clouds, of great big white clouds coming thicker and thicker till they seem to stand welded into a solid canopy."[2] Their

* To share a day in the life of a Dutch seagull as it raids urban back yards, and then takes a dip in the sea, visit https://vimeopro.com/south422/animal-gps-track-animation/video/33587018.

hope is that the westerlies will have blown rare seabirds from further west in the Atlantic towards the Irish coast. These might include Great Shearwaters whose breeding home is the Tristan da Cunha group of islands of the South Atlantic. But the shearwaters passing Ireland are only a minority of the millions heading south at this season. What is the normal route of the shearwaters when they head north from their breeding grounds to spend the northern summer in the North Atlantic and then return south in September? Do they follow the same route north- and southbound, or do their travels take them on some sort of circular loop, the better to exploit prevailing winds? Do they travel continuously when migrating, or stop off for a week or more at oceanic 'oases' where the pickings are particularly good?

Forward a few months to the month of January, to the grey waters off Newfoundland where many Great Shearwaters passed by in late summer. The weather is grim, the nights long. Yet this is a part of the world chosen by many seabirds from Greenland, for example Brünnich's Guillemots, to spend the winter. To catch food, the guillemots dive many metres below the surface. Even in the middle of a winter's day, light levels and hence visibility will be poor at the depths where guillemots catch food. What allows them to succeed, as assuredly they do, and do they feed at night, when the difficulties are presumably still greater?

If guillemots face daunting dives, spare a thought for Emperor Penguins. Once a female has laid and left the male to incubate the egg through the darkness, the blizzards, the numbing –40°C chill of the Antarctic winter, she heads north to seek food in open water. But available light will be very limited, especially at depth and even more so if she dives under floating ice. Catching fish would certainly be easier if the fish (rashly) signalled their presence by flashing lights.

Further north in the Southern Ocean, the westerlies are roaring through the stormy latitudes of the forties and fifties. This is the domain of albatrosses. If there is no wind, they sit becalmed on the water. Flapping is not their forte. But let the wind blow. Let the albatrosses spread their wings and lock them open using a special skeletal mechanism. Then the birds, be they the smaller mollymawks, or the giant Wandering and Royal Albatrosses with a 3.5 m wingspan, can glide. A wind of 50 knots is no buffeting enemy; it is a source of free energy. It helps the birds to cover immense distances and to provide cheer for lonely sailors a thousand miles from land. Despite their ability to bring joy in the midst of emptiness, albatrosses have not always been treated kindly. Little heeding the fate of the Ancient Mariner, nineteenth-century emigrants bound for Australia regularly tormented and killed albatrosses as they traversed the Southern Ocean, as immortalized in Charles Baudelaire's *L'Albatros*. Sailors used the webs of the albatrosses' feet to make tobacco pouches and the wing bones to make pipes. Yet whatever the circumstances of the encounter, the seafarer surely wondered. Where do these albatrosses nest? How do they return home against the unrelenting wind if their outward journey had taken them far downwind? Or do they follow the tactic of the tea clippers and circle the globe, forever chased by the west wind?

North of the albatrosses' home of grey-green productive waters, churned by the wind, lies the blue zone of the subtropics. Look down into the limpid water from a small yacht and fancy that the water is so clear as to allow a peep into the miles-down deep. Yet the water is clear for a reason. It contains few nutrients, such as nitrates, and consequently there is little planktonic growth to cloud the water. Creatures higher up the food chain are correspondingly scarce, and so a day at sea can be overwhelmingly boring for a birdwatcher. A single petrel, the size of a small gull, arcs over the horizon, but the view is too brief to permit discrimination among several rather similar species. And that's it for another day. Even here in the midst of emptiness, the ornithologist wonders: can that lone petrel make a living in these barren waters, the blue water desert, or is it using its power of economical flight to at least seek out regions where the seas are more productive and its prey, small squid, more easily found?

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Perhaps the next logical step in this tale would be to recount how far the traditional observer has taken this story. I am thinking of the seawatcher peering into the storm from a headland or the researcher, stuck unwashed on an island, who unravels the breeding habits of a seabird species with the help of binoculars, notebook and a healthy dollop of scientific intuition. This step must be postponed until I have introduced the *dramatis personae*, the world's seabirds. Among the global total of around 10,000 bird species, the seabirds are the 300–350 species that feed along the coast or out to sea, in some instances thousands of kilometres out to sea.

Luckily, the flippered penguins need little introduction. Ranging in size from the 1.2 kg Little Penguin, about the weight and shape of a magnum bottle of champagne, to the 40 kg Emperor Penguin, the 18 flightless species breed from the Galápagos Islands on the Equator in the north to Antarctica in the far south.[3] All are clad in a tight waterproof plumage that is dark above and white below, a pattern that may be helpful in camouflaging the penguins from their prey. Most colonies are on remote islands but there are exceptions: penguins breed, for example, on mainland South Africa, on New Zealand's South Island, and on Antarctica.

The largest seabird group comprises the tube-nosed birds in the order technically known as the Procellariiformes. This order, containing both highly aerial species that feed at the surface and others that are more or less adept divers, is divided into four families. One family, Diomedeidae, contains the charismatic albatrosses. Most species, 17, are found in the Southern Ocean, and there are another four confined to the North Pacific, while the final species, the Waved Albatross, mostly nests in the Galápagos and feeds off the coast of Peru. All have the long narrow wings that make for efficient gliding and the ability to cover huge distances while spending little energy.

Another worldwide tube-nosed family is the Procellariidae, comprising some 90 mostly mid-sized species. In plumage they are a motley crew; some species are all dark-brown or black, some wholly white, and others dark above and white below, maybe with a distinctive pattern on the underwing.

