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Global weather variability affects avian phenology: a long-term analysis, 1881–2001

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Abstract. The North Atlantic Oscillation (NAO) has been used as a simple approximate descriptor of the global weather fluctuation over Europe. Spring arrival dates of 37 migratory bird species (summer visitors) recorded in Moravia, Czech Republic during 103 years between 1881 and 2001 were correlated with the seasonal NAO index. Bird arrivals occurred significantly earlier following positive winter/spring NAO values (causing a warmer spring than normal in Central Europe) in all short-distance migrants with a European (Mediterranean) winter range (*Alauda arvensis, Anser anser, Columba palumbus, Larus ridibundus, Phoenicurus ochruros, Phylloscopus collybita, Remiz pendulinus, Saxicola torquata, Serinus serinus, Sturnus vulgaris, Turdus philomelos, Vanellus vanellus*). On the other hand, the timing of arrival did not correlate significantly with seasonal NAO in long-distance migrants having largely an African (sub-Saharan) winter range (*Acrocephalus schoenobaenus*, *Anthus trivialis*, *Apus apus*, *Ciconia ciconia, Cuculus canorus*, *Ficedula albicollis*, *Hippolais icterina*, *Hirundo rustica, Jynx torquilla*, *Lanius collurio*, *Luscinia megarhynchos, Muscicapa striata*, *Oriolus oriolus*, *Phylloscopus sibilatrix*, *Riparia riparia*, *Streptopelia turtur, Sylvia atricapilla, S. curruca, Upupa epops*). The prevailing positive phase of winter/spring NAO conditions observed in Europe at the end of the 20th century has obviously determined the trend of an earlier than normal arrival of short-distance migratory species.

Key words: migratory birds, North Atlantic Oscillation, spring arrival, temperature

Introduction

The North Atlantic Oscillation (NAO) system is the major mode and cause of weather and climate fluctuation in Europe and eastern North America (Wallace & Gutzler 1981, Barnston & Livezey 1987, Hurrell 1995). A number of recent papers have reported a relation between the NAO variability and plant or animal phenology (for references, see Hubálek 2003) including avian breeding – e.g., egg laying dates (Forchhammer et al. 1998, Przybylo et al. 2000, Saether et al. 2000, Both & Visser 2001, Møller 2002, Nott et al. 2002, Sanz 2002). The effect of NAO on the arrival dates of birds has been studied only very recently (Forchhammer et al. 2002, Jonzén et al. 2002, Tryjanowski et al. 2002, Hubálek 2003, Hüppop & Hüppop 2003).

In the present survey, a relatively very long record (103 years) of avian spring phenology in Moravia (Czech Republic) has been correlated with the seasonal NAO indices that present simple, approximate descriptors or determinants of global weather fluctuation over Europe.

Materials and Methods

Bird records

Long-term records of arrival dates of migratory birds (summer visitors) in Moravia (48°37'–50°27'N, 15°15'–18°51'E), Czech Republic between 1881 and 1960 were published in a series of phenological yearbooks (Niessl 1882–1911, Novák & Šimek 1926, 1930–1938, Zítek 1953–1964). However, the records for 18 years (1907–22, 1925–26) were either inaccessible or missing. For the years 1961–2001, the same data as in a previous study (Hubálek 2003) have been used. When the number of records for particular species in a year did not reach three, that year was omitted. In total, 103 years were covered in this survey, and 37 well-known bird species with a sufficient number of annual records were selected for the analysis. The common English names as well as wintering areas of particular bird species can be found in Voous (1960).

North Atlantic Oscillation data

Monthly (December, D; January, J; February, F; March, M; April, A) and seasonal (DJFM – 'extended winter'; DJF; JFM; FMA) NAO indices for particular years between 1881 and 2001 were found at URL http://www.cgd.ucar.edu/~jhurrell/nao.html (Hurrell 1995). The indices are based on normalized sea-level pressure differences between Ponta Delgada (Azores) and Stykkisholmur /Reykjavik (Iceland). The positive NAO index means that the atmospheric pressure over the subtropical part of the North Atlantic is higher than normal while that over the northern sector of the North Atlantic is lower than normal; this increased pressure difference between the two sectors results in more and stronger storms crossing the Atlantic Ocean and, in turn, causes warm and wet weather (especially in winter) in northern and central Europe (Hurrell 1995). The negative NAO index reflects an opposite pattern of height and pressure anomalies over these sectors; this reduced pressure gradient results in fewer and weaker storms crossing the Ocean, bringing cold air to northern (and central) Europe and moist, often cold air into the Mediterranean. For the Czech Republic, a significant correlation was found between the winter NAO index and local air temperature (r = +0.78), but that between this index and local precipitation (r = -0.30) was insignificant (Tkadlec 2000).

