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Scientific paper

Co-variation between climate signals and breeding phenology of high-arctic breeding kittiwakes (*Rissa tridactyla*)

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Abstract: Climate changes in the Arctic may have important consequences for the breeding of Arctic birds, though few studies are available to evaluate the possible effects. I studied the breeding phenology of kittiwakes (*Rissa tridactyla*) breeding at two colonies (Krykkjefjellet and Ossian Sarsfjellet) in Kongsfjorden, Svalbard (79°N). Eleven years of data (in the period 1970–2001) from Krykkjefjellet showed no long-term temporal trend in the timing of hatching. The spread of the median hatching date among the years was 14 days. The median hatching date was negatively correlated with the local average April ambient temperature. Correlation analysis with large-scale climate indices showed that the time of hatching was negatively correlated with the Scandinavia index in late winter (February and March), and slightly (but not statistically significantly) negatively correlated with the NAO (North Atlantic Oscillation) winter-index. A similar analysis of the number of breeding kittiwakes in study plots at Ossian Sarsfjellet showed a positive correlation between the number of breeders and average local March temperatures. These observations indicate that the kittiwakes may be able to adjust their spring arrival and breeding phenology to local or large-scale climate variations.

key words: climate change, Svalbard, kittiwake, breeding phenology, North Atlantic Oscillation

1. Introduction

There is strong evidence of recent climate change in the Arctic, and in general the future warming of the Arctic is expected to be stronger than at lower latitudes (ACIA, 2004). Climate changes may have important consequences for the breeding of Arctic birds, but few studies have addressed the possible effects of climate changes for these birds. However, it has been documented that the breeding phenology of Arctic terrestrial birds varies considerably among the years and is related to the timing of snow melt (Prop *et al.*, 1984; Prop and de Vries, 1993; Martin and Wiebe, 2004; Meltofte, 2004). Here we use the definition of phenology as "the seasonal timing of animal and plant activities" (Beebee, 2002; Berteaux *et al.*, 2004). Delayed egg-laying and reduced reproductive output in years with late break-up of sea ice in the region surrounding the breeding colony, have been reported in Arctic seabirds (Belopolskii, 1957; Gaston and Hipner, 1998; Gaston *et al*., 2005).

In Arctic seabirds, the nest site must be free of snow and ice before nest building and egg laying can start. Additionally, the birds need access to open water with a suitable amount of prey within flight range of their breeding colonies. The birds' physical condition at the start of the breeding season may influence the reproductive performance. The physical condition is known to influence several aspect of breeding performance (Martin and Wiebe, 2004), including the proportion of birds attempting breeding, timing of egg-laying, clutch size, etc. For migratory Arctic seabirds, not only the environmental conditions experienced in the breeding area may influence the birds' physical condition, but also the environmental conditions experienced in the wintering areas and during migration to the breeding area.

During climate change, the selective pressures on bird populations are changing rapidly and it is unclear how individual species will react to such changes. It might be possible to predict possible effects of climate changes on Arctic bird populations by studying how they react to climate variability such as early and late onset of the spring. Such phenological parameters can also prove particularly sensitive of climate change.

In the present study, I correlate time-series of inter-annual variation in breeding phenology and breeding numbers in two colonies of kittiwake (*Rissa tridactyla*) in the high-arctic region of Svalbard with local and large scale climate indices. These correlations were used to explore possible responses in breeding biology to climate change.

2. Material and methods

Kittiwakes are widespread breeders in Svalbard (Anker-Nilssen *et al*., 2000). Svalbard breeding kittiwakes are thought to have a widespread winter distribution in the North Atlantic, similar to other North Atlantic kittiwake populations (Cramp and Simmons, 1983). Recoveries of ringed kittiwakes breeding along the coasts of the Barents Sea, indicate that important wintering areas for these populations are located between Iceland, Newfoundland and SW Greenland (Nikolaeva *et al*., 1997; Bakken *et al*., 2003). All four winter recoveries of kittiwakes ringed in Svalbard were from the coasts of Canada and Greenland. According to Løvenskiold (1964) most kittiwakes arrive in Svalbard in April, and egg-laying starts in late May or June in the western parts of Svalbard.