Within this family is a group of seven species including the fulmars and giant petrels, whose large hook-tipped bill is well able to rip open a seal carcass. These birds nest in the open at higher latitudes where burrow-nesting may not be an option – it is impossible to dig into frozen ground – and so the chick often protects itself by spitting oily vomit at would-be predators.

A

B

C

D

The petrel family named Procellariidae contains a variety of mostly mid-sized species. These include (A) shearwaters exemplified by a Scopoli's Shearwater photographed against the Mediterranean Sea carrying a geolocator device on its leg (© Maties Rebassa), (B) the extremely oceanic gadfly petrels such as Murphy's Petrel of the Pacific (© Michael Brooke), (C) the fulmars and allied species such as the Southern Fulmar (© Richard Phillips), and (D) the prions, a group where the several species look very similar. Illustrated is an Antarctic Prion (© Oliver Krüger).

Then there are the shearwaters, named because their graceful flight intermingles bursts of flapping with glides when the wing tip seems to touch and indeed may touch the water. The species breed – mostly in burrows – in temperate and tropical latitudes both north and south of the Equator.

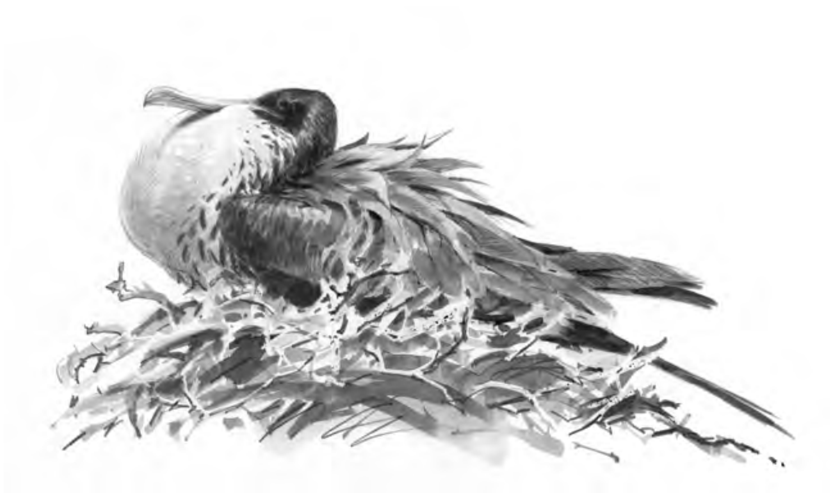
The gadfly petrels, also primarily burrow-nesting, are another large group within the family. Their lively helter-skelter flight includes high arcs that take the bird many metres above the sea. Perhaps the high point of the arc, when the bird is on its side with wings vertical, is an opportunity to spot other petrels that have found food, or a chance to smell food from afar. That food is often squid.

A final group in the family are the prions, quite small and dull grey with flattened bills containing combs that serve to sieve plankton, especially crustacea, from the surface waters. Prions are confined to the Southern Ocean.

Also conspicuously tube-nosed are the storm petrels, now placed in two families, the Oceanitidae of the Southern Hemisphere, and the Hydrobatidae of the Northern. All of the 25 or so species are small, weighing in at between 20 and 70 g, and often black with a stand-out white rump. In other words, the smallest species, the Least Storm Petrel, is outweighed by a skinny House Sparrow. To spot such small birds pitter-pattering on thin legs over the sea surface in the slightly sheltered troughs of a 10 m swell, while the storm flails white spume off the wave crests, is to enjoy a brief respite from seasickness.

Finally, among the tube-nosed birds, the four diving petrel species (traditionally in the Pelecanoididae) are restricted to the Southern Hemisphere. With chubby body and whirring wings, used for underwater propulsion, they are remarkably similar to their northern ecological counterparts, the smaller auks, which will be introduced shortly.

The three gannet species are familiar large white seabirds with black wing tips, 'dipped in ink'. One species dwells in the North Atlantic, another off South Africa, and the third in waters adjoining Australia and New Zealand. While they are essentially temperate in distribution, their close allies, the seven booby species, are tropical. Booby of course also means 'duffer', and boobies never appear the smartest birds on their



The bare-skinned red throat of a male Magnificent Frigatebird is inflated to attract a mate.

beach, especially when showing off their brightly-coloured feet of which they seem unreasonably proud. Gannets and boobies commonly plunge from a height into the sea to feed.

The three tropicbird species are all birds which plunge to catch their prey. They are exclusively (and predictably) tropical and have mainly white plumage, adorned by a pair of spectacularly-long central tail feathers, white in two species and red in the third.

Also tropical are the five frigatebird species which are predominantly black. By way of sexual ornamentation, mature males have red throat pouches that can be inflated to attract females. Since their legs are tiny, frigatebirds are virtually unable to walk, but the reduced undercarriage and the large angular wings mean that their wing loading, the weight of bird supported by each square centimetre of wing surface, is the lowest of all birds. This gives them extreme agility, well displayed when they are chasing other seabirds, forcing them to regurgitate, and then catching the vomited spoils in mid-air before they splat into the sea.

There are about 35 species of cormorant or shag. Because various different species with vernacular names of cormorant and shag are placed in the same scientific genus, it is fair to say that there is no defining difference between the two. Perhaps this is confirmed by the first two lines of Christopher Isherwood's ditty celebrating "The common cormorant (or shag) lays eggs inside a paper bag."[4] With a worldwide distribution, these are familiar dark birds, the size of a small goose. Because of poor waterproofing, they often hang their wings out to dry after a period of swimming which involves dives from the surface to catch food underwater. While most of that food is marine, a handful of cormorant species uses freshwater habitats.