Statistical analyses

Calendar days of phenological instants were transformed into Julian dates, i.e. sequential numbers (1 for 1st January, 32 for 1st February, 60 for 1st March, 91 for 1st April, etc.; in leap-years, the sequential numbers were corrected by adding 1, starting from 1st March). Arithmetic average of the arrival days (mean arrival date) was calculated in each species for every year. Linear correlation and regression models were then used to examine relationships between the NAO index and avian phenological instants of particular bird species; Pearson's simple and partial correlation coefficients were calculated and statistical tests done for all comparisons using SOLO 4.0 (BMDP Statistical Software, Los Angeles, CA). The statistical null hypothesis has been formulated as an independence of the two phenomena, i.e. weather represented as the NAO index, and avian migration timing expressed as the mean arrival date; accordingly, individual years have been treated as independent samples. Moreover, it was found that there is no significant autocorrelation within the seasonal NAO indices DJFM, JFM and FMA at a lag of one year: r values were 0.15, 0.12 and 0.08 (p>0.05), respectively.

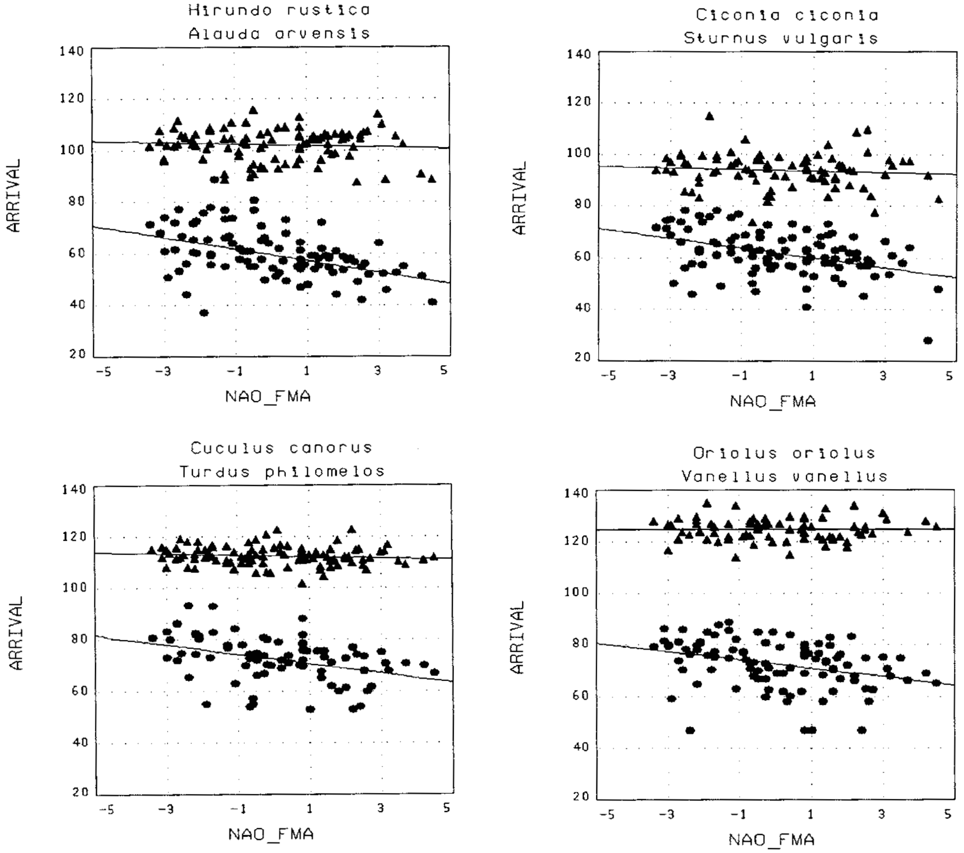

Fig. 1. Scatter plot comparison (examples) of pairs of long-distance (the upper line; triangles) vs. short-distance (the lower line; circles) migratory species of birds for the regression of their arrival (Julian dates) in Moravia on seasonal (FMA) NAO index, 1881–2001.

