INTRODUCTION: THE FREE ADVICE OF BIRDS

Rockhopper numbers drop off cliff

> The ability of the birds to show us the consequences of our own actions is among their most important and least appreciated attributes. Despite the free advice of the birds, we do not pay attention.
>
> Marjory Stoneman Douglas, 1947

In the world's southern oceans, the declining fortunes of a small penguin hint at a profound and widespread change in its environment. Ocean warming is suspected but many questions remain, in part because it is not easy to study southern rockhopper penguins, *Eudyptes chrysocome*. Getting to their remote colonies, like those on Campbell Island, is costly and logistically challenging. Then there is the subantarctic weather. Storm-force winds routinely blast the island, and rain and drizzle drench it most days of the year.

Arriving at a rockhopper colony, one finds hundreds or thousands of incubating birds, packed cheek by jowl, just beyond pecking distance of each other. Others jump along steep, rocky slopes, intent on their daily commutes between nest and ocean. This penguin's reputation as one of the most aggressive penguins tallies with its appearance: red eyes, black head feathers evocative of a punk rock singer, and yellow eyebrows ending in plumes that fly in a golden halo when it shakes its head to attract a mate. When a human visitor passes amongst them, rockhoppers slowly rotate on their nests, hundreds of eyes fixed on the interloper. If one should approach too closely, an incubating bird will attack. Though standing well short of a human knee it will nip the intruder's legs with its beak and batter them with a tattoo of its sharp flippers. 'If you pick them up, they go bananas,' says marine biologist David Thompson of New Zealand's National Institute of Water and Atmospheric Research, who has studied these seabirds.

Southern rockhoppers' pugnacity and jostling, frenetic colonies belie their huge population declines over the past century. A colonial lifestyle means worsening conditions at one colony can affect tens of thousands of birds. Numbers at the Falkland Islands, for example, plummeted from 1.5 million pairs in the 1930s to 210 418 pairs in 2007, an 86 per cent decline. The global population is now estimated at between half a million and one million adults. While this may appear a large number in absolute terms, the International Union for the Conservation of Nature (IUCN) has listed the southern rockhopper as vulnerable to extinction because its long decline has apparently worsened in recent years. Threats may vary from colony to colony, but include fishing, oil exploration, introduced predators and disturbance from ecotourism. However, some other quite profound change is suspected to have happened in the wider marine environment, where penguins forage, to help southern rockhopper numbers to nosedive.

John H. Sorensen probably never expected that his off-duty passion for birdwatching would help identify a new rockhopper threat. During World War II, Sorensen was posted to Campbell Island as part of a highly secret force of New Zealanders and given the task of looking out for enemy ships that might attempt an occupation. In his spare time, he photographed and studied the island's wildlife, making meticulous notes (he went on to become a noted ornithologist).

Half a century later, Sorensen's information, along with other similar records from the island, was used to bolster more recent observations and demonstrate how Campbell Island's southern rockhopper colonies plummeted from 1.6 million to 103 000 breeding birds between 1942 and 1985.[1] With no evidence for land-based causes, warming ocean conditions were suspected. Numbers declined most during a period of substantial summer warming of the ocean's surface, and one colony's numbers temporarily increased after seas temporarily cooled.

This effect was suspected to occur via changes in rockhoppers' ocean prey, but a lack of long-term records on the seabirds' food supplies made this difficult to show. This time, researchers turned to museums to help fill in the gaps. By analysing isotopes in the feathers of rockhopper specimens, along with those of living birds, they reconstructed the seabirds' diets over time. The story advanced. Though their results were still not conclusive, what researchers found suggests insufficient food for the penguins in recent decades, in a marine ecosystem that has become less productive. In New Zealand's subantarctic, this downwards trend in marine productivity coincided with the start of the rockhopper's decline.[2]

Although climate-change effects on their marine food supplies (krill, squid, octopus and fish) are strongly suspected to contribute to this penguin's decline, the mechanisms are not yet fully understood. Apart from the penguins themselves, there is nothing obvious to measure above the ocean's surface, to which changing ocean temperatures can be linked. New research planned for Campbell Island could help fill more gaps in the southern rockhopper puzzle.

As avian instigators of scientific inquiry, southern rockhoppers are hardly unique. Birds have long prompted us to ask, and helped us to illuminate, nature's big questions. Consider Hawaiian honeycreepers. Their spectacular adaptive radiation, from a single ancestral finch to dozens of honeycreeper species that fill virtually every Hawaiian songbird niche, is a spectacular natural experiment in evolution and island biogeography. Or take bar-tailed godwits, *Limosa lapponica baueri*, whose 10 000-kilometre transoceanic journeys may entail nine-day flights completed without once stopping for food, water or rest. This feat challenges preconceptions about birds' physiological capabilities and raises new questions about animal energetics.

