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Original article

Relation between climatic factors, diet and reproductive parameters of Little Terns over a decade

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ABSTRACT

We used 10 years of data on clutch size, egg size and diet, and 8 years of data on timing of laying on Little Terns (*Sternula albifrons*) breeding in Ria Formosa lagoon system, Algarve, Portugal to assess whether diet acts as an important intermediary between climatic conditions and breeding parameters. We used Generalized Linear Models to relate (1) the relative occurrence and size of the main prey species, sand smelts (*Atherina* spp.), with environmental variables, a large-scale climate variable, the North Atlantic Oscillation (NAO) index, and a local scale variable, the sea-surface temperature (SST), and (2) the respective effects of sand smelts relative occurrence, NAO index and SST on Little Tern breeding parameters. The diet of Little Terns was dominated by sand smelts, with a frequency occurrence of over 60% in all years. The winter SST (February) was negatively associated with the relative occurrence of sand smelts in the diet of Little Terns during the breeding season which, in turn, was positively associated with Little Tern clutch size. Our results suggest that negative NAO conditions in the Atlantic Ocean, often associated with rougher sea conditions (greater vertical mixing, stronger winds and lower SST) were related with earlier breeding, and lower SST in the surroundings of the colony during winter–spring favour the abundance of prey fish for Little Terns as well as their reproductive parameters. Climate patterns at both large and local scales are likely to change in the future, which may have important implications for estuarine seabirds in Southern Europe.

1. Introduction

The distribution and abundance of prey fish for marine top predators is largely determined by climate and oceanographic conditions, which therefore influence prey availability to top predators such as seabirds (Aebischer et al., 1990; Furness and Tasker, 2000). Marine birds are therefore of potential use as sentinels to identify changing states in their prey populations and environmental conditions (Piatt et al., 2007 but see Grémillet and Charmantier, 2010). During the breeding season coastal tern species such as small terns of the genus *Sterna* and *Sternula* are particularly sensitive to changes in their prey distribution and abundance, because they have a very restricted foraging range and need abundant food resources very close to the colony in order to breed successfully (Furness and Camphuysen, 1997; Furness and Tasker, 2000).

Marine climate conditions are closely related to large-scale atmospheric phenomena, of which, the North Atlantic Oscillation (NAO) index is one of the best known. The NAO refers to a north–south alternation in atmospheric mass between the subtropical Atlantic and the Arctic (Hurrell et al., 2003) and induces changes in surface temperature, precipitation and storm tracks over the North Atlantic and Europe (Pinto and Raible, 2012; Stenseth et al., 2003). During the positive phase of the NAO index the westerly winds strengthen and move northwards, inducing increased precipitation and sea-surface temperature in northern Europe and opposite conditions in Southern Europe. During the negative phase of the NAO the storm track is diverged towards southern Europe, leading to an increase in warm conditions, windspeed and vertical water mixing along the Iberian Peninsula and in Southern Europe (Pinto and Raible, 2012). Local climatic conditions are influenced by the NAO index, and for the Iberian Peninsula there is usually a negative relationship between NAO and sea-surface temperature (SST) (Báez et al., 2013 and references therein), although local climatic conditions cannot always be clearly predicted by the NAO (Becker and Pauly, 1996). Recent studies show an effect of NAO on life-history traits of North Atlantic seabirds including breeding success (e.g. Frederiksen et al., 2004; Wanless et al., 2005) and annual survival

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(e.g. Grosbois and Thompson, 2005; Votier et al., 2005). However, all studies to date have dealt with pelagic seabirds, mostly in Northern Europe, and there is virtually no data on the NAO effects for seabirds in Southern Europe, particularly for coastal/estuarine seabirds (breeding and foraging in estuarine areas and along the coast, mostly up to 5 km offshore) such as the Little Tern *Sternula albifrons*.

Breeding success may be of limited value as a response variable to assess the influence of climate and oceanographic conditions for estuarine terns, because several studies indicate that factors such as predation and anthropogenic disturbance are often more important in explaining variability in breeding success than changes in prey abundance (Holloway, 1993; Medeiros et al., 2007 and references therein, but see Dänhardt and Becker, 2011). However, other breeding parameters such as timing of laying and clutch size are less influenced by predation, and are positively correlated with breeding success and also influenced by climate and oceanographic conditions (Ramos et al., 2002; Monticelli et al., 2007; Wanless et al., 2009). Therefore, they are likely to be more adequate response variables for estuarine seabirds such as Little Terns, when assessing the influence of environmental factors such as climate and prey abundance on reproductive parameters.