Various pelican species may visit the sea, but only one, the Brown Pelican, is wholly marine. It is a resident of the Atlantic and Pacific coasts of the Americas roughly from the Canadian border south to Venezuela and Peru.

The roughly 100 species of gull and tern are familiar. No wonder. They are extremely widespread, breeding on remote islands in all oceans, mainland coasts and well inland. They are found from the high Arctic (Ivory Gull) to the milder margins of the Antarctic continent (Antarctic Tern). Characteristically long-winged, they tend to be shaded grey above and white below. When at sea, they catch prey at the surface or by plunges that take them to no great depths. This latter habit is particularly the tactic of the terns.

The seven species of skua, all mostly brown in plumage, are allied to the gulls and indeed are gull-like in size and shape. Some species are essentially terrestrial during the breeding season. For example, the Long-tailed Skua (= jaeger) then eats lemmings on the Arctic tundra, and some South Polar Skuas are specialist predators at the colonies of Antarctic seabirds. When not breeding, skuas largely remain at sea. How much of their living is made by piracy of other birds and how much by independent feeding remains uncertain.

The auks are a family of seabirds confined to the Northern Hemisphere, with a stronghold in the North Pacific. The 24 extant species are specialist divers, as was the extinct flightless Great Auk, and they can be thought of as the ecological equivalents of the southern hemisphere penguins. Both groups use their wings (or flippers in the case of penguins) for underwater propulsion when hunting prey, often at remarkable depths (see Chapter 9). However, crucially, the living auk species can all fly as they are distinctly smaller than the penguins, ranging in size from around 85 g (Least Auklet) to 1 kg (Brünnich's Guillemot*).

That almost closes the curtain on the *dramatis personae*. Nevertheless there are other birds that routinely use the sea. Think of them as the courtiers and countryfolk of a Shakespearean cast. They adorn the stage but contribute little to the narrative. All the divers (= loons) and some grebes are marine outside the breeding season. This pattern is followed by a number of ducks, whilst the eider ducks are marine throughout the year. Finally two of the three phalarope species are essentially marine when not breeding and can be seen bobbing cork-like in such places as the Arabian Sea and among the Galápagos Islands. For reasons of convention as much as logic, these species are generally not considered seabirds, and they will make only the briefest appearances in the chapters that follow.

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The introductory pages raised questions about the activities of seabirds as they go about their daily and nightly business in their watery realm. My hope in this book is to describe how far modern gadgetry, much of it electronic, has enabled enthusiastic researchers to answer these questions. Before embarking on this exciting tale of revelation, it is worth recounting quite briefly the sort of information that has been the mainstay of seabird research in the past.

Centuries of observation on land and at sea have yielded a fair picture of how many species of seabird there are. Nonetheless surprises still occur when supposedly extinct species are found to persist and wholly new species are discovered. As recently as 2008 Monteiro's Storm Petrel was described from the Azores, to be followed in 2011 by Bryan's Shearwater from Midway Island in the Hawaiian chain. But these two cases are complicated by the fact that the birds were known in earlier years. Only the availability of new evidence, on timing of breeding, DNA, and fine-grained plumage features has allowed the description of new full species. The most recent, more dramatic, announcement happened in

* Known as Thick-billed Murre in North America

2011 when Peter Harrison, a doyen of seabird identification, announced the discovery of a brand-new species, the Pincoya Storm Petrel, that flits over the fjords of southern Chile.[5] It had escaped the notice of Charles Darwin who had sailed those waters aboard the *Beagle* almost 200 years earlier.

Once the who's who of seabirds has been established, it begins to become possible to establish broad migration patterns. Consider, for example, Great Shearwaters, an 800-gram species whose stronghold is the Tristan da Cunha group of islands in the South Atlantic. There they are harvested by Tristan Islanders, and I can vouch for the superlative chips made from potatoes nurtured in the islanders' potato patches and fried in shearwater fat. It has long been known that the Great Shearwaters appear in force off Newfoundland in the northern summer, and it is obvious they migrate between North and South Atlantic. That leaves unanswered a multitude of questions about the speed and precise route of the journey.

While such simple observations have been a source of knowledge about seabird migrations, surprising gaps have persisted. Atlantic Puffins, much photographed with a beakful of fish at their colonies, all but disappear in the winter despite being one of the most numerous seabirds of the North Atlantic. They must be all at sea somewhere. Conversely Hornby's Storm Petrel, a pale grey sprite found 40–300 km off the coasts of Peru and Chile, is a common bird of the cool waters of the Humboldt Current. American ornithologist Frank Chapman, quoted by Robert Cushman Murphy,[6] the long-serving Curator of Birds at the American Museum of Natural History, describes the petrels on the wing as "the most erratic flier[s] I have ever seen . . . like a bat, swift and nighthawk in one." Young Hornby's Storm Petrels on their first journey from the nest to the sea are regularly attracted to the lights of Chile's northern desert cities, implying the colonies cannot be far away. Yet no-one has ever found a colony of this species, probably the world's commonest seabird whose breeding places are wholly unknown.* Less surprisingly,

* In April 2017, while this book was in press, an active colony of Hornby's Storm Petrel was finally discovered in the Atacama Desert 70 km from the coast. See http://www.redobservadores.cl/equipo-de-la-roc-encuentra-el-primer-sitio-de-nidificacion-de-la-golondrina-de-mar-de-collar (accessed 14 June 1017).

the colonies of several other very rare species have only recently been discovered or remain unknown. A colony of the Chinese Crested Tern was first discovered in 2000, but the species' world population is tiny, perhaps fewer than 100 individuals. MacGillivray's Petrel of the South Pacific may be equally rare. It probably nests somewhere among the Fijian Islands but no-one knows where.

