Seasonal variations in the North Atlantic Oscillation and the breeding success of arctic-nesting geese

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Abstract

Long-term studies of 18 populations of eight goose species breeding from arctic Canada to western Siberia have recorded annual variation in the breeding success of geese as the percentage of juveniles seen in autumn. Regression of the annual breeding success data on seasonal values of the North Atlantic Oscillation (NAO) suggest that the passage and intensity of weather systems across eastern North America and northwest Europe have influenced the breeding success of most of these populations. Replacing the NAO by mean sea level pressure (MSLP) at Reykjavik gave similar results. Geese breeding close to the centre of the Icelandic Low appeared to show less response to the NAO than those at greater distances from Iceland. While the NAO indices may be useful for forecasting the breeding success of a population in that year, sea surface temperature changes, which fluctuate more slowly, may be better predictors of goose breeding success over several years.

Key words: *Anser*, arctic, *Branta*, breeding success, geese, mean sea level pressure (MSLP), North Atlantic Oscillation (NAO).

Hans Egede Saabye, a Danish pastor living in Greenland, recognised in the 18th century that there was a see-saw effect of air-masses moving over the North Atlantic, so that in winters when West Greenland was cold Western Europe was mild, and vice-versa, with frequent, and sometimes abrupt, shifts from one phase to the other (Stephenson 1997). This phenomenon, now known as the North Atlantic Oscillation (NAO), affects the behaviour of weather systems across much of North America and Europe, as well as over the North Atlantic Ocean. The NAO has since been explored in some detail, and has been quantified as an index of mean sea level atmospheric pressure (MSLP) (Hurrell 1995, 2001, 2006; Hurrell & Deser 2007).

Local and specific weather variables have long been known to impinge both directly and indirectly on the breeding season. For instance, the onset of egg-laying for arctic-nesting birds, which correlates with clutch size (earlier clutches being larger), is influenced by the timing of the snow-melt (Bowler 2002; Cooke *et al.* 1995; Dalhaug *et al.* 1996; Raveling & Lumsden 1977; Rohwer 1992). Adverse weather during incubation may also cause nest abandonment or the mortality of eggs and hatchings (Bradley *et al.* 1997; Syroechkovsky *et al.* 2002). Among most stocks of geese wintering in northwest Europe, a higher proportion of adult geese are accompanied by young in the winter following warm arctic summers (Boyd 1982). Potential indirect effects of climate on productivity include the effects of weather on food supply or food intake rates, which would influence whether birds reach breeding condition and the food supply for the young (Gardarsson & Einarsson 1994; Newton 1998). Weather may also affect predator levels which, given that predation at the vulnerable egg and pre-fledging stages can be high in some species (review in Bowler 2002), would have a major impact on breeding success.

In recent years, the effects of macro-environmental conditions on goose populations have also been considered. For instance, several studies of long-distance migrants have found that changes in their spring arrival times and breeding performance have been associated with fluctuations in the winter values of the NAO (Forchhammer *et al.* 2002; Møller 2002; Nott *et al.* 2002; Vähätalo *et al.* 2004). Fewer have addressed the influence of spring NAO values, but see Boyd & Petersen (2006). A high correlation in the breeding success of pan-arctic-nesting geese (de Boer & Drent 1989) suggests that large-scale environmental conditions affected these species at the population level. The study reported here therefore uses long-term productivity data recorded for several goose populations to determine whether correlations in their breeding success can be explained by macro-environmental weather variables such as the NAO.

Since the NAO affects weather conditions in Europe and the eastern part of North America, the study focussed on goose populations breeding and wintering in these areas. Annual breeding success was taken as the percentage of juvenile geese in winter flocks, since this is the most widely-used index of annual variations in productivity, having first been employed for Pacific Brant *Branta bernicla* by Moffitt (1934), then becoming a routine component of goose monitoring programmes in the second half of the 20th century (Boyd 1951; Lebret 1956; Lynch & Singleton 1964). Seasonal (i.e. autumn, winter, spring and summer) values of the NAO were investigated to determine the time of year when weather has the greatest or most consistent influence on goose breeding success. Only results for winter, spring and summer are reported here, as there were no significant associations found between goose breeding success and autumn NAO values.

