

## S08-4 The influences of global climate change on marine birds

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**Abstract** Global climate fluctuates at several temporal scales. For the purposes of this review, we characterize these scales as “cycles”, “trends” and “regime shifts”, as exemplified by ENSO, Global Climate Change and the North Atlantic Oscillation respectively. We investigate whether seabird populations have experienced changes in abundance that correlate with climate variability at each of these scales. There are numerous examples of seabird populations responding to cyclic variation in climate, especially ENSO. Indications so far are that, by virtue of longevity, seabirds recover quickly from declines caused by El Niño. More recently, data have accumulated to demonstrate longer-term changes in populations that correlate with long-term (decadal or more) changes in oceanic climate. While there are clear examples of past regime shifts in the marine ecosystems of the North Pacific, North Atlantic and Antarctic Oceans, these shifts have not yet resulted in major changes in the structure of seabird communities.

**Key words** Climate change, Climate scales, Seabirds, Community structure, Marine ecosystems

### 1 Introduction

The earth's atmosphere has warmed by 1°C since 1900, the most of the change having taken place since 1975 (Hayward, 1997; Hughes, 2000). This rate of warming is some ten times higher than any rate of change in the past one thousand years (Hughes, 2000). The increase in temperature has been most pronounced at the poles and decreasingly evident towards the equator, such that mean air temperature has increased by 0.05°C/year since 1945 in the Antarctic Peninsula (Smith et al., 1999). This accelerating trend has been reflected in a warming of the world's oceans (Roemmich and McGowan, 1995); the waters of the California Current have warmed by 0.75°C between 1975 and 1990 (Roemmich, 1992; Roemmich and McGowan, 1995; McGowan et al., 1998). One consequence of increasing sea temperatures is a direct effect on primary productivity through changing patterns of upwelling and advection (Hayward, 1997). Changes in primary productivity then flow up through marine food chains, ultimately affecting populations of upper level predators such as marine mammals and seabirds (Veit et al., 1996, 1997; Montevecchi and Myers, 1997).

In this review, we investigate whether the temperature shifts described above have had demonstrable effects upon populations of marine birds. The scope of our study is limited to responses at the population level, even though there are several studies of phenologic change in seabirds (e.g., Divoky, 1998).

Changes in seabird populations have indeed occurred over the past 30 years or so. However, because of the lag in

population responses to environmental change and buffering by behavioral flexibility and life history patterns, it is difficult to ascribe causes to declines and increases (Morrison, 1986; Montevecchi and Berruti, 1991). Changes in abundance have occurred in response to several climatic scales, so we address them here under three categories that more or less reflect these different spatial and temporal scales. First, there are *cyclical changes* that correlate with periodic changes in climatic variables, especially the ENSO (El Niño-Southern Oscillation). Secondly, there are longer-term changes that to date resemble non-periodic *trends* but which correlate with longer-term climatic change, often referred to as Global Climate Change. Thirdly, there are dramatic *regime shifts* in species composition which have occurred over relatively short periods of time, as evidenced from some marine and limnological studies (Cushing, 1982; Steele, 1998).

### 2 Cycles

The ENSO cycle has a period of 5–7 years. The most immediate effects of ENSO are evident near the equator, but associated fluctuations develop north and south well into temperate parts of the Pacific and elsewhere (Chelton et al., 1982; McGowan et al., 1998). Cyclical variability in seabird reproduction is evident along the California Current (Ainley et al., 1995, 1996), and as far away as Sub-Antarctic islands in the Indian Ocean (Chastel et al., 1993; Guinet et al., 1998), all of it correlated, with time lags, with the ENSO cycle.

Seabird populations have suffered catastrophic breeding failures, and occasionally substantial mortality of adults, during El Niño events in the Pacific and elsewhere (Barber

and Chavez, 1983, 1986; Boersma, 1997, 1998; Schreiber and Schreiber, 1984; Schreiber, 2002). Generally, these episodes of high mortality have been followed by a return to pre-perturbation conditions in following years such that the long-term viability of affected populations has not been impaired.

