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The Ecological Effects of Climate Change on Seabirds

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Introduction

Numerous scenarios exist regarding the extent of climatic change this century, with debate over predicted regional changes in temperature, precipitation, sea level and the resulting ecological consequences. What is certain is that CO₂ levels, global temperatures and sea levels are rising and will continue to do so. Over the past 100 years, the global mean surface temperature has increased by 0.6°C and scientists believe that there will be further increases over the next 100 years of 1.4 to 5.8°C. Temperatures in the mid- to high latitudes of the Northern Hemisphere are predicted to be 40% higher than the global average with Southern Hemisphere temperatures less than the average. Glaciers and ice caps are projected to continue their retreat, sea levels rise 0.09 to 0.88 meters over the next 100 years, sea temperatures continue to increase, and more weather extremes expected, including more hot days, higher maximum temperatures and more intense storms (IPCC, 2001a; IPCC, 2002). The effects on natural systems and the biota they support is a complex and contentious issue, yet important to understand as they have a direct effect on seabird populations.

Birds have already been affected by changes in breeding success, distribution and migration timing due to climate change (Crick, 2004). This report focuses on general impacts of climate change on seabirds (see Appendix 1 for summary of families), reviews responses and includes predictions of future direct and indirect impacts. Along with impacts due to changes in weather, seabirds will also be indirectly affected by the impacts of climate change on their ecosystems (Frederiksen, 2006). This includes the marine ecosystem that contains the main prey of seabirds and also the various ecosystems that provide the diverse range of seabird breeding habitats. Many predictions are based on the documented effects on seabirds during short warming events, such as El Niño, and other weather-related events.

Effects on Seabird Prey

The main diet of seabirds is marine prey and the timely abundance and appropriate distribution of this prey is required for breeding, moult, migration and survival during winter. The marine ecosystem will be influenced by climate change; consequently, seabird prey will also be affected (Lanchbery, 2005).

Plankton at the base of the food chain provides the seabirds' main diet of fish, squid, krill and other zooplankton (Robinson et al., 2005). They are brought to the ocean surface by an upwelling that is the result of wind action which moves the surface layers of the water along

a coastline to the open sea, leading to a vertical flux along the continental shelf (Lévêque, 2003). Climate change influences both wind patterns and wind strength (IPCC, 2007) and this can change the timing of an upwelling. In the North American Spring 2005, an unprecedented seabird breeding decline on the west coast was documented and associated with a two month delay in northerly winds that delayed the spring upwelling (Wormworth and Mallon, 2006). The distribution of plankton will be influenced by changes in ocean currents caused by increased temperatures (Robinson et al., 2005) and by sea surface warming. Increased plankton in cooler regions and decreases in warmer regions are predicted (Richardson and Shoeman, 2004). With rising sea surface temperatures, the species composition and biomass of plankton can change; this occurred in the North Sea in the 1980s and led to a reduction in sand eels (Mitchell, 2006) that was linked to the death of thousands of seabirds (Lanchbery, 2005).

With the shift in plankton, the distribution and abundance of seabird prey may also shift. Many seabirds are adaptable and can move to where prey is more abundant. This movement has already been observed in the guano-birds of Peru following an El Niño event that caused mass deaths of adult birds due to a lack of anchovies (Jahncke, 1998). However, some species that have a defined range may not be able to make the transition, such as some penguin species in the tropical zones and other species living in Polar Regions (Boersma, 1998; Chambers et al., 2005; Cunningham and Moors, 1994; Wormworth and Mallon, 2006).

Of major concern is the effect of climate change on krill, a key food source for several penguin species and other species such as kittiwakes (*Rissa* spp.) (Robinson et al., 2005). The abnormally high temperatures in the Southern Ocean during the 1970s caused a high mortality rate in adult Emperor Penguin (*Aptenodytes forsteri*) in Terre Adélie due to a shortage of krill (Barbraud and Weimerskirch, 2001). A ten-fold decline in krill during the past ten years in the Antarctic region has been documented; Loeb et al. (1997) believe this is related to diminishing sea ice, as the algae that grows on the underside of sea ice is a food source for krill.

