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Brief report

Large scale climate affects the timing of spring arrival but local weather determines the start of breeding in a northern Little Tern (*Sternula albifrons*) population

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In migratory birds, the timing of arrival to the breeding grounds can be affected by weather on the migration routes and breeding sites at arrival. Timing of breeding can be affected by arrival dates but also by local weather conditions during the pre-breeding period. Because long-distance migrants arrive and breed late in the season, weather is thought to be less important, but more information is needed especially from seabirds that are vulnerable to climatic effects. I used observation data from the Little Tern (*Sternula albifrons*), a long-distance migrant, made by bird watchers during 2006–2016 to examine whether their spring arrival to the breeding grounds in Finland is associated with the large-scale weather pattern (the North Atlantic Oscillation; NAO index) or local weather. In addition, I used breeding data to examine whether the start of egg laying is associated with the annual first arrival dates, local weather or the NAO index. Spring arrival was associated with large scale weather patterns rather than local weather conditions. Little Terns arrived earlier when the April–May NAO index was positive being consistent with most migratory birds. However, early arrival dates did not translate to early timing of breeding which was more determined by local temperatures before egg laying. Arriving early allows preparation for breeding, e.g., courtship feeding, and makes it possible to start breeding when conditions become suitable for egg laying, and suggests that these long-distance migrants should be able to track advancing springs and start their breeding in the most optimal time.

1. Introduction

The timing of breeding in migratory species can be affected by endogenous factors and conditions in the non-breeding, migration and breeding grounds (Both *et al.* 2006). Large scale weather patterns and weather at the stopover sites usually affect the timing of migration and arrival to breeding sites (Hubalek 2003, Hüppop & Hüppop 2003, Vähätalo *et al.* 2004, Polakowski *et al.* 2018). Thus, weather during spring migration can potentially affect the timing of breeding. For many species, however, the environmental conditions after arrival determine the start of egg laying, and the timing of breeding may be more associated with local weather during the pre-breeding stage and be less linked with weather during migration (Weidinger & Král 2007, Valtonen *et al.* 2017).

Long-distance migrants arrive later and breed later than short-distance migrants, and may be less flexible in responding to environmental conditions such as weather during migration (Rainio *et al.* 2006, Palm *et al.* 2009, Calvert *et al.* 2012, Kullberg *et al.* 2015). This means that they are not as able to advance their breeding in response to climate change (Lehikoinen *et al.* 2004, Hubalek & Capek 2008), and are more vulnerable to climate change through e.g., trophic mismatches, warranting information on the effects of climate on the timing of arrival and breeding (Robinson *et al.* 2009).

Life histories of seabirds are particularly vulnerable to climatic effects (e.g. Sandvik *et al.* 2005, Sandvik & Erikstad 2008, Frederiksen *et al.* 2008, Catry *et al.* 2013). While weather affects timing of their reproduction (Moe *et al.* 2009, Wanless *et al.* 2009), a recent meta-analysis indicates that seabird populations have not adjusted their breeding seasons over time (Keogan *et al.* 2018). So far, few studies have examined climatic effects on both arrival and laying dates (e.g. Ramos *et al.* 2002, Wanless *et al.* 2009), especially in long-distance migrants breeding at high latitudes.

Here, I studied a northern population of a long distance migrant, the Little Tern (*Sternula albifrons*), breeding in Finland during 2006–2016 to test (1) whether the timing of spring arrival is associated with large scale weather patterns or local weather, and (2) whether the start of egg laying is associated with annual first arrival dates, local weather or large scale climate patterns.

2. Material and methods

2.1. Data on arrival dates

I used observation data collected by bird watchers to retrieve information on the timing of arrival to the breeding grounds in Northern Ostrobothnia during 2006–2016 (Supplementary material, Fig. S1). The spring migration season from mid-April to late May is a very active bird watching time on this coastline where people come to follow bird migration at numerous towers and vantage points. Surveillance can be considered rather continuous across this spring season, and nothing suggests that effort varied substantially across the study years. I retrieved information on the first arrival date and the fifth arrival date. I consider the data on first arrival to be reliable in particular, because the coast is under strong surveillance during the spring months (April–May), the Little Tern is easy to observe and identify, and because first spring sightings are efficiently reported to the database. The fifth arrival date was used as proxy that would depict more of an overall arrival date than first arrival date. When calculating it, one day constituted an observation at one distinct area per one day. I gathered the data from the online service TIIRA (https://www.tiira.fi/) maintained by Birdlife Finland.