Results

The number of significant (p<0.05) correlations between the avian phenological instants and seasonal NAO indices DJFM, DJF, JFM and FMA were 13, 6, 15 and 14, respectively (of the 37 species tested). The winter and early-spring (D, J, F, M, A) NAO weather system conditions correlated significantly with the spring arrival of 16 summer visitors (Table 1); out of them, 15 spp. were significantly inversely correlated with the JFM and/or FMA seasonal NAO index (i.e., the phenological instants occurred earlier following the early spring air pressure difference in the North Atlantic higher than normal). All these species are early-spring, short-distance migrants that usually winter in southern Europe or in the Mediterranean (including North Africa). On the other hand, the remaining species, having their winter ranges largely in sub-Saharan Africa, either did not correlate with NAO at p<0.05 or, exceptionally, revealed a positive correlation (*Delichon urbica*).

Table 1. Spring phenology instants of 37 migratory bird species in Moravia, 1881–2001, with the number of years (n), and Pearson's correlation coefficient (r) values between the avian arrival dates and seasonal NAO indices (DJFM, December to March; JFM, January to March; FMA, February to April).

	Arrival date		Correlation (r) with NAO indices			
Bird species	Mean	S.D.	n	DJFM	JFM	FMA
Principal wintering areas: western or southern Europe, the Mediterranean						
Alauda arvensis	59.5	10.51	101	**-0.346**	**-0.267**	**-0.409**
Sturnus vulgaris	61.8	8.66	102	**-0.368**	**-0.398**	**-0.412**
Anser anser	62.6	17.89	70	**-0.343**	**-0.284**	**-0.309**
Turdus philomelos	72.3	8.91	77	**-0.292**	**-0.261**	**-0.394**
Motacilla alba	72.5	9.12	99	-0.124	-0.137	**-0.266**
Vanellus vanellus	72.6	9.18	98	**-0.319**	**-0.302**	**-0.339**
Larus ridibundus	73.2	6.53	66	**-0.292**	**-0.323**	**-0.345**
Columba palumbus	77.0	9.81	77	**-0.351**	**-0.342**	**-0.325**
Phylloscopus collybita	83.1	6.34	50	**-0.402**	**-0.404**	**-0.369**
Phoenicurus ochruros	83.3	6.01	73	**-0.263**	**-0.270**	-0.214
Saxicola torquata	84.7	11.68	38	**-0.328**	**-0.451**	**-0.559**
Gallinago gallinago	84.8	8.59	27	**-0.458**	**-0.563**	**-0.432**
Remiz pendulinus	89.3	10.97	37	**-0.412**	**-0.380**	**-0.494**
Tringa totanus	90.8	11.27	27	**-0.400**	**-0.457**	-0.242
Serinus serinus	91.0	9.20	50	-0.267	**-0.409**	**-0.395**
Principal wintering area: sub-Saharan Africa						
Ciconia ciconia	94.0	6.71	84	-0.084	-0.086	-0.087
Sylvia atricapilla	96.6	8.47	58	-0.171	-0.164	-0.184
Phylloscopus trochilus	97.4	8.73	45	-0.168	-0.251	-0.270
Anthus trivialis	99.8	9.51	61	+0.186	+0.198	+0.193
Hirundo rustica	102.3	6.17	98	-0.036	-0.087	-0.090
Upupa epops	104.3	8.43	70	-0.198	-0.113	-0.126
Jynx torquilla	104.7	7.54	77	-0.093	-0.043	-0.117
Ficedula albicollis	105.8	5.48	50	+0.039	+0.055	+0.105
Sylvia curruca	106.1	6.14	59	-0.207	-0.140	-0.099
Acrocephalus schoenobaenus	109.6	7.23	34	-0.086	-0.193	-0.133
Delichon urbica	110.1	6.51	75	+0.182	**+0.230**	**+0.265**
Actitis hypoleucos	110.1	9.47	41	-0.051	-0.001	-0.079
Phylloscopus sibilatrix	112.4	6.73	40	-0.280	-0.202	-0.101
Cuculus canorus	112.6	3.72	103	-0.146	-0.194	-0.147
Riparia riparia	113.0	9.33	32	-0.181	-0.055	+0.078
Luscinia megarhynchos	113.1	5.71	70	-0.185	-0.130	-0.114
Streptopelia turtur	115.3	4.70	72	-0.037	-0.046	+0.064
Apus apus	120.5	3.99	66	-0.092	-0.089	-0.024
Oriolus oriolus	124.9	4.15	78	+0.023	+0.021	+0.008
Hippolais icterina	125.9	5.02	70	+0.049	+0.022	+0.106
Muscicapa striata	126.0	4.69	46	+0.246	+0.084	+0.100
Lanius collurio	127.1	5.79	62	+0.119	+0.051	-0.009