Methods

Goose data

Seven species of arctic-nesting geese winter in the British Isles or on the mainland of northwest Europe. Several have two or more populations that breed and spend the winter in separate regions, with little mixing of individuals. Annual records of the percentage of juveniles in autumn published for 12 populations of these species were used here (Table 1). Many of the juvenile percentages were taken from Madsen, Cracknell & Fox (1999), with some updated from unpublished sources. Equivalent data were also available for six populations of geese breeding in arctic Canada and wintering in the east or south of the United States (Table 2). Productivity records for these populations, collected mainly by the US Fish & Wildlife Service, were formerly distributed in internal reports. Since 2000 these have been available at http://www.fws.gov/migratorybirds/reports/reports.html. Geese breeding in Alaska and those wintering along the American Pacific coast were excluded because they are more influenced by atmospheric activities over the North Pacific Ocean, and therefore should be analysed in relation to the climate conditions in that area.

No large forms of Canada Geese *Branta canadensis* and only one of the several groups of Greylag Geese *Anser anser* in Europe could be used because, in both of these species, many young geese begin to replace their juvenile feathers with a first-winter plumage as early as October. It is therefore difficult to distinguish young geese from those more than a year old during field observations, and reliable 'age-ratios' can not be obtained. However, Greylag Geese which breed in Iceland delay their first moult until well into November, after their autumn migration, so juveniles can be recognised in early autumn. Since the Icelandic Greylag Goose population winters mainly in northeast Scotland, with limited overlap with the indigenous native and naturalised Greylag Goose populations which also occur in Britain, it was included in the analyses.

The percentages of juveniles recorded in autumn flocks provide indices of success for the goose populations each year, rather than an absolute value, because of gaps and biases inherent in the monitoring programmes. For instance, breeding success records may vary across the wintering range because groups of geese breeding in different parts of the summer range do not mix completely in winter (Fox *et al.* 2002). There may also be a bias through the tendency of large families (those with three or more juveniles) to monopolise the best feeding patches at the edges of flocks (Black *et al.* 1992; Prop 2004), so observers must ensure that they age the birds throughout the flock. In practice, however, the results obtained by observers in different parts of the wintering range are often remarkably similar (Pettifor *et al.* 1999), even when flocks are observed on different habitats. Moreover, as long runs of data have accumulated, most annual samples provide remarkably consistent patterns. High-arctic species, often subject to severe summer weather, show wider fluctuations in success

Goose species	Breeding population	Staging area(s)	Main wintering areas	*n*	Mean (± s.d.)	Range	Trend as % of mean
Tundra Bean *Anser fabalis rossicus*	NW Russia	Baltic countries/ Russia	Northwest Europe (Belgium/Netherlands/ Germany)	19	28.6% (± 4.4%)	21.1–36.3%	–1.19
Pink-footed *Anser brachyrhynchus*	Iceland	Denmark/Norway	Northwest Europe (Belgium/Netherlands)	50	20.2% (± 7.1%)	5.6–37.4%	–0.84
	Svalbard	Iceland	Scotland/England	16	16.1% (± 7.2%)	7.0–30.0%	
Greylag *Anser anser*	Iceland	Iceland	Scotland	43	19.3% (± 7.3%)	5.9–40.1%	–0.97
White-fronted *Anser albifrons*	NW Russia	W Russia/Baltic	Northwest Europe (Belgium/Netherlands/ Germany)	36	31.4% (± 7.5%)	10.0–43.3%	
	W Greenland	Iceland	Ireland/W Scotland	28	17.6% (± 7.1%)	6.0–35.6%	–1.71
Barnacle *Branta leucopsis*	NW Russia/ Baltic	NW Russia/Baltic	Netherlands	35	20.8% (± 4.4%)	4.9–30.6%	–2.52
	Svalbard	Norway	Scotland/England	40	16.8% (± 10.4%)	2.0–47.2%	
	E Greenland	Iceland	Scotland/Ireland	35	26.1% (± 9.7%)	8.1–42.7%	
Dark-bellied Brent *Branta b. bernicla*	NW Russia	NW Russia/Baltic	Netherlands/England	35	18.6% (± 15.2%)	1.5–45.0%	–2.77
Light-bellied Brent *Branta b. hrota*	Svalbard	Norway/Denmark	England	18	16.1% (± 11.4%)	1.0–34.0%	
	NE Canada	NE Greenland/ Iceland	Ireland	34	20.8% (± 12.4%)	0.0–43.3%	

Table 1. Breeding, staging and wintering areas for European goose populations included in the study, together with the mean annual percentages of juveniles recorded in autumn at sites in the wintering range. n = number of years. Long-term trends in breeding success are given as a percentage of mean breeding success.