Birds are also sentinels, the quintessential 'canaries in the coal mine' of dangerous environmental change. Highly visible, mobile and reactive to changes in climate, they are among key indicators of global warming. Even if we were oblivious to the present changes in Earth's climate, a careful look at birds' patterns of responses over recent decades would warn us that some sort of widespread and systematic change is afoot.[3]

Prime witnesses to climate change, birds can also serve as proxies to illuminate the wider impacts of this new threat for wildlife. Migratory birds could reveal much as they travel between far-flung regions, assembling and combining information on their diverse habitats. Seabirds, like sooty shearwaters whose annual odysseys embrace the entire Pacific, provide tangible links to unfathomable ocean ecosystems. Antarctic penguins are highly responsive to changes in sea ice, and can relay information about the state of the cryosphere.[4] In essence, birds can be seen as flying (and swimming and walking) data collectors that reveal the health of diverse ecosystems they use.

Colourful, vocal and charismatic, birds hold a special place in our hearts, minds and myths. These qualities may also explain birds' status as the best-studied major group of animals. Ornithological studies of weather effects on population biology span more than 50 years, and some continuous records gathered by birdwatchers stretch back more than two centuries. Each year, birds are tracked across the globe by a multi-million-strong army of birdwatchers.

Taking the global avian pulse

Before delving into the ramifications of the relatively new climate-change threat, let us first ask how birds are weathering other, longstanding human threats. Human contact most likely led to many unrecorded bird extinctions, as species were lost before their discovery by science.[5] Polynesians' first contact with islands across the Pacific, for example, may have caused extinctions on the order of 1000 bird species. Since 1500, a total of 153 bird species are definitively known to have gone extinct.[6] Yet population levels are falling even more rapidly than this extinction rate would suggest; global bird abundance dropped by as much as a quarter over this same period.[7]

Today, roughly one in eight (1244) bird species face the threat of global extinction from wide-ranging impacts, with habitat destruction being the most serious present-day hazard. Not just rare birds, but common species – familiar due to their abundance – are declining. In fact, birds' conservation status has steadily deteriorated since the first global assessment in 1988, with birds in Oceania and seabirds declining fastest over this period. More recently, sharp declines have been driven by forest destruction in Asia. Tallies of risk to birds, however, have barely begun to account for the emerging threat of climate change.

Any new threat to birds should concern us, because their existence is very much intertwined with our own. Nearly half (46 per cent) of the world's almost 10 000 bird species are directly used by people in some way, mostly as pets or hunted for food or sport. Uses may be as esoteric as the sky burial services provided by vultures for Tibetan Buddhists or Indian Parsees (a service diminished in the Parsee case due to the recent radical decline of some vulture species), or as mundane as the use of guano for fertiliser. In Peru, where climate conditions allowed guano to accumulate over millennia at seabird colonies, 'mining' it became the greatest national revenue source for more than a century.

Birds are also critical 'mobile links', ecological actors that connect disparate habitats in time and space. From penguins pursuing ocean prey to depths of hundreds of metres to tiny hummingbirds whirring through tropical forests to pollinate bromeliads, birds possess an astonishing diversity of ecological function, unsurpassed among vertebrates. Their ecological activities benefit humans in myriad indirect but important ways. Of these so-called ecosystem services, seed dispersal is probably paramount. The seeds of more than half of Costa Rica's tree and shrub species are dispersed by birds. Birds also pollinate plants, including dozens of species of crops, and eat harmful insects.[8] In economically valuable forests, for example, birds' services may be worth US$1820 per square kilometre per year, based on the cost of replacing them with insecticides to counter western spruce budworm, *Choristoneura occidentalis.*

Scavenging birds like vultures probably do not receive enough credit for efficiently disposing of dead animals. Seabirds are increasingly appreciated as chemical and physical engineers that can shape entire ecosystems. The new volcanic island of Surtsey, Iceland erupted from the sea in 1963, but its vegetation developed best after gulls settled there in 1985. They brought seeds and organisms on their feet and in nesting materials, and ocean nutrients in their faeces, setting off a veritable explosion of plants, lichen, fungus and invertebrates around their colony.