The r values printed in bold are significant at $p<0.05$.

Table 2. Linear regression ($y = a + b.x$) of spring arrival (y, Julian date) on DJFM and FMA seasonal NAO indices (x) in short-distance migratory bird species in Moravia, 1881–2001.

Bird species	DJFM Regression slope (b)	DJFM Intercept (a)	FMA Regression slope (b)	FMA Intercept (a)
Alauda arvensis	**-1.7893**	59.7	**-2.2735**	59.5
Sturnus vulgaris	**-1.5739**	62.1	**-1.8998**	61.9
Anser anser	**-3.0790**	63.7	**-2.9230**	63.2
Turdus philomelos	**-1.2621**	72.7	**-1.8418**	72.6
Motacilla alba	-0.5584	72.6	**-1.2004**	72.6
Vanellus vanellus	**-1.4766**	72.8	**-1.6399**	72.6
Larus ridibundus	**-0.9115**	73.6	**-1.2118**	73.5
Columba palumbus	**-1.6561**	77.5	**-1.6978**	77.3
Phylloscopus collybita	**-1.3037**	83.9	**-1.2804**	83.5
Phoenicurus ochruros	**-0.7523**	83.6	-0.6820	83.5
Saxicola torquata	**-1.8241**	85.6	**-3.5159**	86.2
Gallinago gallinago	**-2.1705**	86.3	**-2.2243**	86.2
Remiz pendulinus	**-2.1027**	90.9	**-3.1274**	90.8
Tringa totanus	**-1.9928**	91.3	-1.4722	91.4
Serinus serinus	-1.1304	91.4	**-2.0698**	91.4

The b values printed in bold are significant at $p<0.05$.

Table 3. Simple and partial correlation coefficients of the differential effect of variables “NAO” (DJFM, FMA) and “Year” (calendar year of observation) on the arrival dates of the bird species that revealed significant simple correlation with a seasonal NAO index (Table 1). ‘Controlled for’ means the variable that is kept constant (i.e., its effect has been removed) in the partial correlation analysis.

	Simple correlation			Partial correlation			
	Year	DJFM	FMA	DJFM index		FMA index	
Controlled for:	–	–	–	Year	DJFM	Year	FMA
Alauda arvensis	-0.07	**-0.35**	**-0.41**	**-0.322**	-0.017	**-0.405**	-0.004
Sturnus vulgaris	**-0.25**	**-0.37**	**-0.41**	**-0.318**	**-0.213**	**-0.391**	**-0.208**
Anser anser	**-0.58**	**-0.34**	**-0.31**	**-0.292**	**-0.566**	**-0.274**	**-0.566**
Turdus philomelos	**-0.40**	**-0.29**	**-0.39**	-0.205	**-0.379**	**-0.368**	**-0.375**
Motacilla alba	**-0.28**	-0.12	**-0.27**	-0.083	**-0.262**	**-0.219**	**-0.249**
Vanellus vanellus	**-0.21**	**-0.32**	**-0.34**	**-0.299**	-0.175	**-0.317**	-0.174
Larus ridibundus	**-0.62**	**-0.29**	**-0.35**	**-0.329**	**-0.614**	**-0.323**	**-0.614**
Columba palumbus	**+0.39**	**-0.35**	**-0.33**	**-0.375**	**+0.458**	**-0.423**	**+0.472**
Phylloscopus collybita	**-0.39**	**-0.40**	**-0.37**	**-0.394**	**-0.362**	**-0.341**	**-0.362**
Phoenicurus ochruros	-0.09	**-0.26**	-0.21	**-0.255**	-0.058	-0.203	-0.059
Saxicola torquata	**-0.61**	**-0.33**	**-0.56**	-0.311	**-0.601**	**-0.595**	**-0.641**
Gallinago gallinago	-0.33	**-0.46**	**-0.43**	**-0.466**	-0.299	**-0.409**	-0.299
Remiz pendulinus	-0.10	**-0.41**	**-0.49**	**-0.352**	-0.052	**-0.486**	-0.033
Tringa totanus	-0.24	**-0.40**	-0.24	**-0.383**	-0.212	-0.214	-0.216
Serinus serinus	**-0.45**	-0.27	**-0.40**	-0.022	**-0.428**	**-0.369**	**-0.428**
Delichon urbica	+0.14	+0.18	**+0.26**	**+0.245**	+0.103	**+0.249**	+0.103