In the present study, the breeding phenology of kittiwakes was studied at a breeding colony, "Krykkjefjellet" (78°54′N, 12°13′E) located in Kongsfjorden 6 km SE of the research station at Ny-Ålesund, NW Svalbard. The median date of hatching was used for comparing the timing of breeding among the years. A 3 m wide transect was laid out on a steep slope below the bird cliff. In this transect, all empty egg-shells were collected approximately every other day and removed. The median hatching date was estimated from the cumulative percentage curve of hatched eggs collected in the sampling transect. The number of days from 10 to 90% of eggs hatched (the middle 80%) was used as an index of the hatching synchrony (Coulson and White, 1956).

Another, nearby colony, Ossian Sarsfjellet (78°56′N, 12°29′E) was used for monitoring the number of breeding birds in selected study plots. Similar data were not available from the Krykkjefjellet colony. The census was conducted in accordance with standard methods given by Walsh *et al.* (1995). The number of occupied nests was counted in each of four study plots during a single visit each year (1988, 1990 and 1992–2000, $n = 11$ years). The sum of occupied nests in the four plots was used in this analysis.

Ambient temperature data from the Ny-Ålesund station was obtained from the Norwegian Meteorological Institute. The daily temperatures averaged for each month of January to May were used for Pearson correlation analysis with kittiwake data. Correlations with $p < 0.05$ were treated as statistically significant.

The North Atlantic Oscillation and Scandinavian indices were used as proxies for large-scale climate fluctuations. The North Atlantic Oscillation index is a common index used for expression of the different modes of the climate of the North Atlantic region. The index represents the pressure difference between the Icelandic Low and the Azores High. A high index value is associated with westerly winds and mild winters in the eastern North Atlantic. High values of the Scandinavian index is equivalent to the Eurasia-1 pattern and is associated with height anomalies over Scandinavia and the oceans north of Siberia, while negative values are associated with mild winters over these regions (Barnston and Livezey, 1987). Weather pattern represented by these indices might influence the kittiwakes during their wintering period in the North Atlantic or on their migration towards Svalbard. NAO index and Scandinavian index data were obtained from US National Weather Service Climate Prediction Center http: //www.cpc.ncep.noaa.gov/data/teledoc/telecontents.html

3. Results

The median hatching date for 11 years of data at the Krykkjefjellet colony (in the period 1970–2001) was 10 July (sd. 3.8 days). The spread of the median hatching date among the years was 14 days, and the median date ranged from 1 July (1984) to 15 July (2001) (Fig. 1). No temporal trend in the timing of hatching was detected (Fig. 2).

There was a high synchrony in the date of hatching. On the average, the middle 80% of the eggs hatch within 10 days (range 7–12 days over 11 years). No significant temporal trend in hatching synchrony ($r = 0.25$, $p = 0.46$, $n = 11$) or correlation between hatching date and degree of synchrony were observed ($r = 0.10$, $p = 0.71$, $n = 11$).

The number of occupied nests in the study plots at Ossian Sarsfjellet averaged 106 nests (sd. 29.0) for the period 1988–2000. There was a high inter-annual variation (range 85–213 nests), but no linear temporal trend was observed in the data ($r = 0.25$, $p = 0.45$).

Hatching date was negatively correlated with local average April temperature (Fig. 3a, Table 1), but no correlations were found for the months March, May or June (Table 1). A similar analysis of the number of breeding kittiwakes in study plots in Ossian Sarsfjellet showed a positive correlation between the number of breeders and average March temperatures (Fig. 3b, Table 1). No correlations were found for April, May or June (Table 1).

Analysis of relationships between large-scales winter climate indices and the kitti-

