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Indicators of seabird reproductive performance demonstrate the impact of commercial fisheries on seabird populations in the North Sea

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ABSTRACT

In a world of growing anthropogenic pressures on biodiversity, effective indicators need to be specific and sensitive to the pressures in the ecosystem concerned, yet be simple enough to be interpreted by non-experts and straightforward enough to facilitate routine monitoring. Globally, seabirds are under increasing pressure as a result of anthropogenic activities and environmental variation. Traditionally, seabird indicators have been based on abundance at breeding colonies. However, as many species do not reach sexual maturity for several years, and may not attend the colony over this time period, such indicators may fail to capture the ecological complexity of the system concerned.

We constructed two indicators of the state of nine seabird species that breed along the UK coast of the North Sea: (i) abundance of seabirds at breeding colonies, and (ii) probability of seabird breeding failure. The indicators were significantly and strongly correlated with each other for eight out of nine species, but the abundance indicator typically lagged the indicator on seabird breeding failure by two to three years. We then considered a third indicator which compared kittiwake (*Rissa tridactyla*) breeding success to the levels expected given the underlying environmental conditions; changes in the abundance indicator also lagged this by three years. We investigate how sensitive each of these indicators was to the impacts of fishing. We found that the species which had seen the greatest increases in breeding failure rate over the study period were those species which were most sensitive to fisheries pressure.

By focussing on demographic parameters, and correcting for the underlying environmental conditions, we can detect potentially important population level changes at an earlier stage than by focussing on abundance alone. These indicators are able to more accurately capture the complexity of the ecosystem concerned and can be readily interpreted by policy-makers.

1. Introduction

Globally, seabirds are under increasing pressure from anthropogenic activities, such as fishing, pollution and resource extraction (e.g. Cury et al., 2011; Furness, 2002; Furness and Camphuysen, 1997; Furness and Tasker, 2000; Tasker and Becker, 1992; Wiese and Ryan, 2003). These pressures may exacerbate the impact of variation in environmental factors, such as climate (Frederiksen et al., 2004a; Gremillet and Boulinier, 2009; Sandvik et al., 2005). Consequently, there is an increasing recognition of the importance of monitoring the impact of pressures on seabird populations (Parsons et al., 2008; Rogers and Greenaway, 2005).

Monitoring population-level impacts of pressures on seabirds, however, presents a number of challenges. Counting the number of birds or breeding pairs attending colonies is relatively straightforward for most species (Walsh et al., 1995), but variation in the number of birds attending a colony may not necessarily reflect the influence of environment on population size. This is because, seabirds are long-lived and can delay breeding for several years following fledging. Adult birds may refrain from breeding in years when environmental conditions are poor (Erikstad et al., 1998; Oro and Furness, 2002) and immature birds vary in the age at which they start attending the colony, and the age at which they start breeding (Crespin et al., 2006; Dittman and Becker, 2003; Halley et al., 1995). Consequently, a need has been identified to develop approaches to monitoring that allow the integration of processes acting at different levels (Gremillet and Boulinier, 2009). Evidence

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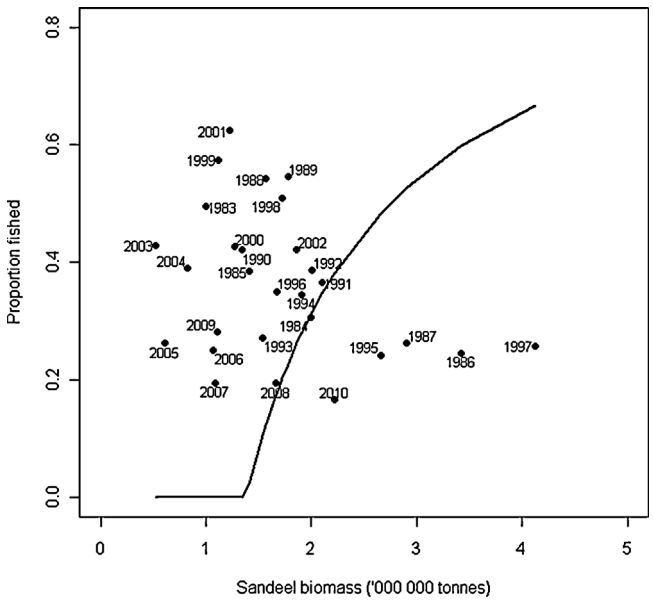

Fig. 1. The proportion of the sandeel population fished in each year in relation to total sandeel biomass in the North Sea. The black line shows the maximum proportion of the sandeel population that can be fished for any given population size whilst sticking to the "Third for the Birds" rule of Cury et al. (2011), that a third of the long-term maximum biomass of sandeel must be left by fisheries to support sustainable seabird populations in the North Sea.

suggests that reproductive performance of seabirds, rather than the number of birds attending a breeding colony, may be a better reflection of variation in environmental conditions (Erikstad et al., 1998; Piatt et al., 2007; Regehr and Montevecchi, 1997).