Once the rough picture of the cast of seabird species and their global distribution has been painted, studies at colonies – and nearly all species nest in colonies – can start to flesh out details of the birds' breeding habits. Most obviously, they reveal when the species breeds and how long it takes to incubate eggs and raise young. That said, it is remarkable how little was known just a human lifetime ago. For example, Ronald Lockley, a pioneer of seabird research, studied Manx Shearwaters, a 500-gram species dear to my own heart, on the Welsh island of Skokholm before World War II. He had no idea how long they incubated their eggs. He continues the story[7] "On the fiftieth day our shearwater had beaten all records for incubation that I, at least, had heard of. The white stork takes 30 days . . . and the tame swan 38 days, usually less, to incubate its eggs . . . and even the vulture takes only 48 days. . . .

Ada [the female] was on the egg on the fifty-first day. I had determined to test the egg by gently shaking it. . . . There was no need for any test with Ada's egg that morning, however. To my delight it was pipped. Next morning. . . . Ada was brooding the chick. . . . The egg had taken 52 days to hatch and so had made a record for length of incubation of a fertile egg laid and brooded by a wild bird."

Since then, the incubation periods of many species have been determined. They range from just under three weeks among the smaller terns to about 10 weeks in the great albatrosses. Rearing the chick to fledging can be correspondingly protracted, about 10 months in the largest albatrosses. These spans of parental care are decidedly longer than in most landbirds.

More intriguing information emerges when birds are ringed (or banded) and given an individual identity. It transpires that the great majority of seabirds remain faithful to the same partner year after year, the pair bond being broken by death or the occasional divorce.

Ringing is also a powerful tool for assessing survival from one year to the next. Despite often spending most of their lives in seas apparently so hostile, seabirds are actually rather long-lived, and researchers, the people who love nothing more than to smell the guano, expect their marked birds to return to the colony year after year, and become old friends. Ninety-seven percent of adult Wandering Albatrosses survived from one year to the next in the days before longlining added a fearful extra threat to these maestros of gliding. In contrast, when just three-quarters of adults survive the year – the case for Common Diving Petrels – the survival figure seems low to an experienced seabird ornithologist, despite being high in comparison to the survival of a garden bird in a temperate country.

If seabird survival is high, it might be anticipated that the number of young produced by breeding birds would be low. Were that not the case, the oceans would be awash with birds. And, indeed, low output is the order of the day. The great ornithologist David Lack pointed out how species that range furthest over the oceans tend to lay a single egg.[8] The presumption is that bringing enough food for a single youngster is hard enough work for these parents, which of course helps explain the very long fledging period of albatrosses. It is only species feeding inshore and fairly close to their colonies that lay larger clutches, for example two or three eggs are laid by certain gulls and terns, and up to five by some cormorants.

Another piece of this introductory jigsaw is the observation that the most oceanic, wide-ranging species laying a single egg tend to nest in colonies that are far from one another, and sometimes huge. Sooty Tern colonies can exceed one million pairs. On the other hand, the species feeding closer to shore nest in smaller colonies that may be sprinkled along a coastline at no great distance from each other.

Once a seabird has a lifestyle that promises many years on the wing, natural selection will set to work. In particular natural selection will favour individuals which do not imperil their own long-term chances of survival by recklessly over-investing in any single year's offspring. It would simply be counter-productive to die in the defence of one chick, and fail to survive to rear many chicks in future years. This line of argument helps explain the small clutches of seabirds. It also bears on the age at which seabirds start to breed. While some species begin breeding at two years old, between four and six is commonplace. Life in the windy lane of the Light-mantled Sooty Albatross is so leisurely that, on average, the birds do not start breeding until the age of 12. This general pattern is part and parcel of a life history involving high adult survival. Birds do not start breeding until several years have passed. Those years may be needed for them to acquire the maritime feeding skills necessary to take on the extra burden of feeding a chick. Or they may need to acquire knowhow to minimize the additional hazards encountered when visiting land. A storm petrel dismembered and crushed in an owl pellet, a shearwater with a broken neck after a night-time impact with a rock face at the colony: these are nature's failures.

Another aspect of seabird biology much illuminated by colony studies is diet and feeding habits. Sometimes the findings can be guessed in advance. Food ferried from sea to colony in the bill is likely to have been caught close at hand since this mode of transport is aerodynamically inefficient. When a tern feeds its chick a sand eel that is still glistening salty wet in the bird's bill, it has obviously been caught nearby. Food brought from further afield is likely to be regurgitated to the chick by the parent, and the inquisitive ornithologist can persuade the unlucky bird to regurgitate its hard-won catch into a collecting vessel, there to be sifted and identified. Sometimes such observations lead to surprising conclusions. French researchers Henri Weimerskirch and Yves Cherel studied Short-tailed Shearwaters breeding on Tasmanian islands.[9] Some of the food, krill and fish characteristic of colder seas, brought back to chicks after the adults' longer trips, indicated that the birds were travelling at least 1,000 km south of Tasmania into Antarctic waters to forage. When New Zealand ornithologist Mike Imber noticed that the food brought by Grey-faced Petrels to their chicks was substantially made up of squid species that migrate from the depths towards the surface at night and there emit light, he wondered whether the petrels actually fed at night, perhaps targeting the glowing molluscs.[10]

Whilst the type of food brought by seabirds to their colonies certainly allows inferences about where that food was caught, so, sometimes, does the length of the foraging absence. A tern that returns to the colony after an hour's absence gripping a fresh sand eel has not gone far. At the other extreme, some petrels and albatrosses sit on their egg for 20 days whilst the mate feeds at sea before reappearing to resume incubation duties. There evidently has been time enough for the mate to cover immense distances – but did he or she go north, south, east or west? Did the outward and return journeys follow the same route, or was the overall track a loop? Can the absence be split into obvious and distinct travelling and feeding phases? Only the recent arrival of tracking devices has begun to provide answers to such questions.