Catry et al. (2006) showed that adult Little Terns in the Ria Formosa lagoon system, Algarve, Southern Portugal, feed mainly on the two most abundant prey present in the lagoon: sand smelts (*Atherina* spp.) and gobies (*Pomatoschistus* spp.). As these two prey species explained the main differences in diet among years, Catry et al. (2006) suggested that diet composition of adults Little Terns would be a reliable indicator of the relative abundance of these two fish species in the lagoon system. Paiva et al. (2006a, 2006b) showed that sand smelts are more profitable than gobies, because, although the energetic content of both prey is similar, sand smelts provide more energy yield per unit foraging effort due to its significantly larger size. Therefore, the abundance of sand smelts should have an important influence on Little Tern breeding parameters, but this was not examined. We anticipate that oceanographic conditions may influence the abundance of sand smelts, which in turn will influence timing of breeding and clutch size of Little Terns. This is expected, because the nesting season of terns (Safina et al., 1988), including Little Terns (Catry et al., 2006) and the sister species Least Tern *Sternula antillarum* (Zuria and Mellink, 2005) has been demonstrated to coincide with peak prey fish abundance.

We used 10 years of data on clutch size, egg size and diet and 8 years of data on timing of breeding of Little Terns to evaluate whether diet acts as an important intermediary between climatic conditions and breeding parameters. Specifically, we evaluated (1) the correlations between the relative occurrence and size of the main prey species (sand smelts) and environmental variables, a large-scale climate variable, the NAO index, and a local scale variable, sea-surface temperature, and (2) the respective effects of sand smelts relative occurrence, NAO index and SST on variability in Little Tern breeding parameters (timing of laying, clutch size and egg size).

2. Material and methods

2.1. Breeding parameters and diet

We used published data for 2002–2004 (Catry et al., 2004, 2006) and collected data for 2005–2011 on timing of breeding, clutch size, egg size and diet of Little Terns breeding on the salinas (man-made salt extraction ponds) of Santa Luzia, Ria Formosa, Algarve, Portugal (N 37°06′303″; W 7°38′203″), an area about 10–245 m distance from the lagoon and 800 m from the sea (Fig. 1). The lagoon, where most of the terns forage (Paiva et al., 2008), is separated from the sea by sand barrier islands and, each tidal cycle, exchanges very large volumes of water with the sea through entrance channels (Newton and Mudge, 2003). Each year the whole area of the salinas was searched; some birds appeared to change the exact nesting location by at least 20–250 m, apparently determined by an increase in local vegetation cover in some areas of the salinas since 2002 (J. A. Ramos and V. H. Paiva, pers. observations).

Each nest was numbered and egg length (L) and egg breadth (B) were measured with callipers to 0.1 mm, and volume was calculated using the formula: $V\ (\mathrm{cm}^3) = K \times L \times B^2$, where $K = 0.4866$ (Coulson, 1963). The nesting area and all nests were visited every 2–5 days and daily between 13 and 17 May to ascertain whether nests were initiated in the first or second 15-day period of May. From 2005 to 2011 we stopped searching the nesting area by 3–15 June, because previous years showed that very few clutches were laid after this period (replacement clutches were not considered). Clutch size and egg size were calculated using data from complete clutches only. To prevent pseudo-replication problems (Hurlbert, 1984) in egg measurements data we first calculated the mean for each clutch and then the annual mean of all clutches. Visits to the nesting areas lasted between 10 and 20 min and did not seem to cause undue disturbance, as birds resumed incubation soon after we left the areas (Catry et al., 2004).

In our study area Little Terns regurgitate along the water line of the ponds while resting, and to ensure that pellets were collected from many different individuals this whole area was searched. Pellets were collected from 2 May to 15 June (the main laying season of the Little Terns) and stored in individual paper bags for later examination in the laboratory. There, hard parts in the pellets, mainly sagittae otoliths, were separated from other remains and identified to the lowest taxonomic level possible (Catry et al., 2006) with the help of our own otoliths reference collection and identification guides (Nolf, 1985; Härkönnen, 1986; Tuset et al., 2008). Diet composition of adult Little Terns was expressed as frequency of occurrence, calculated as the number of pellets with a given prey type. We used this measure, because it enables a reliable comparison among years; most of the pellets contained either sand smelts or gobies and the other species were present at much lower frequencies, with only one otolith/pellet for virtually all pellets (Catry et al., 2006). An assessment of diet using pellets may be biased, particularly towards smaller otoliths, largely due to the differential digestibility of otoliths of the various prey items. However, it allows reliable comparisons among years (Duffy and Jackson, 1986; Catry et al., 2006), and we were interested on the annual variation in the relative importance of the most important prey items.

2.2. Environmental variables

We used the Gibraltar minus Iceland version of the NAO index (Jones et al., 1997), as this encompasses the Algarve, southern Portugal (downloaded from http://www.cru.uea.ac.uk/~timo/datapages/naoi.htm). We used IGOSS (Integrated Global Ocean Services Systems, Reynolds et al., 2002) mean monthly SST blended from ship, buoy and bias-corrected satellite data (available from http://iridl.ldeo.columbia.edu/SOURCES/.IGOSS) for the location of 7° 5′W and 36° 5′ N, which is the closest marine area to the salinas of Santa Luzia available in the site (Fig. 1). This SST should provide an indication of inter-annual variation in sea-surface temperature affecting the lagoon of Ria Formosa and the immediate adjacent sea area where terns are observed foraging (Paiva et al., 2008).

2.3. Data analysis

We used Spearman correlation to assess whether each environmental variable (NAO index and local SST) and each Little Tern