The r values printed in bold are significant at $p<0.05$.

The JFM seasonal NAO index explained on average 13 % (range, 2–32 %) variability (r^2) in the phenological instants of the 15 short-distance migrants, whereas only 2 % (range, 0–6 %) variation in the 22 long-distance migrants; the difference in r^2 values between the two groups of migratory birds is highly significant (t = 5.835; $p<0.01$). The other seasonal NAO indices, FMA and DJFM, explained on the average 14 % (range, 5–31 %) and 12 % (range, 2–21 %) variability, respectively, in the phenological instants of the short-distance migrants, but only 2 % (range, 0–7 %) and 2 % (range, 0–8 %) variability, respectively, in the long-distance migrants; also these differences are significant (t = 5.808; $p<0.01$). According to monthly NAO indices, the numbers of avian species significantly ($p<0.05$) correlated in their phenology with NAO indices of December, January, February, March and April were 0, 3, 11, 10 and 1, respectively. Therefore, especially the NAO conditions in February and March have had a significant impact on certain migratory species.

Table 2 shows linear regression of arrival data on the DJFM and FMA seasonal NAO indices in 15 avian species belonging to short-distance migrants (see also Fig. 1). The regression coefficient *b* values indicate that the effect of NAO was more pronounced

Table 4. Correlation (*r*) between NAO and bird arrival dates: comparison of two periods. Only the species with at least 20 observation years (*n*) during both periods have been analyzed.

Period:	1881–1959			1960–2001		
	n	DJFM	FMA	*n*	DJFM	FMA
Calendar year	61	-0.009	-0.075	42	**+0.456**	**+0.492**
Alauda arvensis	61	**-0.426**	**-0.480**	40	-0.292	**-0.380**
Sturnus vulgaris	61	**-0.313**	**-0.347**	41	**-0.402**	**-0.453**
Anser anser	36	-0.283	**-0.367**	34	**-0.370**	-0.228
Turdus philomelos	42	**-0.452**	**-0.485**	35	-0.071	-0.193
Motacilla alba	61	-0.176	-0.184	38	-0.004	-0.214
Vanellus vanellus	58	-0.141	-0.163	40	**-0.408**	**-0.489**
Larus ridibundus	31	-0.223	-0.243	35	**-0.366**	**-0.338**
Columba palumbus	41	**-0.470**	**-0.331**	36	**-0.444**	**-0.616**
Phoenicurus ochruros	36	-0.017	-0.185	37	**-0.392**	-0.280
Ciconia ciconia	57	+0.011	-0.060	27	-0.265	-0.214
Sylvia atricapilla	26	-0.086	-0.160	32	-0.006	+0.055
Anthus trivialis	20	+0.213	+0.131	41	+0.147	+0.113
Hirundo rustica	61	+0.144	+0.109	37	-0.036	-0.094
Upupa epops	40	-0.289	-0.185	30	-0.130	-0.054
Jynx torquilla	39	+0.024	+0.023	38	-0.125	-0.164
Sylvia curruca	20	-0.121	-0.013	39	-0.209	-0.079
Delichon urbica	38	+0.095	+0.294	37	+0.207	+0.228
Cuculus canorus	61	-0.080	-0.182	42	-0.186	-0.094
Luscinia megarhynchos	37	+0.112	+0.060	33	-0.327	-0.170
Streptopelia turtur	39	**+0.365**	+0.281	33	-0.218	-0.040
Apus apus	30	+0.119	+0.244	36	-0.134	-0.126
Oriolus oriolus	40	-0.156	-0.122	38	+0.144	+0.134
Hippolais icterina	30	-0.019	+0.116	40	+0.050	+0.011
Lanius collurio	33	+0.099	-0.040	29	+0.052	-0.159