Goose species	Breeding population	Staging area(s)	Wintering range	Where age sample recorded	Observed mean (± s.d.)	*n*	Shot mean (± s.d.)	*n*
White-fronted *Anser albifrons*	Central Canadian arctic	Prairie provinces	Gulf coast	Prairie provinces			43.7 (± 9.2)	29
				Mississippi flyway	33.9 (± 9.3)	47	37.9 (± 11.8)	30
				Central flyway			41.6 (± 9.2)	32
Greater Snow *Anser caerulescens atlanticus*	NE Canada/ NW Greenland	Quebec *	Atlantic coast*	Quebec	22.2 (± 13.4)	45	63.3 (± 21.0)	28
				Atlantic flyway			47.4 (± 19.4)	28
Lesser Snow *Anser c.caerulescens*	Central Arctic/ Baffin Island/ Hudson Bay	Prairie provinces*/ Mississippi flyway	Gulf coast	Prairie provinces			45.5 (± 8.8)	29
				Mississippi flyway	29.2 (± 6.1)	18	39.1 (± 13.5)	32
				Central flyway	26.1 (± 13.5)	32	42.1 (± 12.5)	32
Cackling Canada *Branta hutchinsii*	Foxe Basin/ Hudson Bay	Manitoba*/ Saskatchewan	Gulf coast	Manitoba			53.4 (± 12.6)	27
	Queen Maud Gulf, Mackenzie District	Alberta*/ Saskatchewan	Central interior USA	Alberta			49.4 (± 13.1)	27

Table 2. Breeding, staging and wintering areas of geese wintering along the Atlantic and Gulf coast or in the interior of the United States included in the study (i.e. for which there are annual records of % juveniles in autumn from field observations and/or from tails of shot geese [*]), together with the mean annual percentages of juveniles recorded in the wintering range. Juveniles seen in goose flocks were for the years 1951–2002; tail samples of geese shot in autumn were for the years 1971–2002. *n* = number of years with goose age data.

than geese breeding further south, which rarely fail to rear some young. The percentage of juveniles in autumn thus seems a reasonable measure of annual variation in breeding success for the geese.

In North America, a second source of data is provided by the 'tail-fans' taken from shot geese supplied by hunters selected to take part in the national harvest surveys run by the US Fish & Wildlife Service and the Canadian Wildlife Service since the 1960s. Except when the tail feathers are badly damaged or fouled, trained examiners can identify the species and determine whether the feathers were from a juvenile or an adult. The national tail samples for each species are numerically smaller than the field observations, but their wider geographical scatter may make them more representative of the population as a whole. These data are published in the form of age-ratios (juveniles per adult), converted here to percentages [J/(A + J) %] to be directly comparable to the field counts. The juvenile percentages in tail samples are usually higher than reported by observers of live geese. Juveniles are easier for hunters to attract, using decoys or by calling, than older geese, and their bodies are more readily penetrated by shot. The bias caused by 'juvenile vulnerability', first demonstrated by Hanson & Smith (1950), seems to be consistent within each species (H. Boyd, unpubl. data). For Cackling Geese *Branta hutchinsii*, the tail samples provide the only measure of breeding success. For other species, they provide a second source that can be compared with the field observations.

Climate data

Many alternative NAO series have been published, and were tested during this study. The NAO data analysed here were derived principally from Hurrell's climate indices on the climate analysis section of Climate and Global Dynamics Division (CGD) website (http://www.cgd.ucar.edu/cas/jhurrell/indices.html). The monthly index of the NAO was calculated from difference of normalised sea level pressures (SLP) between the Azores (represented by Gibraltar, 36°11´N, 5°22´W) and Reykjavik, Iceland (64°08´N, 21°54´W). Normalisation (i.e. division of each seasonal mean pressure by the long-term, 1864–1983, mean standard deviation) is used to avoid the NAO series being dominated by the greater variability of SLPs at the northern station (Hurrell 2006) though, as most arctic-breeding geese spend their lives north of 36° N, that decision is not necessarily advantageous for this study.

In winter, the "positive phase" of the NAO reflects below-normal heights and pressure across the high latitudes of the North Atlantic and above-normal heights and pressure over southeast North America and western Europe, leading to circulation patterns with strong storm tracks with a northeast orientation taking depressions into northwest Europe. These positive phases are associated with above-normal temperatures in the eastern USA and across northern Europe, and above-normal precipitation over Scandinavia. In the "negative phase", weaker storm tracks take more depressions into

Mediterranean Europe, where temperatures and precipitation become relatively higher than further north. During prolonged periods dominated by one phase, abnormal temperature patterns often extend well into eastern North America, or to central Russia and north-central Siberia (Stephenson 1997; Plummer & Nott 2002).