Seabird biologists love to count seabirds, to the extent that we now have a tolerably accurate estimate of the number of breeding pairs of most species. Make some assumptions about how many immature birds there are in the queue to join the colony, and it is possible to estimate the number of each species on the wing. Add them together and there may be some 700 million seabirds on earth, about one-tenth the number of people. Especially numerous are the diving species of higher latitudes: the penguins, shearwaters and auks. Knowing the food requirements of birds of various sizes, it is possible to calculate the aggregate amount of food they extract from the sea in a year. The total of at least 70 million tonnes is remarkably similar to the amount, some 80 million tonnes, the fishing industry has brought ashore each year since 2000.[11]

This sketch of the sort of knowledge seabird biologists have accrued from land-based studies might, one would think, be expanded by observations at sea. That is true to a degree. When North Sea oil production was getting underway in the 1970s, numerous surveys were undertaken to assess which parts of the basin were preferentially used by seabirds that might fall foul of oil spills. Although such information may help conservation planning, it reveals nothing about the origins of the birds seen. In the same era, Pierre Jouventin and colleagues travelled south from the French Département of La Réunion, in the tropical Indian Ocean. Heading south towards Antarctica, they showed how certain albatrosses, such as Wandering and Indian Yellow-nosed, and the Great-winged Petrel, were seen most frequently near two zones where sea temperature altered abruptly, the Subtropical Convergence and the Antarctic Polar Front.[12] This implies that the birds were seeking out these zones of water-mixing and therefore enhanced marine productivity for feeding (see Chapter 8). It tells us nothing about the colonies from which the birds hailed, or whether they were breeders or non-breeders. Again it is recourse to tracking gadgetry that leads towards answers to these finer-grained questions.

I remember crossing the North Sea from Newcastle to Oslo in January 1968 aboard a smart passenger ferry. For a large fraction of the limited daylight I was wedged in a secure nook astern. The air was chill, the ship's wake serpentine, twisted by the lumpy waves. And the Northern Fulmars enchanted me, gliding this way and that with no apparent care in the world. Of course, they did have a care; the imperative need to find food. And that leads to the persistent worry about such surveys as those from the North Sea, and from the Indian Ocean mentioned in the last paragraph. They recorded the presence of auks and fulmars, and albatrosses and petrels respectively, but it can be quite rare for observers to see the birds actually feeding. Is this because the birds manage to catch enough food to last, say, a couple of days during infrequent bouts of gorging, or is it because much feeding happens at night when they cannot be seen? Devices that tell us when birds actually ingest food have the potential to provide an answer.

Without question, birds follow ships in the hope of grabbing food. That might be galley waste from a yacht but of course fishing vessels are potentially the richest source of food. Sometimes this is offal thrown overboard after the fishers have gutted the catch, or it could be discards, fish thrown away because they are of no commercial value. Sometimes birds target fish leaking out of a trawl as it is retrieved, and put themselves in danger from the taut trawl wires. Even more perilously birds are attracted by the baited hooks that are accessible while a longline of several kilometres is being set. As the line streams astern, there is a short time window when each baited hook can be grabbed by a bird before that hook goes too deep to be reached. If a bird grabs the bait, it may be lucky and win a meal. It may be unlucky. It gets hooked, is dragged underwater, and drowns. For some species, such as the Northern Fulmar, food sourced from fishing vessels has been hugely important and a major driver of twentieth century population growth. Just what proportion of the diet of a typical individual fulmar is derived from this source is less clear. For other species, for example the Southern Ocean gadfly petrels which barely interact with these vessels, it is of no importance. The overall picture then is that seaborne observations may be giving a biased picture of the feeding habits of some seabird species, and no picture at all of other species. Can modern technology help steer us away from such biases?

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Until the middle of the twentieth century, it was possible to watch seabirds on land and at sea, and to study them in more detail at colonies. The latter activity included, *inter alia,* putting metal rings on the birds' legs, a well-established means of studying bird migration. In the case of seabirds, those bearing rings could be recaptured at the colony or, possibly, found dead on some more or less distant shore. How informative is that washed-up carcass? Had the bird strayed from its normal route, encountered barren seas, and died? Had it drifted as a corpse some hundreds of miles from the position of death? While doubt clouds the picture painted by dead ringed birds, modern tracking devices yield much higher quality information about birds' whereabouts.

Attaching transmitting VHF radios to animals has occupied biologists since the late 1950s. It is a powerful technique for relocating, say, a troop of chimpanzees that assuredly will not have travelled far since their last known position. It is less useful for seabirds which travel far greater distances, taking them beyond the line of sight of any scientist deploying a receiving aerial on some windy clifftop. Couple this problem with the fact that a seabird will often dip into the trough below the wave crests or, even worse, submerge underwater, and the upshot is that VHF radio-telemetry has not transformed seabird research.