### 3 Trends

#### 3.1 Sooty shearwaters in the California Current

Surface temperatures of the California Current warmed by 0.75 °C between 1949 and 1990, and a significant, 70% decrease in zooplankton abundance followed (Roemmich, 1992; Roemmich and McGowan, 1995). The result of warming surface temperatures and zooplankton decrease is a decline in nutrients at the surface which decreases primary production. Whether the decline in nutrients is due more to decreased upwelling or advection from the north in the California Current is not clear (Hayward, 1997). Upper trophic level predators such as salmoniids and seabirds have declined along with the zooplankton (Fig. 1a; Francis and Hare, 1994; Veit et al., 1996, 1997; Francis et al., 1998). The diets of these predators are similar in the eastern Pacific, consisting primarily of euphausiids, larval rockfish and squids.

Large mobile predators are difficult to census because of the enormous ranges that they cover, making interpretation of what might represent either distributional shifts or population declines difficult. Nevertheless, two pieces of evidence indicate that sooty shearwaters (*Puffinus griseus*) have in fact declined since the 1970s. First, numbers of shearwaters have not shifted elsewhere in the interim according to substantial pelagic surveying, supporting the findings of Veit et al. (1997). Secondly, a significant decline in the breeding population of sooty shearwaters has been found in New Zealand through analysis of Maori harvesting records; and the New Zealand decline is significantly correlated with the decline within the California Current (Lyver et al., 1999). It indicates that the decline in sooty shearwaters is due, at least in part, to a decline in their prey base in the California Current.

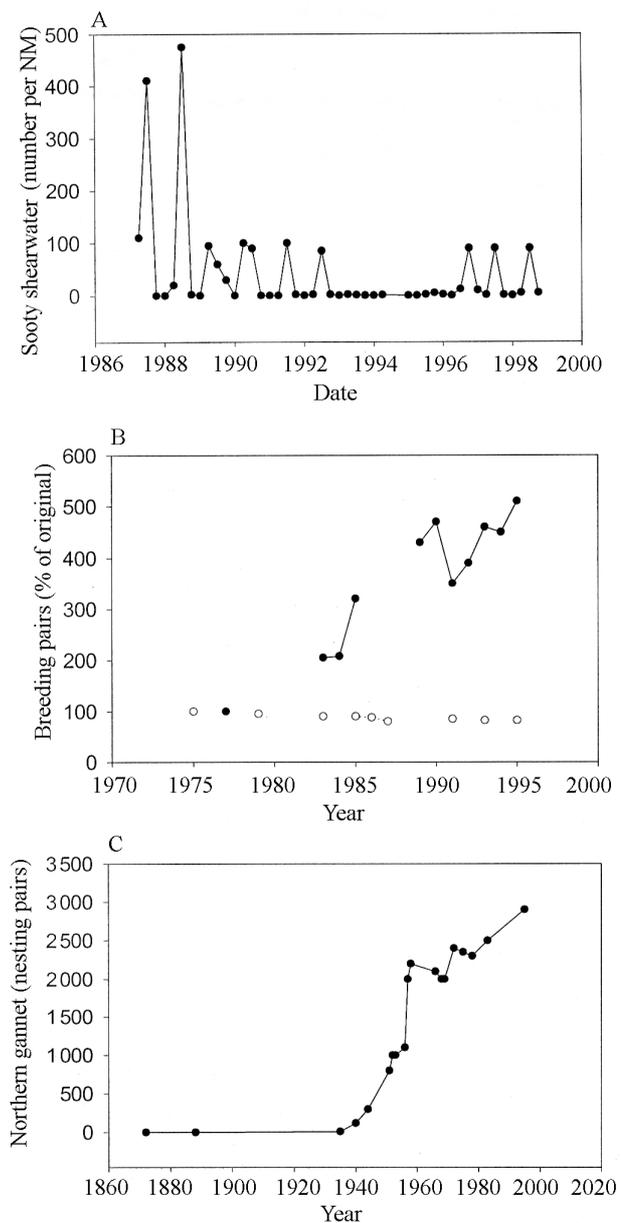
#### 3.2 Adelie and chinstrap Penguins in the Antarctic