The United Kingdom (UK) provides a valuable case study with which to test indicators based on species breeding performance, because a wealth of monitoring data have been collected there over a number of years (JNCC, 2012; Lloyd et al., 1991; Mitchell et al., 2004). The UK is of great significance in terms of seabird conservation, hosting a large number of internationally important breeding colonies for several species (Mitchell et al., 2004). The implementation of the, legally binding, Marine Strategy Framework Directive (MSFD) across the European Union and in some neighbouring states requires an ecosystem-based approach to the management of human activities within the marine environment (EC, 2008). This means ensuring that "*the collective pressures from human activities acting on the marine environment are kept at levels consistent with seas that are clean, healthy and productive, whilst providing for the sustainable use of marine goods and services by present and future generations*" (EC, 2008). This legislation provides a strong policy driver to monitor seabird populations, to assess anthropogenic impacts on them, and to instigate management measures where necessary to reduce these impacts.

One of the main anthropogenic pressures on seabird populations, especially in UK waters, is caused by commercial fishing (Frederiksen et al., 2004b; Furness, 2002; Furness and Tasker, 2000). Commercial fishing can compete with seabirds over increasingly limited stocks of fish species. Based on data from seven seabird ecosystems, Cury et al. (2011) suggest that as a general rule, a third of the peak long term maximum stock size of forage fish should be left for birds in each year to ensure that seabird populations remain stable. For sandeel *Ammodytes* spp., key prey species for many seabirds in the North Sea (Rindorf et al., 2000; Wanless et al., 2005; Wright and Begg, 1997), this target was only met in five years between 1986 and 2010 (Fig. 1). We assess the impact that this pressure has had on seabird populations using long-term monitoring data collected in a standardised fashion throughout the UK between 1986 and 2010.

We develop three indicators with which to assess the state of nine UK seabird populations. The first indicator examines annual variation in numbers of those nine species attending the breeding colonies and the second indicator examines the annual variation in breeding failure, defined as the probability of birds from that years' cohort recruiting into the breeding population is close to zero, in these species. Furness and Tasker (2000) ranked species based on their sensitivity to reductions in sandeel abundance. If current levels of fisheries are having a detrimental impact on seabirds, we would expect this to be reflected in these indicators, with those species most sensitive to depleted stocks of prey species exhibiting the highest breeding failure rates and the most severe population declines. The third indicator focuses on the annual breeding success of a single well-studied species, kittiwake *Rissa tridactyla*, for which there are well established links between population trends and the availability of sandeel, a key prey species (Frederiksen et al., 2005, 2007; Harris et al., 1997; Lewis et al., 2001; Rindorf et al., 2000). Breeding success in the kittiwake has been shown to vary in relation to sea surface temperature in February and March of the previous year (hereafter SST_{-1}, see Frederiksen et al., 2004a). This relationship reflects the availability of sandeel during the current breeding season because birds prey primarily on 1-group sandeels, whose abundance is related to water temperature in the spring of the previous year, when they hatch (Frederiksen et al., 2004a). This allows us to determine when breeding success has deviated from the level that would be expected under the observed environmental conditions at each kittiwake colony throughout our study period.

The potential for developing seabird indicators based on the breeding success has been widely discussed (Frederiksen et al., 2004a, 2008; Wanless et al., 2007) and there is a clear ecological rationale for doing so. Amongst long-lived species, which may not breed every year, changes in abundance and survival may not be apparent for several years. In contrast, changes in factors such as breeding success may be more responsive to environmental pressures. With this in mind, we may expect abundance-based indicators to lag those based on measures of breeding success or failure.

In order to assess the relative health of the seabird populations within North Sea and Celtic Sea, corresponding to the Greater North Sea and Celtic Seas OSPAR regions (Tromp and Wieriks, 1994), we compare the indicator values between these two regions. A key aim of these indictors is to assess the impact of commercial fisheries on seabird populations. The use of seabirds as quantitative indicators in this fashion has been questioned (Gremillet and Charmantier, 2010), with concerns over the plasticity of species response to change and the applicability of indicators beyond species breeding grounds (Dänhardt and Becker, 2011). We therefore examine whether the indicators are sensitive to changes in fish stocks and fishing pressure and discuss regional population differences between populations in relation to likely food stocks. Finally, we consider whether the inclusion of demographic parameters can improve our existing suite of indicators.

2. Materials and methods

2.1. Data collection

Seabird populations in Britain and Ireland are monitored on an annual basis at a range of colonies throughout Britain and Ireland as part of the Seabird Monitoring Programme (SMP, http://jncc.defra.gov.uk/page-1550). Data describing the number of pairs (typically estimated as either the number of adult birds present or the number of apparently occupied nests, sites or