Those disparaging words notwithstanding, radio-telemetry has had its moments. In 2003, the ornithological world was amazed when the New Zealand Storm-petrel, thought extinct for over a century, was rediscovered at sea off New Zealand's North Island. That led immediately to the question of the whereabouts of its colonies, and the tricky task of discovering those colonies. The problem was solved when it proved possible to attract the birds close to a 3.5 m inflatable with chum, the ornithologists' term for a smelly sludge of fish bits. Once in range, the storm-petrels were captured by a small net fired over them. Fitted with

Believed extinct for over a century, the New Zealand Storm-petrel was re-discovered in 2003. Subsequently, radio-tracked birds led scientists to a colony near Auckland.

a transmitter weighing two-thirds of a gram, the released birds then led the searchers in 2013 to nesting burrows in the rainforests of Little Barrier Island, a mere 50 km from Auckland, New Zealand's largest city.[13]

Other techniques may bear future fruit in the search for breeding sites of other species whose colonies remain unknown. For example thermal imaging and radar have helped pinpoint nesting areas of the Black-capped Petrel in the mountains of Hispaniola, and given hope that the species, long thought extinguished from the Caribbean island of Dominica, still breeds there. Drones carrying a thermal-imaging camera may contribute to identifying the whereabouts of Marbled Murrelets nesting under the dense canopy of the old-growth forest running along the western seaboard of North America.

The overall impacts of VHF radio-telemetry and radar have been slight compared to what has been learnt from satellite telemetry! The first successful deployment of satellite transmitters (on any bird) was achieved by Pierre Jouventin and Henri Weimerskirch in 1989.[14] They attached 180 g devices to male Wandering Albatrosses breeding on the

French Iles Crozet in the heart of the Roaring Forties. Five males were followed as they made off-duty journeys between 3,700 and 15,200 km while their mates incubated the single egg and awaited the return of the wandering males. These values represent minimum journey distances since the satellite passed overhead to collect positional information every 90–100 minutes, and it was assumed, conservatively and probably incorrectly, that the bird had followed a straight line between the two points.

Since these pioneer studies, devices reporting to satellites, known in the jargon as PTTs (platform transmitter terminals), have been deployed on countless species, as we shall see. Meanwhile the weight of devices has fallen dramatically, and continues to fall. Devices weighing about 5 g are readily available today. At a pinch such devices could be deployed on a 100 g bird, although the 'industry' standard is for the load not to exceed three percent of the bird's weight, especially as it is scientifically pointless and ethically reprehensible to obtain data from a bird behaving abnormally. Since a major component of the overall weight of a PTT is the battery, this has been minimized in the smallest modern devices by including a small solar panel that regularly trickles current to the reduced tiny battery.*

Because of the technicalities of how the satellite system computes position, accuracy of PTTs is around 500 m. Impressive and good enough for many seabird studies, but poor compared to GPS accuracy. GPS (global positioning system) entered the public domain in the late 1980s. Come the summer of 1993, the US launched the 24th Navstar satellite into orbit. That completed the modern GPS constellation of satellites, 21 of which were active at any one time, leaving three more as spares. Today's GPS network has around 30 active satellites in the GPS constellation, delivering an accuracy of comfortably below a metre to the building industry, navigators and many more users. This accuracy is a boon to seabird researchers, especially as the smallest devices weigh in at around 1 g. At present this weight only allows a limited number of position fixes.

* This development has allowed the deployment of 1.6 g devices onto a number of Spoon-billed Sandpipers, enchanting and fearfully endangered tiny waders that migrate between north-eastern Siberia and south-east Asia.

Increase the weight to around 3 g and add a solar panel trickle charger to power the tiny battery to deliver more fixes.

Superlative accuracy has come at a price. The scientist has faced the need to recapture the subject in order to download the data stored on the GPS tag. That can be problematic if the seabird has learnt that scientists bearing nets or hooks are best avoided. Even this constraint is starting to dissipate. Some GPS devices will 'talk' to satellites. Others will transmit the stored data to base stations set out in the colony to which the birds will assuredly return. Those base stations then send the data to the ornithologists via the mobile phone network.

The accuracy available is astonishing. I am especially fond of an animated online plot of the day's travels of a GPS-tracked Dutch gull, as seen from the air. After leaving its roost on a coastal sandspit, the gull heads a short distance inland, visiting a succession of urban backyards. The day's feasting done, the bird washes away the accumulated grime with a dip in the sea before returning to roost on the very same sandspit.[15]

Finally positional information can be gathered from geolocators (also known as Global Location Sensing [GLS] trackers or geologgers), light-sensitive devices which, attached to the bird, record the time of local sunrise and sunset. This allows determination of day length and local midday, as a function of the day of the year, which in turn yield the bird's latitude and longitude, respectively.[16]

The very earliest geolocators were attached to Northern Elephant Seals on California beaches in the late 1980s, and revealed the seals headed to the North Pacific when not breeding.[17] Ten years later, device size was down to 20 g, and the flood of information from albatrosses was underway. The most modern geolocators weigh well under 1 g and can be attached to small 20 g passerine birds, giving unimagined insights into their migratory routes.

Geolocators have two snags. Latitude information is poor around the equinoxes when daylength everywhere in the world is around 12 hours, and accuracy may be no better than a few hundred kilometres. Notwithstanding these drawbacks, the relative cheapness of geolocators and their ability to run for two years or more until the subject bird is re-captured for data retrieval mean that they have been wonderfully informative. In the desk drawer beside me, as I write, are half a dozen retrieved geolocators. They have accompanied me by aeroplane from Cambridge via Los Angeles airport to the South Pacific and back. They have been deployed for two years on six Murphy's Petrels, each of which has flown from the Pitcairn Islands to the North Pacific and back, not just once but twice – and that is not to mention the birds' excursions from the nesting colony of thousands of kilometres.