2.2. Data on laying dates

Breeding of the largest Little Tern colony in Finland was followed closely in the Port of Oulu (65°00’ N, 25°28’ E; Fig. S1) during 2006–2016 (Pakanen *et al.* 2014). The number of pairs varied annually between 9–20. I monitored the breeding site starting from mid-May and searched for nests after clear settlement to some location. I continued nest searching throughout the season, and followed the nests until hatching. I determined the timing of the start of egg laying based on floating eggs in water, egg number and hatching dates. See Pakanen *et al.* (2014) for detailed description of data collection.

2.3. Covariates

I used the station based Hurrell North Atlantic Oscillation (NAO) Index from April–May, May and June (https://climatedataguide.ucar.edu/). I retrieved air temperature data from the Vihreäsaari station (https://climexp.knmi.nl/) for different spring periods. Here I used the earliest sighting (May 2) and the earliest first egg laying date (May 25) as a basis for dividing the spring into periods of 10, 20 or 30 days. The covariates for arrival dates included periods between April 3 and May 12, and

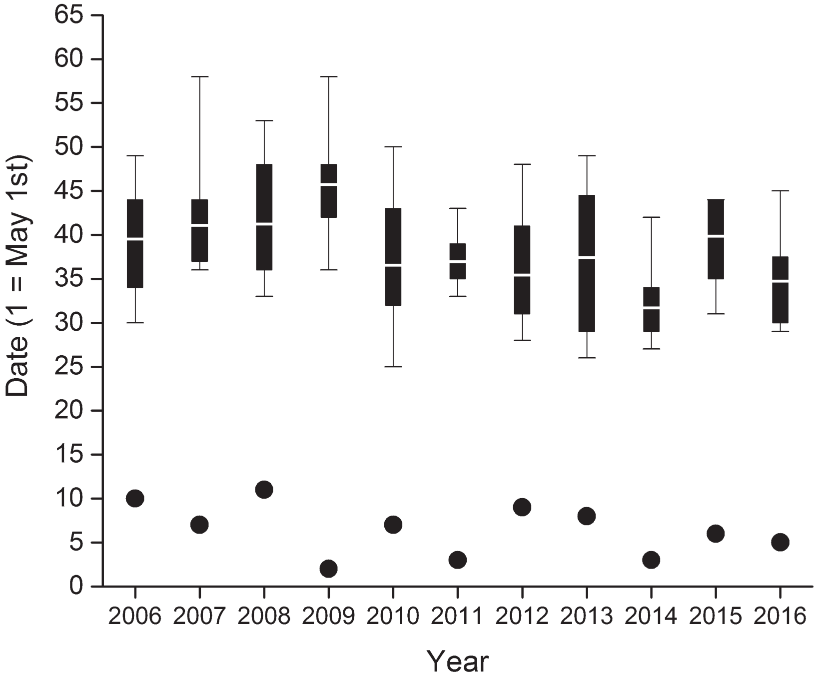

Fig. 1. First annual arrival dates (circles) of Little Terns in Northern Ostrobothnia, Finland and laying dates in Oulu, Finland (boxplot: box = 25–75% of observations, mean = white line and whiskers = min–max).

for first egg laying dates for periods between April 26 and June 13.

2.4. Data analysis

I fitted linear regression models to explain variation in annual arrival dates (the first spring sighting day and fifth observation day), annual laying dates (first egg and mean egg laying date) and the time between first arrival date and first egg laying date. The independent variables included the different NAO indices and temperature variables. When analyzing laying dates, I also used the arrival dates as independent variables. I also examined for temporal trends. The Durbin-Watson statistic suggested no temporal autocorrelation in the trend models.

The model sets included univariate models with the NAO index and temperature as independent variables and multivariate models with two variable combinations of the NAO index and temperature, or combinations of arrival dates together with the NAO index or temperature. I used the Akaike's information criterion that is corrected for small sample size (AICc) to rank models. I made inferences based on the best models, and considered models within ΔAICc ≤ 2 to be equally supported.