As the sea temperature rises as a result of climate change, water will have less oxygen (Attrill et al. 2007); therefore, fish stocks are predicted to fall as the sea temperature rises. Jellyfish (*scyphomedusae*), use their intragel oxygen rather than oxygen from the water (Thuesen et

al., 2005) and like fish, feed on phytoplankton (Attrill et al., 2007). Thus, with the concomitant decrease in fish, jellyfish populations will likely increase. In Antarctica, salps are more prolific in years when the water is warmer and krill are correspondingly in short supply in those years (Wormworth and Mallon, 2006). Seabirds are known to eat jellyfish, but these alone are not nutritious enough to sustain them (Harrison, 1984; Loeb et al., 1997).

With the rise in sea temperatures, warm-water fish will expand their range towards the Polar Regions and the range of cold-water fish will either decrease or they may be driven deeper out of reach of seabirds (Meehan et al., 1999). Some seabirds have already extended their range to take advantage of prey expansions, including tropical seabirds on the west coast of Australia (Chambers et al., 2005), and Northern Gannets (*Sula bassana*) in Newfoundland where warming surface temperatures permitted a northward expansion of migratory warm-water mackerel into the area (Veit and Montevecchi, 2006). An increase in myctophic fishes in the Southern Ocean as a result of a regime shift may have led to an increase in King Penguin (*Aptenodytes patagonicus*) populations; however, a concurrent decrease in several other seabird species was also reported (Weimerskirch et al., 2003).

Sub-Antarctic seabirds may be affected by a southward shift or reduction in the extent of the Marginal Ice Zone and changes in the nutrient availability near the South Polar Front. These areas are important foraging zones as they cannot easily move their breeding sites (Croxall, 2004). Adélie Penguins (*Pygoscelis adeliae*) stay within the Marginal Ice Zone throughout the year (Ainley, 2002). During winter, they feed near its northern limits where there is still some light. If this zone retreats too far, the birds will not have enough light to see their prey and may starve (Ainley, 2002).

In the Arctic, rapid decrease in sea ice volume and extent will affect seabirds that forage at the margins of sea ice. The Ivory Gull (*Pagophila eburnea*) fishes through cracks in the sea ice and has already declined by 90% over the last two decades in Canada (Gilchrist and Mallory, 2005). However, other species may benefit by being able to feed in open water near nesting sites earlier in spring and fledge their young before the autumn (Meehan et al., 1999).

Glaciers are already receding in all regions due to climate change (Hughes, 2000). Of the many seabird species in these glacial areas, one which has attracted attention in Alaska due to its declining numbers is the Kittlitz's Murrelet (*Brachyramphus brevirostris*). This

species breeds in Prince William Sound and Glacier Bay and its decline may be related to the retreat of tidewater glaciers. Increased sedimentation and lower salinity in the fjords with receding glaciers can lower biological productivity, leading to lack of phytoplankton bloom, which then reduces the biomass of invertebrates and of forage fish (Kuletz et al., 2003).

Species that have a specialized food type or habitat are at risk. On Shetland in the 1980s, the Arctic Tern (*Sterna paradisaea*) population declined by 55% due to an inability to adjust feeding technique or to feed on alternative prey (Suddaby and Ratcliffe, 1997). The limited range of the Galapagos Penguin (*Spheniscus mendiculus*) along with its small population puts this species at risk as well (IPCC, 2001b).