The pressure differences between the Azores High and Iceland Low are usually greater in winter than in other seasons, when smaller and shallower pressure gradients result in fewer and less intense depressions in northern latitudes, especially in the arctic. The signal-to-noise ratio of the NAO is as high as 2.5 in winter and closer to 1.0 at other seasons (Hurrell 1995), which is one reason why most investigators have concentrated on the behaviour of the winter index.

Several versions of the NAO have been constructed, and some of them have been modified since first being published. Those variations lead to different numerical relationships with the percentages of juvenile geese. Because of those inconsistencies, it seemed desirable to find out whether it might be better to replace normalised versions of the NAO either by the monthly differences in mean sea level pressure (MSLP) between stations representing the Azores High and the Iceland Low (A–I), or by the MSLP at Reykjavik alone, as those direct measurements are unlikely to be altered. Only the results for Reykjavik are reported here. Seasonal variations in the MSLP are 2–3 times greater at Reykjavik than those at Gibraltar or Lisbon, especially in the winter months. Mean monthly MSLP at Reykjavik is published in kiloPascals (kPa). Here, for computing purposes, 10,000 was subtracted (e.g. 10,012 became 12). For comparison with the results from the NAO, the sign of the relationship between the juvenile percentages and the MSLP was reversed (T. Jonsson, pers. comm.). Variations in the spring values of the MSLP at Reykjavik from 1973 to 2006 were highly correlated with the normalized values of the spring NAO in those years ($r = -0.702$, d.f. = 32, $P < 0.001$).

Statistical analysis

The annual percentages of juveniles in autumn flocks of each goose stock were regressed on monthly and on seasonal values of the NAO. The years of goose data available varied from 14 to 52. Most attention was paid to seasonal values: winter (December–February, or March in some series), spring (March–May), summer (June–August) and autumn (September–November). Although both the dependent variable (percentage of juveniles) and the independent variable (NAO) are simplified representations of complex situations, it was considered that the direction of the correlations should not change where NAO has a persistent, significant association with goose breeding success.

Results

Juvenile percentages

The mean annual percentages of juveniles seen in goose flocks in Britain and northwest Europe between 1970–2002 ranged from 13.4% for Dark-bellied Brent Geese, which breed on the high-arctic tundra in western Siberia, to 31.4 % for White-fronted Geese, which breed at rather lower latitudes in northwest Russia and western Siberia (Table 1). Breeding success appeared to be higher for the North American geese, with mean values per population ranging from 26.1–33.9% for field observations and from 37.9–63.3% in shot samples (Table 2). Grey geese (*Anser* spp.) tended to be accompanied by rather more young than black geese (*Branta* spp.).

Six of the seven stocks for which juvenile percentages have been collected over many years had higher mean proportions of young before 1970 than in more recent years; the difference for White-fronted geese was negligible (Table 3). The mean annual percentages of young has been stable over time in some of the other populations, and some have showed decreasing trends. For populations showing a decrease in breeding success over time, tests of association with the NAO were carried out first with the observed annual values, then with those values replaced by residuals (the deviations from a fitted linear trend line). Results presented in the tables are for tests using the residual values.

Juvenile percentages and seasonal values of the NAO

Regression coefficients between the annual juvenile percentages for goose populations wintering in northwest Europe and the mean values of the NAO in winter (December–February) indicate that, although there was a negative correlation for Greenland White-fronted Geese and Dark-bellied Brent Geese, none of the correlations reached statistical significance (Table 4). There were, however, significant negative correlations between goose breeding success and the spring (March–May) NAO

Table 3. Mean annual percentages of juveniles recorded in autumn in 1950–1970 and in 1971–2003. *n* = number of years' data.