Because some of the response variables showed evidence of temporal trends (see results), I repeated the analysis with detrended dependent and independent variables (Haest *et al.* 2018). I refer to the results from the detrended variables in cases where the results changed. The analyses were performed in program R version 3.3.2 (R Development Core Team 2016).

3. Results

3.1. Timing of arrival

First arrival dates of Little Terns varied between May 2 and May 11 (Fig. 1). There was no significant temporal trend (β_{TREND} = –0.355, SE = 0.275, R^2 = 0.16, Supplementary material, Table S1). First spring arrival dates occurred earlier when the April–May NAO index was positive ($\beta_{NAO4–5}$ = –1.124, SE = 0.459, R^2 = 0.40; Fig. 2), but the effect was not strong as the null model was equally supported (ΔAICc = 1.69, Table S1). With detrended variables, the effect became stronger ($\beta_{NAO4–5}$ = –1.167, SE = 0.382, R^2 = 0.51; ΔAICc = 3.89; Table S1). Multivariate models did not receive support, and first arrival dates were not linked to local temperatures (Table S1).

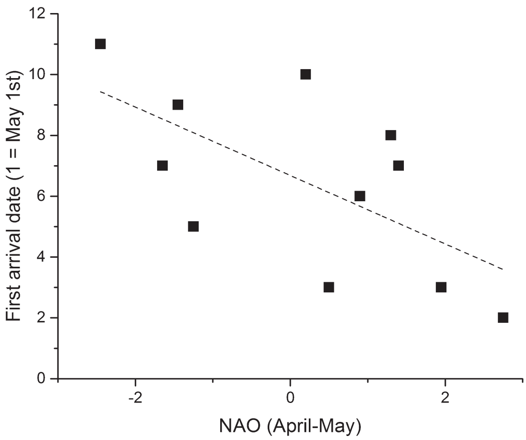

Fig. 2. First arrival date of Little Terns in Northern Ostrobothnia, Finland in relation to the April–May NAO index.

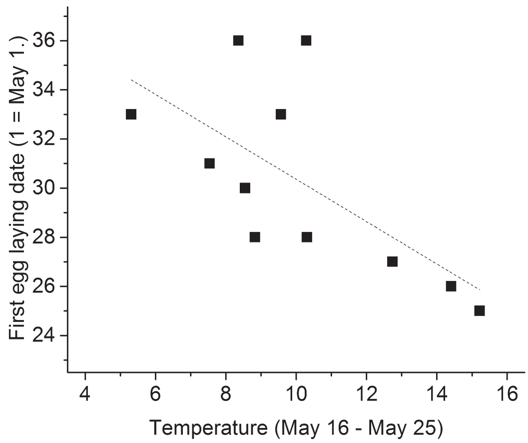

Fig. 3. First egg laying date of Little Terns in Oulu, Finland in relation to mean temperature (° C) during May 16–May 25.

The fifth observation date varied between May 7 and May 18. The trend model was clearly the best model and suggested an advancement of about six days during the study (β_{TREND} = –0.791, SE = 0.216, R^2 = 0.60, ΔAICc = 6.12, Supplementary material, Table S2). Models encompassing weather variables did not receive support (Table S2). When using detrended variables, the best model (with 2.89 ΔAICc difference to next) indicated a negative relationship with the April NAO index and temperatures during April 3–22 (β_{NAO4} = –0.905, SE = 0.223; $\beta_{TEMP\_APRIL3–22}$ = –1.255, SE = 0.343; *Adj.* R^2 = 0.70; Table S2).