The *r* values printed in bold are significant at $p<0.05$.

in some species (*Saxicola torquata, Remiz pendulinus, Anser anser*) than in others (*Phoenicurus ochruros, Motacilla alba, Larus ridibundus, Phylloscopus collybita, Tringa totanus, Vanellus vanellus, Columba palumbus,* etc.). The average regression coefficient is about -1.94 which means that an increase of FMA NAO index from -5 to +5 might advance the arrival by about 20 days in an average short-distance migratory species, and corresponding values for the DJFM index are -1.57, and 16 days.

Using the analysis with partial correlation coefficients, differential effects of the variable "NAO" (seasonal NAO index) and "Year" (calendar year) on the avian arrival dates were evaluated by keeping constant either Year or NAO (Table 3). The analysis has indicated that in eight bird species (*Alauda arvensis, Sturnus vulgaris, Vanellus vanellus, Phoenicurus ochruros, Gallinago gallinago, Remiz pendulinus, Tringa totanus, Delichon urbica*) the NAO variable is dominating over Year, in three others (*Turdus philomelos, Columba palumbus, Phylloscopus collybita*) the effect of NAO was approximately as important as that of Year, whereas in five remaining species tested the effect of Year could be greater than that of NAO (*Anser anser, Motacilla alba, Larus ridibundus, Saxicola torquata, Serinus serinus*). Table 4 compares two periods (1881–1959 vs. 1960–2001) for their effect on correlation analysis between seasonal NAO indices and spring arrival of the more common bird species.

Discussion

Common bird species were taken into account in this survey, whose population sizes did not change considerably with time (which could affect the results: Tryjanowski & Sparks 2001). The exceptions, with populations in decline were *Gallinago gallinago, Tringa totanus, Upupa epops* and *Vanellus vanellus* in Moravia (Šťastný et al. 1996). However, the results yielded in these species do not contradict the general conclusion that long-distance migratory species are not affected significantly with NAO activity, in contrast to short-distance migrants.

Partial correlation analysis (Table 3) yielded interesting results about the differential effect of two variables, NAO and Year, on the arrival dates of birds. It was found that the phenological instant was affected by NAO and not by Year in eight species of birds, while in three species the effect of Year was approximately as important as NAO, and in five species the effect of Year could be greater than that of NAO. However, interpretation of the singled-out variable Year is non-trivial: it certainly involves unknown variates other than NAO, e.g., sampling method. In general, longitudinal observations always include, as an inherent and unintentional component, subtle or less than minor changes of the method during the long monitoring period. This might also be the case in this survey, in that the number of field ornithologists and observation sites was not constant over the whole period 1881 through 2001. Therefore the effect of Year should be considered with care.

In an earlier study, a cluster analysis of temporal spring migration patterns of birds in Moravia between 1881 and 1960 revealed several 'migrons', i.e. groups of co-migrating avian spp. (Hubálek 1985): the major ('Mediterranean') migron consisted of short-distance migrants wintering in southern or western Europe (*Alauda arvensis, Sturnus vulgaris, Fringilla coelebs, Columba palumbus, Motacilla alba, Vanellus vanellus, Turdus philomelos, Erithacus rubecula, Scolopax rusticola*), whereas the remaining migrons were called 'African' in that they involved long-distance migrants having their winter quarters largely in sub-Saharan Africa (*Hirundo rustica, Jynx torquilla, Delichon urbica, Cuculus canorus, Luscinia megarhynchos, Streptopelia turtur, Apus apus, Oriolus oriolus*, *Coturnix coturnix*). There is a certain analogy of those results with the output of the present study albeit based on another approach.