Having established the whereabouts of a seabird, the next obvious question is: What is it doing at sea? The first phase in any answer might be to establish whether it is flying or swimming. Enter immersion loggers. Obviously a flightless species, such as a penguin, will have wet feet for as long it remains at sea. The picture for volant species is more complex, as we shall see in later chapters. There may be differences in the proportion of time spent swimming on the water by night and by day, and there may be differences according to season. Many smaller petrels are mostly on the wing whilst at sea during the breeding season but spend over half their time on the water when not breeding. The route towards documenting such behaviours involves immersion loggers. Commonly attached to the legs of birds, these loggers sprout two small electrodes. The impedance between those electrodes diminishes when they are in water, and the associated recorder registers the time of transitions from one state (wet) to the other (dry), and vice versa. As so often, the pioneer devices, deployed on the much-studied Wandering Albatrosses of Bird Island, South Georgia, were chunky at 24 g. Today, such immersion loggers are routinely incorporated within the GLS devices fixed to seabirds, the whole package weighing less than 5 g.

If the species is bobbing on the sea, it might well dive for food. How deep does it dive? Early in the quest for answers capillary tubes were attached to birds. Because the capillary is sealed at one end, the air within becomes compressed when a bird dives and water under pressure enters from the other end. The deeper the dive, the further up the capillary the water moves. This movement was recorded by an indicator powder (e.g. icing sugar, or water soluble dye) dusted onto the inside of the capillary that changes as it gets wet. Thus, when the device is retrieved from the bird, the capillary gives an indication of the maximum depth reached by the bird and the device during the period of attachment. Since the device is not providing a continuous read-out, the longer it is deployed, the greater the maximum depth is likely to be. Crude as this technology was, it yielded surprising answers. Who would have bet on a Short-tailed Shearwater reaching 70 m?

To document how much time a bird spent at various depths en route to the crude maximum, the next step was the development of devices that recorded, either via light- or radiation-sensitive film, the amount of time the air/water boundary was at different positions within the capillary. This was certainly an improvement but it was not the continuous record of depth over time for which the curious naturalist yearns. Such a record would, for example, allow questions about how the time the bird spends at the surface is affected by how deep it has just been, and by how deep it will go on its next dive.

The credit for inventing such a device goes to the Japanese researcher Yasuhiko Naito in the late 1980s.[18] A compressible bellows, responding to pressure and therefore depth underwater, was attached to a stylus inscribing an ultra-thin line on carbon-coated paper on a rotating drum. When the paper was retrieved, it showed the bird's dive profiles. These might be U-shaped if the bird has lingered at maximum depth, or V-shaped if it has descended smartly to maximum depth and returned equally smartly to the surface. This recording system is 'old-fashioned' analogue. The data documented by the latest time-depth recorders (TDRs) are recorded digitally.

This book will delve into the ecology of seabirds rather than their physiology. But physiology cannot be ignored. A penguin diving to beyond 100 m is putting its body through serious stress. Implanted devices can measure some of those stresses. For example, an implanted heart-rate monitor (which has to be retrieved surgically for its data to be downloaded[19]) can reveal how King Penguins, also equipped with a depth recorder, show remarkable fluctuations in heart rate during the course of a dive (see also Chapter 9). Not only does heart rate fluctuate with activity, it is also probably a good indication of the amount of energy being expended in whatever activity the monitored bird is performing. The bird's energy needs translate into its food requirements and hence impact on the marine ecosystem.

Since it will always be difficult to assess without bias when seabirds feed, especially whether they do so at night, indirect means come in handy. One such way is to insert a temperature sensor into the stomach. Remembering that seabirds are universally warm-blooded, and that their prey is cold-blooded and living in waters that are at least somewhat and usually a lot cooler than the bird's body temperature, the ingestion of prey will cause the bird's stomach temperature to drop. The larger the prey item, the greater and longer-lasting the drop.

Such a device was developed by Rory Wilson, then working in Germany, and tried out on captive African Penguins in South Africa. In the dry parlance of a scientific paper,[20] Wilson wrote "Four penguins were captured from a non-breeding group at Dassen Island . . . at 11:00h on 21 June 1991 and housed in a large wicker basket for 1 h before each was induced to swallow a [device]." Scientific persuasion was also needed to retrieve the devices from the birds – but the idea worked. The sensor showed a precipitous drop in temperature when a prey-sized (50 cm^3) shot of water was inserted into the penguin's stomach by catheter. The drop was followed by a gradual recovery in temperature as the 'prey' warmed back to body temperature. Later trials with free-living Wandering Albatrosses on the South African sub-Antarctic island of Marion confirmed the potential of the devices. Today's devices are often inserted in the oesophagus, instead of stomach, allowing more precise timing of ingestion events.

Some ten years later, another technique for registering underwater prey capture was developed. In fact the technique was pioneered during a study of Weddell Seals.[21] Having glued a reed-contact and magnet onto the hair-covered parts of the upper and lower flews, the fleshy outer lips of the seal, the researchers could record when electrical contact was broken, in other words, when the animal opened its mouth. If a depth-recorder revealed that the seal was then underwater, it was a definite possibility that it was opening its mouth to snap up food. The same approach has been extended to Leatherback Turtles, half-tonne leviathans that convert the watery pulp of jellyfish and comb jellies into reptilian flesh. Similar devices have since been attached to penguins and shags. With a magnet on one mandible and the so-called Hall sensor on the other, the voltage recorded from the sensor decreases as the distance to the magnet increases. Thus opening the beak wide leads to a bigger drop in voltage than does a small parting of the beak. Very likely the degree to which the beak is opened is related to the size of the food item ingested.