Effects on Breeding Habitats

Climate warming will cause the permafrost to melt in the Arctic, allowing forests to grow on the tundra. Scientists are still arguing about the rate and speed at which this will happen (Zöckler and Lysenko, 2000), but it will certainly reduce the habitat available to birds that use the tundra for breeding (Wormworth and Mallon, 2006). A number of seabirds breed on the tundra, including Arctic Tern and Sabine's Gull (*Larus sabini*) (Tuck and Heinzel, 1980) and they share this habitat with large numbers of wader species. Increased competition for available habitat will result both from species currently breeding there and from species who may move north due to warmer temperatures in their traditional habitats. For those species that nest in crevices, such as auklets (family Alcidae), there is a risk that increased growth of vegetation may cover crevices (Meehan et al., 1999). On an encouraging note, snow melt in spring will make nesting sites available earlier. This could benefit some species where productivity, particularly survival of young, has been reduced due to the shortness of the available nesting period (Meehan et al., 1999).

The effect of climate warming in Antarctica is already apparent with the retreat in the ice shelves and the reduction of sea ice (Ainley, 2002). In a study analysing long-term data sets on the populations and breeding success of Southern Fulmars (*Fulmarus glacialisoides*), Snow Petrels (*Pagodroma nivea*) and Emperor Penguins, the normal cyclic characteristics of these parameters have shown a significant change since 1980 as a result of climate change (Jenouvrier et al., 2005a). Population sizes of these three species are likely to decline due to

the reduction of sea ice through its influence on food webs (Jenouvrier et al. 2005b). Adélie Penguins exist only where there is sea ice (Ainley, 2002) yet ice shelves that have broken away have created barriers for penguins between their breeding and foraging areas. Enormous grounded icebergs in the Ross Sea in 2002 caused the failure of breeding colonies of Adélie Penguins as the females could not return to their breeding grounds after feeding (National Science Foundation, 2001). Instances of adult mortality due to the physical impact of drifting ice crashing into breeding areas and crushing incubating penguins have also been documented (Griffin, 2004). The Emperor Penguin is dependent on both fast ice during chick incubation and areas of open water (polynya) during winter incubation. Any changes in the duration and persistence of ice cover could have serious effects on the survival of this species (Croxall, 2004). In Antarctica, increases in Chinstrap Penguin (*Pygoscelis Antarctica*) in recent decades have been attributed to the reduction in sea ice and their preference for open water (IPCC, 2001a; Veit and Montevecchi, 2006).

An increase in temperature has caused problems by bringing spring snowfalls. The snow has buried Adélie Penguin eggs under snow banks (Croxall, 2004) and also allowed the Southern Giant Petrel (*Macronectes giganteus*), to 'crash land' at the breeding sites of the Antarctic Petrel (*Thalassoica Antarctica*) resulting in a very poor breeding season due to predation (Chambers et al., 2005).

Sea level breeding habitats include low-lying islands and shores, river banks, burrows near the sea and low cliff ledges. Low-lying islands and shores are at risk to rising sea levels as well as to the increasing frequency of storm surge events that may wash away nests (Wormworth and Mallon, 2006). Increases in the number and severity of storms will also lead to flooding of rivers and the likelihood of destroying sandy lowland river banks and estuaries used by skimmers (*Rhynchopidae* spp.) (Watkinson et al., 2004). New low-lying habitats may be formed on populated continents; however, many cliffs have been protected from erosion and sea-defense embankments have been built. The effect of these defenses is that new coastal habitats will not be formed by the rising sea levels and there will be reduced breeding habitat available for species breeding in burrows or cliffs near or close to sea level (Crooks, 2004).

Some seabirds use mangroves for breeding, including the Lesser Noddy (*Anous tenuirostris*) on the Houtman Abrolhos off the west coast of Australia (Department of the Environment and Heritage, 2005). When mangroves are starved for sediment with rising sea levels, they are submerged and lost. Low island mangroves will be particularly affected in areas such as Bermuda (Ellison, 1993); however, Ellison (2000) states that mangroves on the Pacific Islands will respond sensitively to the rise in sea level. Additionally, hurricanes in the Caribbean destroy mangroves used by Magnificent Frigatebird (*Fregata magnificens*) (Schreiber, 2001) and the predicted increase in frequency of these types of catastrophic events could drastically reduce their habitat.