Species	**Breeding range**	**1950 – 1970**			**1971 – 2003**		
		n	**Mean**	**s.d.**	***n***	**Mean**	**s.d.**
White-fronted	NW Russia	10	32.3	10.0	26	31.8	6.8
Greylag	Iceland	10	25.3	6.2	33	18.0	5.8
Pink-footed	Iceland/ E Greenland	21	25.0	8.8	33	18.1	6.2
Barnacle	NW Russia/ Baltic	10	31.2	10.8	26	24.1	8.9
Brent	NW Russia	15	20.7	15.5	33	13.4	15.4
Brent	High Arctic Canada	8	24.4	12.4	26	19.7	11.7

values for five populations: Tundra Bean, White-fronted (Canadian arctic-breeding), Greater Snow, Lesser Snow and Cackling Canada Geese (Table 4, Table 5). Summer (June–August) NAO was also associated with breeding success for three populations: the Icelandic Pink-footed Goose, Light-bellied Brent Goose (Svalbard) and Greater Snow Goose, but statistically significant only for the Greater Snow Goose (Table 4, Table 5). The Svalbard Pink-footed Goose, Icelandic Greylag Goose, Greenland Barnacle Goose and Canadian High Arctic Light-bellied Brent Goose all showed no significant association with any of the seasonal NAO values.

Russian-breeding White-fronted Geese and Barnacle Geese showed positive though non-significant correlations with the summer NAO (Table 4). Correlation coefficients for Barnacle Geese breeding in Greenland and in Svalbard were weaker for the summer (June–August) NAO, but when their breeding success was tested against the mean NAO values for May and June only, they yielded significant positive correlations ($r = 0.421$, d.f. = 33, $P < 0.05$ and $r = 0.428$, d.f = 38, $P < 0.01$, respectively.)

Concentrating on the responses to the spring NAO, were the geese affected more by conditions in their spring staging or in their nesting areas? The staging sites can be grouped into five areas: (1) central Europe/Russia, (2) North Sea coast (Netherlands and Denmark), (3) Norway, (4) Iceland and (5) eastern Canada. On grouping data for goose populations according to their staging area, analysis of variance found two statistically significant relationships with the spring NAO: for geese staging along the

Table 4. Coefficients of regression of % juveniles seen in autumn flocks of geese in northwest Europe on the seasonal values of the NAO. *n* = years with goose records. $^1P < 0.1$, $^*P < 0.05$, $^{**}P < 0.01$.

Species	Breeding range	*n*	Winter (Dec–Feb)	Spring (Mar–May)	Summer (Jun–Aug)
Tundra Bean	NW Russia	19	–0.097	–0.666**	–0.114
White-fronted	West Greenland	28	–0.257	–0.204	–0.206
	NW Russia	35	0.012	–0.119	0.206
Greylag	Iceland	43	–0.114	0.013	–0.114
Pink-footed	Iceland/E Greenland	53	0.127	–0.157	–0.280^1
	Svalbard	16	–0.115	–0.293	–0.350
Barnacle	East Greenland	35	0.018	0.189	0.194
	Svalbard	40	–0.065	–0.253	0.151
	Russia/Baltic	35	0.056	–0.243	0.266
Brent	Svalbard	16	–0.313	–0.181	–0.574^1
	Russia	43	–0.283^1	–0.254	0.162
	Canadian High Arctic	31	0.183	0.108	0.106

Table 5. Coefficients of regression of % juveniles seen in autumn flocks, or in tail samples from geese shot in eastern and southern North America, on the spring and summer values of the North Atlantic Oscillation. There were no significant associations with winter NAO. Zero indicates $P > 0.1$; blank indicates that calculation was not possible. n = years with goose records. [1]$P < 0.1$, *$P < 0.05$, **$P < 0.01$.

Goose species	**Where seen/ shot**	***n***	**Spring**		**Summer**	
			Seen	**Shot**	**Seen**	**Shot**
White-fronted	Prairie provinces	31		–0.349[1]		0
	Mississippi flyway	32		–0.453**		0
Greater Snow	Quebec	45	–0.407*	–0.500**	–0.334*	
	Atlantic flyway	0	0		0	
	Atlantic flyway	28	–0.367[1]			
Lesser Snow	Prairie provinces	31		–0.496**		0
	Mississippi flyway	19	0	0		
	Mississippi flyway	32		–0.453**	0	
Cackling Canada	Manitoba	27		–0.602**		0
	Alberta	27		0		0
Atlantic Brent	Atlantic flyway	34	–0.452**		0	
	Atlantic flyway	22		–0.370[1]		

North Sea coast, and those in eastern Canada. The slopes of the regressions were similar for all five groups, suggesting a consistent NAO effect on goose populations during spring migration, but the results were not statistically significant ($P = 0.162$).