When oesophageal and Hall sensors are recording simultaneously from the same (tolerant) penguin, there is not a perfect correspondence between the two channels. For example, the bird may open its beak twice a few seconds apart to catch two different items but these are not resolved as different by the temperature sensor. However the overall correspondence is remarkably convincing, allowing the logging of when the bird eats, and roughly how much.

Now imagine a bird carrying not only the oesophageal and Hall sensors but also a time-depth recorder. It is often possible to spot small wiggles in the trace of a bird's depth. This less-than-technical term refers to small, quick changes in depth, exactly the sort of changes one would expect were the underwater bird deviating from a straight course to snap up prey. And indeed it transpires the wiggles coincide with temperature changes in the gut and with beak opening.[22] A wiggle provides another means of detecting when a bird consumes prey.

Presuming it is unrealistic to ask a seabird to keep a diary of its daily diet, the next best might be for it to carry a camera that records the rolling view in front of its beak. Every fish or shrimp eaten would make a smart exit from the field of view as it entered the bird's gullet. Devices attached by Yutaka Watanuki approached this gold standard.[23] His team attached cameras to male European Shags tending small/medium-sized chicks on the Isle of May off Scotland's east coast. Retrieved a day later, the cameras showed the shags diving in a mix of sandy and rocky habitats. Sometimes they returned to the surface where the camera took a picture of the prey, butterfish. However it seemed quite likely that smaller items, such as sand eels, were quickly swallowed underwater and missed by the camera which fired only every 15 seconds. Items are less likely to be missed if the bird is carrying a continuously-recording video camera as described in Chapter 9.

Another recent proof-of-concept study was led by Steve Votier of the University of Exeter. Travelling to the gannetry on the Welsh island of Grassholm, with assistance from a blisteringly powerful jetboat, Votier and team attached 45 g cameras, firing once a minute, to the central tail feathers and GPS loggers to the backs of parent Northern Gannets rearing chicks.[24] Of the ten gannets whose cameras yielded useful results, seven clearly interacted with fishing vessels, mostly trawlers, during their foraging trips. During these interactions, they took pictures not only of the ships, but also of fellow gannets and indeed other birds hoping for discarded fish and other fishery spoils. That said, less than half the time gannets spent in circumscribed food-searching mode was associated with vessels; the gannets were clearly capable of independent 'natural' foraging.

In the past 15 years, accelerometers have proved an increasingly powerful tool for investigating birds' behaviour, especially underwater, and for assessing how hard they have to work to achieve that behaviour.[25] An accelerometer is conceptually simple, and measures g-force – as is needed, for example, to trigger a vehicle's airbag that inflates during the severe deceleration of a collision. Early devices attached to penguins proved useful in describing their swimming habits and how much porpoising above the waves contributed to their journeys to and from feeding areas. These devices recorded information once a second, sufficient to describe body posture. The world has progressed and accelerometers can now record from all three mutually-perpendicular axes at a much higher frequency. A 30-times-a-second (30 Hz) frequency provides data on the beating frequency of a penguin's flipper, and how that alters in the course of a dive. A team at the Isle of May, Scotland, used a recording frequency greater than 50 Hz to show that the island's Shags needed to beat their wings ever faster in order to remain airborne as they progressively filled up with food during an excursion from the colony.[26]

Dogs are routinely 'chipped' with a PIT (passive integrated transponder) tag about the size of a grain of rice. Brian Smyth and Silke Nebel from the University of Western Ontario, Canada, describe the technology succinctly. "Essentially, PIT tags act as a lifetime barcode for an individual animal, analogous to a Social Security number and, provided they can be scanned, are as reliable as a fingerprint. . . . PIT tags are dormant until activated; they therefore do not require any internal source of power throughout their lifespan. To activate the tag, a low-frequency radio signal is emitted by a scanning device that generates a close-range electromagnetic field. The tag then sends a unique alphanumeric code back to the reader."[27] From a seabird perspective, the absence of a battery and its associated weight is a bonus. The need for the scanner to be close to the chipped bird is a drawback, one which may lessen in a densely-packed colony where the comings and goings of a cluster of individuals can be monitored by a single scanner. That approach has been successful in the Antarctic where David Ainley coordinated a study of Adélie Penguins.[28] The penguins were ushered over a weighbridge and past a scanner as they arrived at and departed from the colony, allowing the weight of food delivered to chicks by identified chipped penguins to be determined. Even more sophisticated has been the study of Common Terns led by Peter Becker.[29] The terns nest on six concrete islands in the harbour of the German coastal town of Wilhelmshaven. All chicks fledging from these islands since 1992 have been chipped. Those that survive to return in subsequent years find themselves monitored automatically by an electronic surveillance system of antennas on elevated platforms that remotely record individual attendance throughout the breeding season.

This section has not been comprehensive but it has described the crucial devices now available. They allow seabirds to be studied as never before, despite the obstacles imposed by their journeys covering huge distances across inhospitable seas. Seabird researchers investigating mid-sized and large species can now map where their study bird goes. They can combine garnering this positional information with attaching a device that signals whether it is wet or dry and simultaneously collects data on depth, sea temperature, and light levels. It would be exaggerating to claim that a seabird can be more closely monitored than a patient in intensive care.[30] But the level of understanding of how birds live out their lives away from the apparent comfort of land is growing in a truly remarkable manner.

This book describes that growing understanding. From the data, a picture of mastery emerges. Seabirds are not helpless morsels of life tossed hither and thither by wind and waves. Rather, they employ strategies that enable them to cover huge distances and detect scattered food with relative ease, and with the advantage that they are less subject to day-to-day predation than are landbirds. No wonder seabirds attain an age of 30 regularly, and 50 sometimes, milestones far beyond the reach of any everyday garden bird.