For those species breeding on cliffs and in burrows at some distance above sea level, the key issue will be increased storms, precipitation and hotter temperatures, with likely flooding of burrows and the exposure of chicks to weather extremes (Schreiber, 2001). More competition for available habitat, especially in the crevices, may result. Those species currently breeding close to sea level will move up into these habitats as the sea level rises.

Effects on Breeding Success

Seabirds use different cues to initiate the breeding season. For long-distance migrants, migration to breeding grounds is initiated by photoperiod cues; short-distance migrants may use large-scale environmental cues such as the North Atlantic Oscillation. Resident species use cues such as sea surface or air temperature (Frederiksen et al., 2004; Gill, 2003; Wormworth and Mallon, 2006). Long-distance migrants using photoperiod cues may be less adaptable to changing the timing of migration, leaving them more vulnerable to environmental changes and possibly to competition from resident and short-distance migrants who may have already taken key nesting sites (Wormworth and Mallon, 2006). In addition, long-distance migrants may not be able to reach their breeding area if the distance between their breeding and non-breeding ranges increases (Huntley et al., 2006).

With changes to climate and sea surface temperature, short-distance migrants and resident species may be able to start breeding earlier and for a longer period. Additionally, resident species may benefit from warmer winters and have increased fitness for breeding (Chambers et al., 2005). The possibility of multiple broods may also be increased. Dunlop (*sensu* Chambers et al., 2005) reported atypical double nesting and protracted breeding seasons in

several seabirds including Little Penguin (*Eudyptula minor*) and Pied Cormorant (*Phalacrocorax varius*).

Seabirds time their breeding season to coincide with an abundance of suitable marine prey. Fat reserves need to be built up for egg production, the incubation period and then for raising chicks, at which time peak food abundance is required (Gill, 2003). Synchronizing the breeding season with peak food supply will be a key concern for seabirds. Seabirds in East Antarctica are arriving at their breeding colonies about 9.1 days later and laying eggs about 2.1 days later than in the 1950s. This is linked to decline in krill abundance that is associated with the decrease in sea ice; it may mean these birds are taking longer to build up the fat reserves required for breeding (Barbraud and Weimerskirch, 2006).

If food is not available or in short supply, birds will not breed or will not raise their young. At the Australian Great Barrier Reef in 2002, very high sea surface temperatures were accompanied by a lack of breeding success by Wedge-tailed Shearwaters (*Puffinus pacificus*) due to an inability to find suitable food (Smithers et al. 2003). Off the coast of British Columbia, warm sea surface temperatures over the past 20 years have been associated with drastically decreased growth rates and fledging success of Tufted Puffin (*Fratercula cirrhata*) nestlings, with fledging success near zero when waters were warmest (Gjerdrum et al., 2003).

If food is not available near the breeding area, breeding success may be impacted. Studies of several seabird species have shown that they make both short and long provisioning trips during the breeding season. The short trips enable more frequent provisioning of the young but the adults lose body mass and need to make the long trips to regain their condition. If food is in short supply around the breeding area then there will be fewer short trips and the chicks will suffer. With most long-lived species such as seabirds, adults may sacrifice their chicks for their own survival, thus permitting them to breed in following years (Chauraud and Weimerskirch, 1994; Mauck and Grubb, 1995). On Campbell Island in the sub-Antarctic, Rockhopper Penguin (*Eudyptes chrysocome*) numbers have decreased 94% since the 1940s. This decline is associated with increases in area sea surface temperatures as the food supply is thought to have moved to cooler waters away from the island (Cunningham and Moors, 1994).

For long-distance migrants, it is critical that food is available to build up body reserves before migration. In addition to those seabirds that stop over en route or surface feed, food must be available along their migratory pathways. With climate change, the timing or the location of food may not be synchronized with these events and seabirds will need to be adaptable enough to change their migratory routes. A study by Oedekoven et al. (2001) showed that over a 20 year period in the Californian Current where the sea surface temperature, wind speed and thermocline depth all increased, the Sooty Shearwater (*Puffinus griseus*) changed its migration routes and reduced its association with the Current.