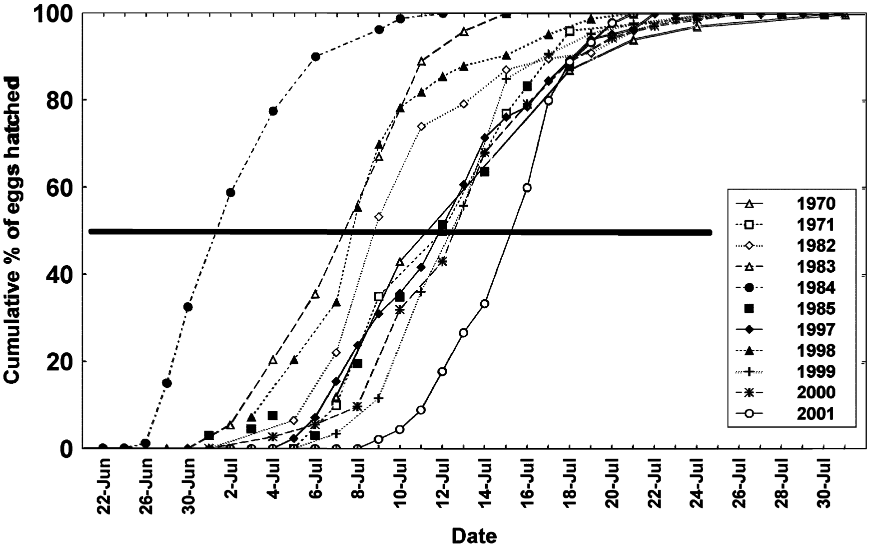

Fig. 1. *Cumulative percentage of hatched kittiwake (Rissa tridactyla) eggs versus dates at Krykkjefjellet, Kongsfjorden, Svalbard (n = 11 years in the period 1970–2001).*

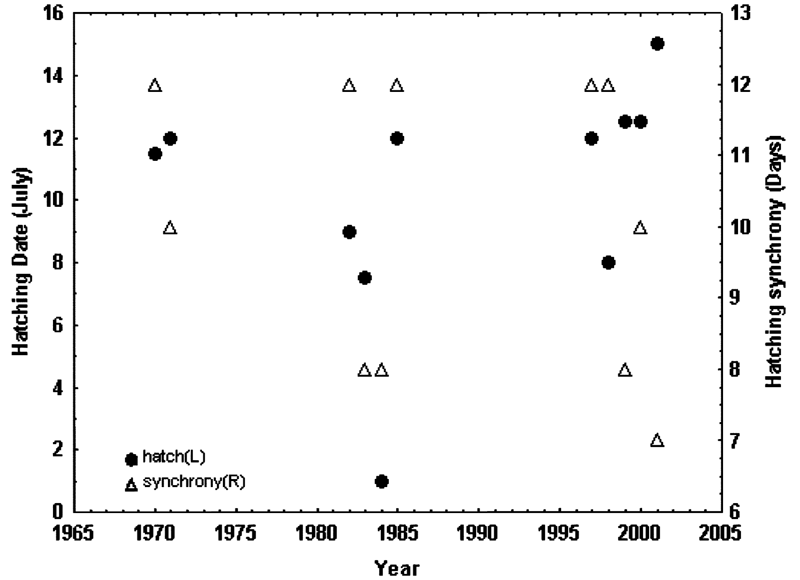

Fig. 2. *Median hatching dates and hatching synchrony (spread in hatching dates of the middle 80% of the eggs) of kittiwake (Rissa tridactyla) eggs at Krykkjefjellet, Kongsfjorden, Svalbard (n = 11 years in the period 1970–2001).*

wake breeding parameters showed that the median hatching date was slightly negatively correlated with the NAO winter-index,(December–March, averaged) (Fig. 4) but the correlation was not statistically significant ($r=-0.463$, $p=0.15$). No correlations were found when monthly NAO-indices were used (Table 2). Monthly averages of the Scandinavian index showed significantly negative correlations for February and March with the median hatching date, but not for December and January (Table 2). There