The dawn of the 'Anthropocene' and high-velocity change

But how do these mobile ecological actors respond to changes in climate? Change has been a feature of Earth's climate over the evolutionary history of today's bird species. In what is now England, hippopotami, straight-tusked elephants and spotted hyenas roamed the landscape 130 000 years ago, when the climate was warmer than during the mid 20th century. Over the last two million years, life on Earth has repeatedly endured periods 5°C colder than the middle of last century, causing ice sheets to expand and sea levels to drop by 100 metres or more.

Yet the past 11 000 years, following the end of the last major glacial epoch and the start of the Holocene (Greek for 'entirely new') epoch, has been an unusually warm and stable period compared to the previous 400 000 years. Humans thrived under this climate stability. Our ancestors learned to domesticate animals, grow crops and transform their energy use from mainly firewood and muscle power to coal, then oil and other fossil fuels.

Burgeoning human populations have denuded and eroded continents and greatly accelerated extinctions and population declines. And as fossil fuels were burned, concentrations of carbon dioxide in the atmosphere rose from pre-industrial levels of about 280 ppm (parts per million) to 390 ppm in 2010. These and other profound changes characterising humans' influence after the Industrial Revolution, some argue, will leave a signal in geological strata so distinct it will be recognisable as a separate epoch, according to formal definition. Thus we humans have ushered in a new epoch of global environmental change of our own making, dubbed the Anthropocene (Greek for 'human' and 'new').[9]

Just as we understand the workings of gravity and tides, the heat-trapping potential of carbon dioxide[10] is also well known. Swedish physicist Svante Arrhenius predicted in 1895 that marked increases or decreases in carbon dioxide abundance would be associated with glacial retreats and advances. In fact, this greenhouse effect is what makes Earth's climate hospitable to life in the first place. Without it, the average temperature on the planet would be an estimated 34°C colder than today, an arctic –19°C. Yet to find periods with concentrations of greenhouse gases equivalent to today's, one must travel back in time two or three million, and possibly even 15 million years.[11]

Over the past century, the global average temperature rose 0.76°C,[12] with the amount of warming being greater over the past 50 years. From the 1980s onwards, each decade has been much warmer than that prior, with the 2000–2009 period being the hottest on record. The Intergovernmental Panel on Climate Change (IPCC) has found global warming to be 'unequivocal', and places an over 90 per cent probability on human activity as its primary cause. Greenhouse gas emissions, mainly from burning fossil fuels including coal, oil and gas, and from clearing of natural vegetation, are the most important drivers of global warming.

Where will the Anthropocene take our global climate? The best estimates point to further global warming of 1.8–4.0°C by 2100 unless new climate policies are put into action to curtail emissions. (This best estimate range reflects the centre point of the lowest and highest IPCC 2007 emissions scenarios, but the full range of projected temperature increase for these scenarios is 1.1–6.4°C.) Yet some climate modelling suggests that even an unimaginable 11°C of warming may be possible under a worst-case scenario.[13] Precipitation patterns are also expected to be altered by climate change. Sea levels will keep rising, sea ice will continue to diminish, and ocean acidification will continue. The warming taking place now is not without precedent in the Earth's history. However, the extent of change expected in the future will probably be beyond what most of today's fauna experienced during their evolution. What is more, the pace of climate change is extremely rapid.

Another feature of climate change is more frequent and severe episodes of extreme weather. This prospect cautions us that the journey to a warmer world may not be a smooth and gradual transition, but instead a bumpy ride punctuated by extremes and 'surprises'. We need be concerned not only about cyclones, heatwaves and droughts, but also about tipping points, for when it comes to Earth's climate, small changes can lead to large changes (chapter 7).

Examining 'fingerprints' to unmask the climate-change threat

In the chapters of this book, the 'fingerprints' of climate change reveal how the living world is responding to global warming. These fingerprints distinguish human-induced climate change from natural background variation. They are discernable not only in biological records, but in those from the oceans and atmosphere as well. Importantly, these signals reveal that birds and other wildlife are already responding to climate change. They also hint at whether birds might adapt, or lag in their responses to climate change in ways that put them at risk.

One of the clearest and most powerful fingerprints is emerging as birds and other organisms shift the timing of seasonal activities. Choosing when to breed (chapter 1) or migrate (chapter 2) can be crucial decisions, and these events are now taking place earlier among many birds. Importantly, warming may not affect plants, insects and other key elements of birds' natural communities at the same rate or to the same degree, a point with important implications for ecology.