Breeding success is also influenced by the fitness of birds over winter. Studies have shown that fish stocks are reduced during warm winters (Frederiksen, 2006); however, some species are able to cope with food shortages. During the 1997 El Niño event in the Pacific Ocean, the Rhinoceros Auklet (*Cerorhinca monocerata*) was able to compensate for smaller or less frequent chick feedings by extending the chicks' time in the burrow (Wilson, 2005).

Seabirds may be affected by more weather extremes during the breeding season as a result of climate change. Heat stress affects the breeding success of many species. Penguins outside of Antarctica are very prone to heat stress and abandon nests during heat waves (Griffin, 2004). In 1979, a heat wave in California caused 90% chick mortality in the Western Gull (*Larus occidentalis*) (Salzman, 1982). Increased rain or sudden torrential downpours can flood burrows or wash away nest scrapes. Increased mortality in small chicks that cannot thermoregulate is often related to precipitation and accompanied chilling (Schreiber, 2001). With higher air temperatures, the cost of thermoregulation in adult birds may influence their ability to provision their young (Schreiber, 2001). With more weather extremes, more unsuccessful breeding seasons are likely; this could lead to aging populations with no replacement birds, leaving populations vulnerable to major catastrophic events.

Weather is also expected to become more variable (IPCC, 2001a) and birds expend more energy after sudden temperature changes. This could be significant at the time of egg-laying, causing smaller eggs to be produced (Pendlebury et al., 2004). Indirectly, insects can also affect seabirds. For example, in Canada the breeding success and adult mortality of Brunnich's Guillemot (*Uria lomvia*) was impacted by peaks in mosquito numbers during

abnormally hot weather (Gaston et al., 2002). For migratory species, increased frequency of storms and changes in wind patterns may affect their ability to reach breeding grounds (Wormworth and Mallon, 2006). However, variations in weather may provide an advantage to some seabirds. The reduction in snowfall in Alaska is providing the Black Guillemot (*Cepphus grille*) and Horned Puffin (*Fratercula corniculata*) with the 80-90 day snow-free period, necessary to fledge their chicks, on a more regular basis (Meehan et al., 1999).

Conclusions

Seabirds are generally adaptable, and many adaptations have been documented over a long period with relatively slow rates of climate change. For example, the Common Guillemot (*Uria aalge*) has advanced its breeding date by 24 days per decade over the last 50 years (Root et al., 2003). With the rapid rate of climate change predicted over the next century, there is little time for seabirds to adapt. This is particularly true in the northern polar region where they will be forced to adapt to rates of warming several times higher than at mid-latitude and where they will be the most vulnerable (Wormworth and Mallon, 2006). Some species will benefit from climate change by extending ranges or by exploiting a more favorable habitat. Seabirds from tropical regions that have the flexibility to extend their range towards the poles are the least vulnerable. Species that have wide distribution and genetic variability will probably survive while those with narrow ecological niches or who are already at the end of their range are most at risk.

The effects of climate change are complex and confounded with many other variables, including other human impacts, and an in-depth understanding of a species' life history is necessary to protect them. As just one example, populations of breeding and wintering Black-browed Albatross (*Thalassarche melanophrys*) in the Southern Indian Ocean decreased from combined effects of both fisheries impacts and climate change (Rolland et al., 2008). The cumulative impacts of humans on seabird survival through climate change, fisheries interactions, pollution and invasive species should not be underestimated and merits an increased level of consideration on an international scale.