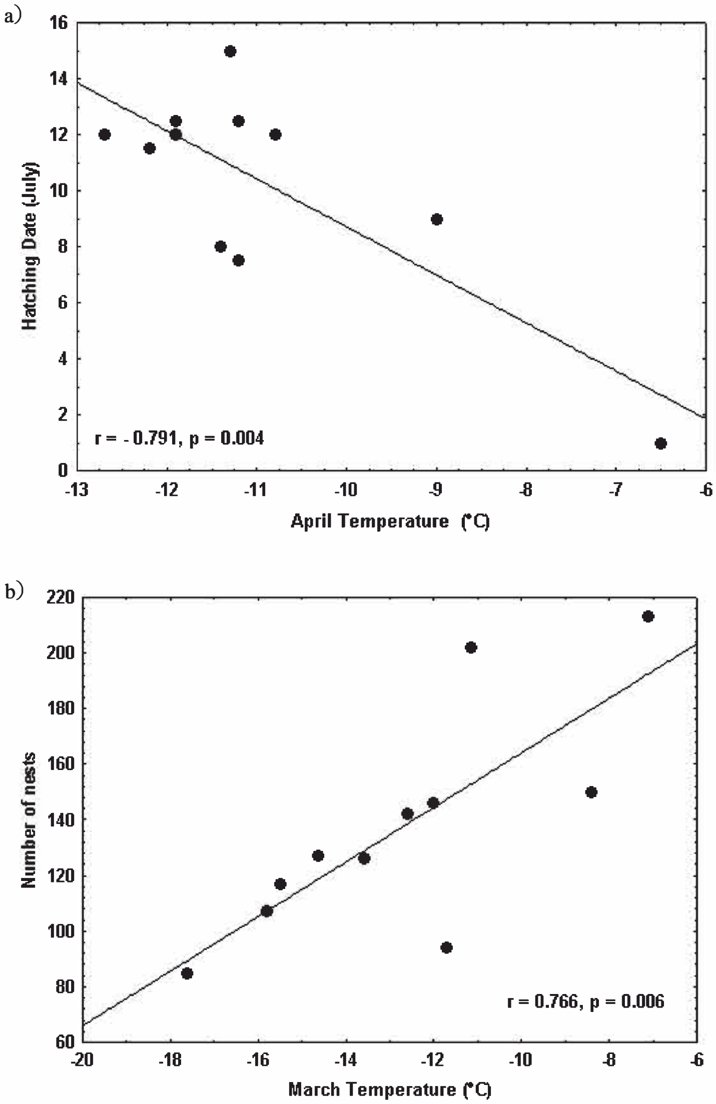

Fig. 3. Median hatching dates in kittiwakes (Rissa tridactyla) breeding at Krykkjefjellet versus (a) local April temperatures (n=11 years in the period 1970–2001); and (b) number of breeders (occupied nests) of kittiwakes in study plots at Ossian Sarsfjellet versus local March temperatures (n=11 years in the period 1988–2000).

Table 1. Correlations (Pearson-r) between monthly ambient temperature and hatching date and number of nesting kittiwakes (Rissa tridactyla) in Kongsfjorden, Svalbard.

Month	Hatching date	No. of breeders
March	0.067	0.766**
April	−0.791**	0.589
May	−0.101	−0.050
June	0.310	0.245

** indicates $p < 0.01$, others correlations: $p > 0.05$

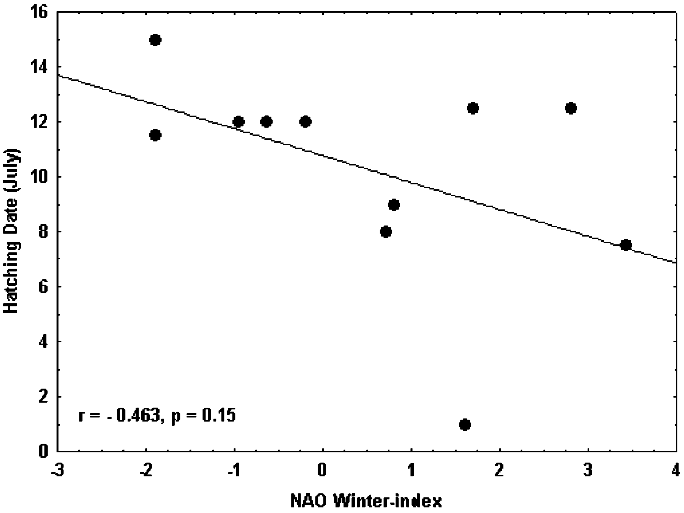

Fig. 4. Median hatching dates in kittiwakes (Rissa tridactyla) breeding at Krykkjefjellet versus the NAO winter-index (n = 11 years in the period 1970–2001).

Table 2. Correlations (Pearson-r) between hatching date of kittiwakes (Rissa tridactyla) (n = 11 years) at Krykkjefjellet, Kongsfjorden, Svalbard and climate indices (NAO- and Scandinavian index).

Month	Index	Correlation
December	NAO	−0.098
	SCAND	+0.378
January	NAO	−0.393
	SCAND	+0.546
February	NAO	+0.189
	SCAND	−0.637*
March	NAO	−0.233
	SCAND	−0.646*

* indicates $p < 0.05$, others correlations: $p > 0.05$

was no significant correlation between the NAO winter-index and the number of breeding kittiwakes ($r = -0.369, p = 0.26$). Similarly, there were no significant correlations between NAO winter-index and monthly local temperature for the months March-June, although there was a positive correlation (non-significant) for the months March–May. A 11 year data series may be too short to detect any significant associations between these variables.