Another key fingerprint is discernable in the shifting distributions of birds and other organisms (chapter 3). Yet as they respond to climate change, birds, plants and other constituent parts of ecosystems are likely to disperse at varying rates, distances and even different directions. Their disparate responses could also tug at the ties that bind ecological communities. Breeding seabirds provide iconic examples of the potential problems this may cause (chapter 4).

Changes in the abundance of birds and to the make-up of their communities are other fingerprints of climate change (chapter 5). In some cases, population declines driven by climate change could be severe enough to cause extinctions. This extinction threat to the birds of 'habitat islands', especially in the tropics, is the focus of chapter 6. How birds may cope with climate change, and how conservation efforts might facilitate this, is the focus of chapter 7. The repercussions for birds of humanity's own planned and unplanned responses to climate change are also explored in chapter 7.

In closing this introduction, the authors wish to clarify that this book's goal is not to exhaustively cover all positive and negative effects of climate change on birds. Although some bird species will undoubtedly thrive in a warmer world, this book is more concerned with those that may not for, as the late Stephen Schneider once quipped, 'extinction is a one-way filter'. The greater focus of this book on matters of conservation also recognises that climate indicators are tracking at or above the high end of IPCC predictions. In summary, this book's bias towards threatening processes and vulnerable species is motivated by the concern that climate change could extinguish unique forms of birdlife, a foreboding harbinger of the future that awaits humanity on a rapidly warming planet.

Chapter 1

PHENOLOGY: SEASONAL TIMING AND MISMATCH

The new significance of phenology

A harmless pastime illuminates a present danger

> . . . birds fly with song and glancing plumage, and plants spring and bloom, and winds blow, to correct this slight oscillation of the poles and preserve the equilibrium of Nature.
>
> Henry David Thoreau, 1854

The meticulous notes of yesteryear's naturalists are helping today's scientists bolster one of the most powerful demonstrations of climate-change effects on the living world. In 1841, when Henry David Thoreau was strengthening his resolve to live alone in the woods, he wrote in his journal, 'But my friends ask what I will do when I get there.' Thoreau answered with his own question, 'Will it not be employment enough to watch the progress of the seasons?'

Observations echoing this simple and timeless desire are found in his book, *Walden*, a record of life in his one-room cabin at Walden Pond near Concord, Massachusetts. 'I was startled by the loud honking of a goose,' he wrote of one early winter night, 'and, stepping to the door, heard the sound of their wings like a tempest in the woods as they flew low over my house.' Yet Thoreau's observations on seasonal change went beyond mere poetic musings. 'I take infinite pains to know all of the phenomena of the spring,' he wrote in his journal in 1856. His detailed records, jotted down in tables drawn on large sheets of surveyor's paper, are now proving invaluable to efforts to document the biological response to climate change.

Thoreau's observations follow a long tradition known as phenology (from the Greek *phainomai*, 'to appear'), perhaps as ancient as the origins of farming. Today, a renaissance in phenology is being driven by the imperative to understand the effects of climate change on the living world.

Broadly speaking, phenology is the study of the timing of plant and animal life-cycle events or phases in relation to climate: the budburst and flowering of plants, the emergence of insects, and the arrival, nesting, egg laying and departure of birds.[1] The timing of these seasonal events is critical, affecting many aspects of ecology including competition between species and their interactions with prey, pests and diseases. The phenology of plants may even feed back and influence climate, via changes to the temperature and humidity of land surfaces, and less directly through plants' uptake of carbon.

The term 'phenology' was coined by the Belgian botanist Charles Morren in 1853, but the earliest signs of phenological accounts stretch back to the great Mediterranean civilisations and Asia. Records for cherry tree flowering in Japan have continued unbroken since the ninth century AD. More of an art until medieval times, the study of phenology was truly galvanised as a science in the 18th century, when Swedish naturalist Carl Linnaeus created the first reported international phenological network.[2]

Like Thoreau, who was a poet and slavery abolitionist, many intriguing characters have embraced phenology over time. Robert Marsham, another passionate naturalist, began meticulous recordings of 27 'Indications of Spring' on his Norfolk estate in 1736. His descendants continued this tradition until 1958, creating the United Kingdom's longest phenological record. For Parisian academic René-Antoine Ferchault de Réaumur, phenology helped unlock nature's mysterious workings. In the 1730s he discovered that plants flower when summed temperatures from over previous months reach a certain value. Phenological forecasts based on weather trends, and phenological maps indicating the expected beginning of spring, had agricultural and economic utility in past centuries. In modern times, however, scientific interest in phenology waned.