The breeding areas can be assigned to four groups: (1) Russia, (2) Svalbard, (3) Iceland and (4) Greenland and north-east Canada. Analysis of variance showed that here the NAO-effect was less strong; differences in productivity between regions did not quite reach significance on grouping data for goose populations according to their breeding area ($P = 0.058$). There were no significant differences in the effect of summer NAO on the breeding success of goose populations among the regions ($P = 0.44$).

This aggregated approach indicates that the spring NAO is linked to goose production in general, though not necessarily for each separate population. The data suggest that the NAO-effect results rather more from weather events in spring staging areas than from those in breeding areas. However, some of those areas overlap, especially in Iceland, and there can be no sharp distinction between the spring NAO as an index of weather conditions in staging or in breeding areas.

Juvenile percentages and MSLP at Reykjavik

Table 6 compares the coefficients between juvenile percentages and spring values of the NAO and of the mean MSLP at Reykjavik over the same time periods. For only four populations (Tundra Bean, Greater Snow, Greenland Barnacle and Atlantic Brent Geese) did breeding success correlate significantly with both of these indices of pressure variation in spring. For most of the populations listed, however, the two coefficients were of the same sign and similar magnitude.

Discussion

Though variations in the seasonal values of the NAO and Reykjavik MSLP seem to have had no significant influence on the Greylag Geese and Pink-footed Geese breeding in Iceland, close to the Icelandic Low, they showed strong statistical links with the performance of geese breeding as far away as northwest Russia and at Foxe Basin in the east Canadian arctic. A preliminary study of the extent to which the northward movements of North American geese in spring might have been influenced by MSLP at stations at 45º–55º N on the Pacific coast (Vancouver), across the Prairies (Jamestown ND, Edmonton, Alta) and near the Atlantic coast (Quebec City), obtained similar results (H. Boyd, unpubl. data). Geese moving north through the interior showed quite strong statistical links with the spring MSLP at Vancouver and Quebec City but not with those at Jamestown or Edmonton.

While the intensity and tracks of weather systems associated with positive

Table 6. Coefficients of regression of % juveniles on spring NAO and MSLP values at Reykjavik in the same years. $^{1}P < 0.1$, $^{*}P < 0.05$, $^{**}P < 0.01$.

Species	Breeding area	N	NAO	Reykjavik MSLP
Tundra Bean	NW Russia	19	–0.666**	–0.616**
White-fronted	NW Russia	23	–0.381^{1}	–0.374^{1}
	W Greenland	33	–0.381	–0.101
Greylag	Iceland	33	–0.139	0.043
Pink-footed	Iceland/Greenland	33	–0.085	–0.172
Greater Snow	High Arctic Canada	30	–0.392*	–0.440*
Barnacle	E Greenland	31	–0.702**	–0.355*
	Svalbard	12	–0.658*	–0.280
	NW Russia/Baltic	23	–0.381^{1}	–0.374^{1}
Brent	NW Russia	31	–0.333^{1}	–0.213
	Svalbard	25	–0.158	–0.232
	High Arctic Canada	31	0.205	0.217
	Foxe Basin, Canada	30	–0.481**	–0.589**

and negative phases of the NAO in winter have been explored in some detail by climatologists, changes in the positions and intensity of storm tracks during spring and summer seem to have received less attention. Thus ways in which the spring and summer NAO patterns impinge on the breeding season for the geese have yet to be determined. The results of this study indicate that the spring NAO is linked to productivity over several populations, rather than having a strong effect on the breeding success of individual populations. Further investigation is needed to determine whether seasonal NAO values have an interactive or additive effect, and whether the grouping of months used here, for obtaining seasonal NAO values, truly matches key periods in the migratory and breeding cycles for each of the populations included in the study.

From the evidence presented here, the NAO seems to be of little immediate help in determining where and how weather events influence the breeding efforts of arctic-breeding geese. Yet, because they become available very quickly, NAO and MSLP measurements in spring may provide advance short-term indicators of the likely success of several stocks of geese nesting in parts of the arctic where on-site evidence is expensive to obtain. More importantly, large-scale climate indices show greater promise for "forecasting the unpredictable" (Anon. 2004), than, for example, spring temperatures. The Atlantic Multidecadal Oscillation (AMO: Higuchi *et al*. 1999; D'Aleo & Taylor 2007), an index of North Atlantic sea surface temperatures (SST), the effects of which are strongly interwoven with the effects of the atmospheric pressure systems characterised by the NAO, may prove especially useful in projecting weather patterns and thus goose breeding success for several years ahead.

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