

Effects of Climate Variation on Seabird Population Dynamics

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There is increasing evidence for recent changes in the climate, but the ecological implications of these findings remain unclear[1]. For many long-lived wildlife species of conservation or economic importance, our understanding of how populations respond to environmental changes is based upon surveys at breeding grounds[2]. These species tend to delay sexual maturity for several years, so it may take many years to detect the impact of climate change on demographic processes related to juvenile stages of their life cycles.

A recent study published in *Nature*[3] has now used data collected during a 50-year field study to show that indices of climate variation may have lagged effects on the population dynamics of the northern fulmar (*Fulmarus glacialis*), a procellariiform seabird.

The North Atlantic Oscillation (NAO) is an alteration in the difference in pressure at sea level between the low pressure zone over Iceland and the high pressure zone over the Azores[4]. This single index explains a significant proportion of variability of the circulation of air and water masses in the Atlantic, and has previously proved useful for exploring the ecological impacts of climate variation[5]. Over the last 10 years, several studies have found links between the NAO and various aspects of the breeding biology and population dynamics of terrestrial vertebrates[6,7]. Similarly, the abundance of marine zooplankton and fish in several parts of the North Atlantic varies in relation to the NAO[8]. However, it has not previously been possible to assess whether this subsequently impacts long-lived marine top predators such as seabirds, seals, and cetaceans.

In 1950, ecologists at the University of Aberdeen initiated studies of a growing colony of fulmars in Orkney, Scotland. This has now become one of the longest-running ecological field studies in the world[9], and annual observations of individually marked adults have provided unique opportunities to explore the influence of climate variability upon different population parameters. In this latest study, variations in the winter NAO index were shown to influence both the probability that adults would breed in any particular year, and their subsequent success in fledging a chick. Breeding probability and breeding success were highest in those years when the

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NAO was in its negative phase, as seen during the cold hard winter in the early 1960s. Such conditions are known to lead to an increase in zooplankton off the Scottish coast, suggesting that increases in the fulmars' prey stocks may have improved breeding performance. Alternatively, variations in wind speeds associated with the NAO could influence foraging costs and the probability of birds being present at the colony, particularly for a soaring bird that will use more energy when flying in calm conditions[10]. In addition to the observations of adult birds, each year's cohort of chicks was ringed to allow detection if they returned to breed at the colony (typically at 8 years old). The proportion of each cohort that subsequently recruited to breed at the colony varied from 0–8%. This variation was unrelated to the NAO, but was strongly correlated to another long-term climate proxy that uses reconstructed tree-ring data to estimate North Hemisphere temperature anomalies[11]. A smaller proportion of the cohorts born in cold years were subsequently found breeding at the colony, whereas recruitment of chicks born in warmer than average years was typically >6%.

The influence of these two climatic variables on different population parameters suggests that overall population responses to climate change are likely to be extremely complex. As predicted from these findings, changes in the size of the fulmar's breeding colony were related to lagged effects of both the NAO and temperature, through their influence on the birds' early life-stages. These findings highlight the importance of long-term ecological studies to explore the responses of wildlife populations to environmental change. Furthermore, such studies promise to be most powerful where information on known individuals can be integrated with population studies. Population dynamics, assessed through survey of population size, integrates all demographic processes (survival, fecundity, emigration, immigration, age of first reproduction, and breeding frequency). Individual based studies give access to some of these processes, particularly survival and, as illustrated in the paper published in *Nature*, breeding frequency.

Assessments of the ecological consequences of climate change on these long-lived vertebrates now require further work in two important areas. First, the dynamics of such species are expected to be influenced strongly by variations in adult survival[12], and work is now underway to use new advances in capture-mark-recapture analyses[13] to determine whether climate variation also influences survival of these birds. Once the influence of climatic variability on adult survival is understood, it will be possible to build demographic models to predict the dynamics of the population under various scenarios of climate change[12]. Secondly, whilst the influence of age and experience upon reproductive success is well reported[14], our understanding of the extent of reproductive senescence in natural populations remains constrained because studies have not controlled for environmental variability[15]. This study has illustrated that the role of environmental variation must be considered when addressing such questions. This is especially true for any influence of the NAO, which shows a periodicity at decadal temporal scales[4]. Studies of demographic processes typically occur over relatively short periods (5–15 years), and may thus cover periods during which an index such as the NAO will be in a predominantly increasing or decreasing phase. Under these conditions, the potential effects of NAO and of age will be difficult to disentangle. To overcome this, studies should focus on individuals of known age to fully understand variation in demographic parameters. Furthermore, researchers must maintain marked individuals and population monitoring programs over time periods that are long enough to cover various climatic regimes, for example both increasing and decreasing phases of the NAO. Future studies of individuals of known age should now be used to explore the relative importance of age, experience and environmental variability upon the dynamics of these populations.

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