3.2. Timing of laying

Timing of laying of the first egg varied between May 25 and June 5, and did not advance during the study (Fig. 1; β_{TREND} = –0.591, SE = 0.333, R^2 = 0.26, Supplementary material, Table S3). All best models included negative associations with the mean temperature before the earliest recorded laying date (May 16–25; Fig. 3) and after it (May 16–June 4), and positive associations with NAO indices in April and May or May ($\beta_{TEMP\_MAY16–25}$ = –0.954, SE = 0.225; $\beta_{NAO4–5}$ = 1.304, SE = 0.400, *Adj.* R^2 = 0.70; Table S3). However, when detrended variables were used, the model including the timing of first arrival and temperature between May 16 and May 25 was clearly the best (Table S3, ΔAICc = 2.91; $\beta_{TEMP\_MAY16–25}$ = –0.922, SE = 0.176; $\beta_{FIRST\ ARRIVAL}$ = –0.824, SE = 0.183, *Adj.* R^2 = 0.79).

Mean egg laying date for first nests tended to advance during the study (Fig. 1; β_{TREND} = –0.672, SE = 0.312, R^2 = 0.34, ΔAICc = 0.64, Supplementary material, Table S4). The trend model and a model with the fifth arrival date ($\beta_{FIFTH\_ARRVIVAL}$ = 0.610, SE = 0.316, *Adj.* R^2 = 0.21) were equally supported to the null model, which suggests weak effects (Table S4). When detrended variables were used, the best model (with 2.46 ΔAICc difference to next model) included June 5–14 temperatures (a time when most nests are laid) and the April–May NAO index ($\beta_{TEMP\_JUNE5–14}$ = –1.184, SE = 0.338; $\beta_{NAO4–5}$ = 1.735, SE = 0.467; *Adj.* R^2 = 0.59).

The time between first arrival date and first egg laying date ranged between 18 and 34 days being on average 23.8 days (±1.60 SE, *n* = 11). It did not change during the study (β_{TREND} = –0.236, SE = 0.526, R^2 = 0.02, Supplementary material, Table S5). The best models included a negative association with the first arrival date and local temperatures in May 16–25 and May 6–25 (Table S5, $\beta_{FIRST\ ARRIVAL}$ = –1.590, SE = 0.294; $\beta_{TEMP\_MAY16–25}$ = –1.057, SE = 0.294; *Adj.* R^2 = 0.76). With detrended data, the support for the best model increased ($\beta_{FIRST\ ARRIVAL}$ = –1.824, SE = 0.183; $\beta_{TEMP\_MAY16–25}$ = –0.922, SE = 0.176; *Adj.* R^2 = 0.91).

4. Discussion

The results indicate that the spring arrival of a long-distance migrant, the Little Tern, is associated with large scale weather patterns rather than local weather conditions. Little Terns arrived earlier in springs when the April–May NAO index was positive. A positive NAO index during the spring means warmer than usual weather on the Atlantic coast, and these conditions lead to earlier migration and arrival in many bird species (Hubalek 2003, Hüppop & Hüppop 2003, Vähätalo *et al.* 2004). As the arrival of the first Little Terns was not associated with local weather, they may arrive to unfavorable conditions that do not yet support the onset of breeding.

Indeed, timing of breeding was linked to local ambient temperatures experienced before the start of egg laying. The results thus indicate a weaker influence of large scale weather patterns on the timing of breeding via timing of migration in this northern population of the Little Tern. While this is consistent with some studies (Moe *et al.* 2009, Álvarez & Pajuelo 2017), several seabird populations in the North Sea breed earlier following a positive spring NAO index (Frederiksen *et al.* 2004, Møller *et al.* 2006, Wanless *et al.* 2009) suggesting a better correlation between the factors affecting breeding conditions. The same conditions lead to earlier arrival in this northern most breeding Little Tern population in Europe, but do not result to earlier breeding. This can happen when the weather patterns along the migration routes and breeding sites, and between different spring periods are uncoupled (Ahola *et al.* 2004).

Early first spring arrival dates did not translate to early first laying dates because breeding was determined by local conditions. In line with this, the period between first arrival date and first egg laying date was longer when Little Terns arrived early (springs of positive April–May NAO index) indicating that in years of early arrival birds indeed had to wait longer for conditions to become suitable for breeding. This led to the counterintuitive positive relationship between the timing of breeding and the April–May NAO index (opposite pattern to first arrival). Long intervals between arrival and start of breeding occur in years when a warm spring is followed by a cold spell that delays egg laying, whereas shorter intervals occur most often during cold springs when the individuals arrive later. Interestingly, Portuguese Little Terns laid their eggs early when the April–May NAO was negative, which coincided with better food availability (Ramos *et al.* 2013).