In the present survey, the seasonal winter/spring NAO index did not correlate significantly with the arrival of a vast majority of long-distance migratory species wintering in tropical and southern Africa; only one of 22 those species revealed a significant correlation, but it was positive, not negative as in short-distance migrants. Timing of the departure of birds from the sub-Saharan winter grounds is obviously unaffected by the weather system fluctuation at northern Atlantic latitudes (Both & Visser 2001). On the other hand, a significant inverse relationship was found between the arrival of all 15 short-distance migrants tested (wintering mostly in southern Europe) and the seasonal winter/spring NAO index, indicating that a higher than normal air pressure difference over the North Atlantic during the winter/spring (especially in February and March) determines an earlier than normal arrival of these birds in central Europe. This result is not in accord with recently published studies of Forchhammer et al. (2002) and Hüppop & Hüppop (2003) who found in Scandinavia and Helgoland, respectively, no significant difference in the effect of NAO on spring arrival between long-distance and short-distance migrants (however, a lower number of species of each group and shorter record series were analyzed), but it corresponds well with the results of Nott et al. (2002) in North America and Tryjanowski et al. (2002) in Poland.

The positive winter NAO index values mean a milder winter and spring in Europe, and specifically a warmer (and drier) than normal weather over central Europe (Hurrell 1995, Tkadlec 2000). The higher mean temperatures associated with the positive NAO phase can lead to an advanced invertebrate abundance in spring which might benefit short-distance migrants more than long-distance migratory species (Nott et al. 2002). The marked effect of NAO on waterbirds and wetland birds wintering in southern and western Europe (*Anser anser, Larus ridibundus, Vanellus vanellus, Gallinago gallinago, Tringa totanus*) is attributable to earlier dates of ice break-up of lakes and rivers in central Europe due to direct effect of a positive phase of winter/spring NAO index (Yoo & D'Odorico 2002).

Recent climate warming in the Northern Hemisphere (Houghton 1995) is often regarded as the cause of the advanced spring arrival and egg-laying dates of migratory birds that has been recorded in Europe and North America (Forchhammer et al. 1998, Both & Visser 2001, Zalakevicius & Zalakeviciute 2001, Sanz 2002, Winkler et al. 2002). The data in Table 4 show that in the last four decades since 1960 (in contrast to the period 1881–1959), the winter/spring NAO indices have correlated significantly with the variable Calendar year, confirming the trend of seasonal warming in central Europe. Some short-distance migratory bird species revealed significant inverse correlation in their arrival dates with the NAO activity during both periods (*Alauda arvensis, Sturnus vulgaris, Anser anser, Columba palumbus*), whereas others correlated significantly only during 1960–2001 (*Vanellus vanellus, Larus ridibundus, Phoenicurus ochruros*) or 1881–1959 (*Turdus philomelos*). However, even some long-distance migrants disclosed a tendency (although statistically insignificant) to negative values of r in the period 1960–2001 compared with the period 1881–1959 (*Ciconia ciconia, Hirundo rustica, Jynx torquilla, Luscinia megarhynchos, Streptopelia turtur, Apus apus*). This might indicate that the influence of NAO on timing of migration in certain short-distance and even a few long-distance migratory species has become amplified in the recent warming period 1960–2001.

On the other hand, this result could be affected, in addition to NAO, by a not-yet disclosed factor in spring migration patterns of those bird species, or by some bias in long-term recording methods.

The global warming of the Earth (in both marine and terrestrial ecosystems) has been recorded since the 1980s (Houghton 1995). The present study shows that the NAO weather system affects spring phenological instants in a number of bird species and that this effect indeed could explain the earlier than normal arrival of common species of birds migrating in early spring (e.g., *Alauda arvensis, Sturnus vulgaris, Vanellus vanellus, Columba palumbus, Motacilla alba, Phoenicurus ochruros, Phylloscopus collybita* and *Serinus serinus*) that has been observed in central Europe approximately since the 1960s when the positive phase of NAO started to predominate. Moreover, milder winter and early spring seasons could also affect directly or indirectly (*via* the diet) resident or wintering bird species, e.g. raptors and owls (Sasvári & Hegyi 2002, Rubolini et al. 2003).

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