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Appendix 1. Summary of avian families that comprise the seabirds of the world. Seabirds are defined as those species that spend 80% of their lives at sea and are dependent on marine sources of food. Families of seabirds are grouped by order showing their distribution, breeding habitat, migration habits and main diet. Sources: Gill (2003), Schreiber (2001) and Tuck and Heinzel (1980).

| | Order | Family | Distribution | Breeding Habitat | Migratory | Diet |
|-----------------------------|--------------------------|-----------------------|---|--|---|--|
| Penguins | <i>Sphenisciformes</i> | <i>Spheniscidae</i> | Southern Hemisphere from the warm tropics to Antarctica | burrows, scrapes, under vegetation or nothing | Southern ocean species spend most time at sea. Tropical species spend most time near colonies | krill, fish, squid |
| Albatrosses | <i>Procellariiformes</i> | <i>Diomedidae</i> | North Pacific, Southern Ocean | colonial nesters on remote island headlands in scrapes | roaming | squid, fish, krill, zooplankton |
| Petrels, Shearwaters | <i>Procellariiformes</i> | <i>Procellariidae</i> | All oceans | Shearwaters nest in burrows on islands and cliffs; fulmars nest on rocky ledges | shearwaters-long distances | fish, squid, zooplankton (prions), krill |
| Storm-Petrels | <i>Procellariiformes</i> | <i>Hydrobatidae</i> | All oceans | colonial nesters on remote islands - burrows or crevices | yes-only on land for breeding | planktonic crustaceans |
| Diving-Petrels | <i>Procellariiformes</i> | <i>Pelecanoididae</i> | Southern oceans | colonial nesters on remote islands in burrows or crevices | yes-only on land for breeding | plankton feeders, taking mostly crustacean prey such as krill, copepods and the amphipod |
| Tropic-birds | <i>Pelecaniformes</i> | <i>Phaethontidae</i> | Tropical oceans | tropical islands on ground or ledges; Red-tailed on coral atolls with low shrubs | yes | fish, squid |

| | | | | | | |
|--|------------------------|--------------------------|---------------------------------|---|---|--|
| Pelicans | <i>Pelecaniformes</i> | <i>Pelecanidae</i> | All continents | colonial nesting in ground scrape on small island or sand spit, and in mangroves | some species migrate | fish |
| Boobies, Gannets | <i>Pelecaniformes</i> | <i>Sulidae</i> | All oceans | colonial nesters on islands, coasts on sandy beaches | varies | fish |
| Cormorants | <i>Pelecaniformes</i> | <i>Phalacrocoracidae</i> | All continents and oceans | colonial nesters, using trees, rocky islets, or cliffs | Some species migrate-brown, white, great white | fish, eels, water snakes |
| Frigatebirds | <i>Pelecaniformes</i> | <i>Fregatidae</i> | Tropical oceans | colonial nesters in trees, bushes | yes | surface feeding on fish, turtles, etc. |
| Phalaropes | <i>Charadriiformes</i> | <i>Scolopacidae</i> | Northern Hemisphere | hollows on tundra or grassy waterside site | yes | plankton |
| Skuas, Jaegers | <i>Charadriiformes</i> | <i>Stercorariidae</i> | Polar regions | some breed in arctic tundras (long-tailed, arctic, pomarine) others in Antarctic | yes | lemmings, other seabirds |
| Gulls, Terns, Noddies | <i>Charadriiformes</i> | <i>Laridae</i> | Worldwide | Noddies nest in trees; terns mostly beaches but also trees and hollows, some inland | Yes Arctic Tern migrates from Arctic to sub-Antarctic | small fish |
| Skimmers | <i>Charadriiformes</i> | <i>Rynchopidae</i> | Americas, Africa, Southern Asia | colonially on sandbars, beaches, sandy lowland rivers | short distances | small fish |
| Auks, Murres, Puffins, Guillemots | <i>Charadriiformes</i> | <i>Alcidae</i> | Northern oceans | variable puffins colonial in burrows between rocks; guillemots on rock ledges | at sea except when breeding | puffins-fish, zooplankton; guillemots-fish, crustaceans, krill |