The sea surface temperatures off the Antarctic Peninsula increased by more than 2°C between 1947 and 1995, resulting in a steady fall in winter ice cover (Smith et al., 1999). During this period, Adelie penguins have decreased while chinstrap penguins have increased (Fig. 1b; Croxall, 1992; Fraser et al., 1992; Loeb et al., 1997; Croxall et al., 2002). Because chinstrap penguins are pelagic and Adelies forage in the immediate vicinity of ice floes, it seems likely that these correlated changes are due to the trend in ice coverage.

#### 3.3 Gannets in the northwest Atlantic

Sea surface temperature off Newfoundland increased by about 0.6°C between 1910 and 1950 (Montevecchi and Myers, 1997). Major changes in commercial pelagic fish

catches in that area reflect this shift. Of particular importance to gannets was the tremendous increase (at 4 orders of magnitude) in the abundance of mackerel through that warming trend. As mackerel are preferred prey for gannets, the nesting population of gannets at Funk Island, off the northern coast of Newfoundland, increased from 0 to 3000 pairs between 1930 and 1970 (Fig. 1c; Montevecchi and Tuck, 1987; Montevecchi and Myers, 1997). It seems likely that the increase of gannets can be attributed directly to the warming of surface temperatures, which permitted a northward expansion of migratory warm-water mackerel into Newfoundland waters.



**Fig. 1** Population trajectories for (A) sooty shearwater off California, (B) Adelie (open circles) and chinstrap penguins (closed circles) on the Antarctic Peninsula, and (C) northern gannets at Funk Island, Newfoundland

Data for (A) from Hyrenbach and Veit (in press), (B) from Smith et al. (1999), and (C) from Montevecchi and Myers (1997).

## 4 Regime shifts

The term *regime shift* derives from analysis of nonlinear equations, and its exact meaning in biological terms is open to interpretation (Cushing, 1982; Steele, 1998; Scheffer et al., 2001). In a time series of biological data, it usually means a dramatic change induced by altered physical factors that is not subsequently reversed when the physical factors return to pre-perturbation conditions. Qualitatively, a regime shift implies much more than just a dramatic change in the abundance of a single species, and implicates changes at community level. There have certainly been major, long-term changes in marine ecosystems that have not reverted to former states (Springer et al., 1984, 1986, 1987; Aebischer et al., 1990; Barry et al., 1995; Piatt and Anderson, 1996; Regehr and Montevecchi, 1997; Springer, 1998; Anderson and Piatt, 1999; Croxall et al., 2002). Some of these changes undoubtedly amount to what Scheffer et al. (2001) describe as regime shifts. What is less clear is whether changes recorded at the level of seabird communities represent what can be called a regime shift.

Nevertheless, what surely qualifies is the abrupt change in ecosystem state in the north Pacific in about 1977 (Francis et al., 1998; Scheffer et al., 2001). This abrupt, so far un-reversed shift involves diverse taxa, from phytoplankton to birds. Yet, while changes in seabird reproductive rates coincided with it (Piatt and Anderson, 1996; Springer, 1998), seabird community structure remained little affected. For example, the ranking of seabird abundance did not change among species in 1977, the year of the shift. A similar regime shift initiated by substantial climatic change occurred in the north Atlantic Ocean around 1980, with impacts on phytoplankton, zooplankton, fish and kittiwake reproduction (Aebischer et al. 1990). Yet again as in the north Pacific, no substantive change in seabird community structure seems to have occurred. It is possible that seabird communities have been selected to withstand such perturbation, even at the long-term, decadal scale, the coarsest scale of temporal resolution so far found.

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