4. Discussion

This study confirms the general feature of a synchronous hatching period in high-arctic birds (Newton, 1977) compared to those of the temperate zone, and 80% of the kittiwake eggs hatched within a period of 7–12 days in the years studied.

The timing of breeding in birds has evolved through natural selection to match environmental conditions and maximize fitness of individuals (Futuyma, 1998; Berteaux *et al.*, 2004). Birds failing to adjust to the local timing of the onset of spring may suffer drastically reduced reproductive success (Wingfield and Hunt, 2002). Thus, it is expected that the Arctic breeding kittiwakes are adapted to variability in the environmental conditions at the breeding site by adjusting the onset of egg-laying and by a high breeding synchrony. On the other hand, the timing of breeding of kittiwakes in the Arctic is constrained by the short summer season. The median hatching date at Krykkjefjellet in most years clustered around 10 July, which in agreement with that reported of kittiwakes breeding at Hopen Island in southeast Svalbard in 1984 (Barrett, 1996; mean hatching: 11 July, estimated from egg-laying date). The total range in median hatching date for the 11-year data set from Krykkjefjellet was 14 days. In a 31-year long study of British kittiwakes, the range of the average date of egg-laying was 10 days (Coulson and Thomas, 1985). This indicates that the Svalbard kittiwakes respond more strongly to inter-annual environmental variation than the British birds. Alternatively, the inter-annual environmental variation is larger in Svalbard than in Britain.

Although the time series was short, this study showed that the variation through the years in the breeding phenology and the breeding population size were correlated with the environmental conditions. These correlations do not allow any firm conclusions on the causal relationship between the breeding parameters and the environment, but give indications of relationships that need further study. The analyses showed significant correlations with both local and large-scale climate variables represented by the NAO and Scandinavia indices. The present data does not tell us whether the local or the distant climate factors act on the kittiwakes breeding in Kongsfjorden. The strongest correlations seem to occur for local ambient temperature. However, the time series may be too short for any firm conclusions. The lack of association between the NAO winter index and local monthly spring temperatures at the Ny-Ålesund station is in accordance with Winther *et al.* (2002), who did not find any correlation between the NAO index and ambient temperature in Ny-Ålesund during 1981–1997.

Studies of the relationship between variations in the NAO-index and seabird breeding performance elsewhere in the North Atlantic may give us a clue to the effects of large-scale climate variability on Arctic seabird populations. A similar study in a

North Sea colony of kittiwakes also showed a negative correlation between breeding phenology and the NAO winter-index, indicating that this phenomenon is indeed related to the large-scale winter climate pattern in the North Atlantic (Frederiksen *et al*., 2004). These observations and recent studies on the relationship between spring arrival date and winter NAO in European migratory birds, indicate that the birds are able to adjust their spring arrival and breeding phenology to large-scale climatic oscillations. These responses happen instantly and imply that individuals have the potential to such adjustments through phenotypic plasticity.

It is still an open question what will happen to the populations of kittiwakes breeding in Svalbard during a future warmer climate. Environmental conditions both in the breeding region of Svalbard, but also in the wintering areas in the North-Atlantic will affect these populations. Milder winters and earlier summers in Svalbard may lead to an increased number of occupied nests in the colonies and a higher reproductive output. But this will also depend on availability of prey both in the breeding and wintering areas. Kittiwakes breeding in Svalbard are opportunistic foragers and may take a variety of prey species depending on availability (Mehlum and Gabrielsen, 1993). Thus, they seem be less prone to food shortage than less opportunistic birds. However, studies from the North Sea seem to indicate that in areas where kittiwakes specialize on lesser sandeel (*Ammodytes marinus*) as prey, they are more sensitive to food shortages than many other seabirds (Furness and Tasker, 2000). Studies from the North Sea indicate that the breeding performance of kittiwakes (and other seabird species) has been at a low level in recent years, and these findings have been attributed to shortage of suitable food sources in the North Sea (Frederiksen *et al*., 2004).

Recent studies in the North Sea have demonstrated a mismatch between the timing of phytoplankton and zooplankton production caused by climate changes, which may lead to lower production at higher trophic levels (Edwards and Richardson, 2004). It is unclear whether a similar situation will occur in the Arctic regions in connection with climate change, but lower availability of prey would have negative impact on the Arctic seabird populations.

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