Little Terns arrive well before the breeding season as breeding started on average over three weeks after first arrival. Arriving early may be beneficial as it makes it possible to start breeding when the conditions become suitable for egg laying, which usually results in highest reproductive success in terns (Arnold *et al.* 2004, 2006, Cabot & Nisbet 2013). Preparation for breeding, such as courtship feeding, can take time among terns, even up to several weeks (Cabot & Nisbet 2013). Hence, early arrival allows adjustments for an optimal laying time. Like for any species, optimal timing of breeding should be linked to food availability (e.g., Dunn *et al.* 2011). Earlier breeding may be restricted by low food availability during egg laying (e.g. Lemmetyinen 1973; Stevenson & Bryant 2002), whereas juvenile survival should be highest when the juvenile phase matches with the peak food supply (e.g., Pakanen *et al.* 2016).

The results provide an example of a long-distance migrant in which the timing of spring arrival and the start of egg laying are linked to weather conditions (Halkka *et al.* 2011). Early arrival well before the start of breeding suggests that these long-distance migrants should be able to track advancing springs and start their breeding in the most optimal time (Valtonen *et al.* 2017).

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Säätekijöiden vaikutus pikkutiirojen (*Sternula albifrons*) ensisaapumiseen ja pesinnänaloitukseen

Muuttolintujen saapuminen pesimäpaikoilleen on usein yhteydessä muuttoreittien ja pesimäpaikkojen säätilaan. Pesinnänaloittaminen voi puolestaan olla yhteydessä saapumisajankohtaan tai pesimäpaikoilla vallitseviin kevään olosuhteisiin ennen muninnan aloittamista. Koska pitkänmatkan muuttajat saapuvat ja pesivät myöhään, sääolojen ajatellaan vaikuttavan niihin verrattain vähän. Lisätietoa sään merkityksestä muuton ja pesinnän aloittamiseen tarvitaan etenkin merilinnuista, jotka ovat erityisen alttiita ilmaston vaikutuksille.

Käytin lintuharrastajien vuosina 2006–2016 keräämää havaintoaineistoa selvittääkseni milloin pikkutiira, joka on pitkänmatkan muuttaja, saapuu pesimäpaikoilleen, ja ovatko kevään ensimmäiset havainnot yhteydessä muuttoaikana vallitsevaan laaja-alaiseen ilmastoon (Pohjois-Atlantin Oskillaatio indeksi, NAO-indeksi) tai paikalliseen säähän pesimäpaikoilla. Lisäksi käytin keräämääni pesimäaineistoa samalta ajanjaksolta tutkiessani, oliko kevään ensimmäisen pesän muninnan aloitus yhteydessä saapumisajankohtaan, NAO-indeksiin tai paikalliseen säähän.

Ensisaapuminen oli yhteydessä huhti–toukokuun NAO-indeksiin, mutta ei niinkään paikallisiin sääoloihin. Pikkutiirat saapuivat aikaisin, kun NAO-indeksi oli positiivinen. Tuolloin vallitsee suotuiset sääolot jotka edistävät lintujen kevätmuuttoa. Saapumispäivä ei kuitenkaan vaikuttanut pesinnänaloitukseen, joka oli paremmin yhteydessä kevään lämpötilaan juuri ennen munintakauden alkamista. Aikainen saapuminen mahdollistaa pesintään valmistautumisen ja pariutumiseen liittyvät vaiheet, ja mahdollistaa tätä kautta olosuhteiden seuraamisen sekä pesinnänaloittamisen heti kun olosuhteet kehittyvät suotuisiksi. Saattaa siis olla, että pikkutiirat pystyvät vastaamaan ilmastonmuutoksen aiheuttamaan kevään aikaistumiseen, ja pystyvät pesimään optimaaliseen aikaan.

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Online supplementary material

Figure S1. A map showing the observation area for arrival dates and the location of the breeding site in Finland.
Tables S1-S4. Model selection for explaining variation in first arrival, fifth arrival, first egg laying and mean egg laying dates.
Table S5. Model selection for explaining variation in the interval between first arrival date and first egg laying date.