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Response of birds to climatic variability; evidence from the western fringe of Europe

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Abstract Ireland's geographic location on the western fringe of the European continent, together with its island status and impoverished avifauna, provides a unique opportunity to observe changes in bird migration and distribution patterns in response to changing climatic conditions. Spring temperatures have increased in western Europe over the past 30 years in line with reported global warming. These have been shown, at least in part, to be responsible for changes in the timing of life cycle events (phenology) of plants and animals. In order to investigate the response of bird species in Ireland to changes in temperature, we examined ornithological records of trans-Saharan migrants over the 31-year period 1969–1999. Analysis of the data revealed that two discrete climatic phenomena produced different responses in summer migrant bird species. Firstly, a number of long-distance migrants showed a significant trend towards earlier arrival. This trend was evident in some species and was found to be a response to increasing spring air temperature particularly in the month of March. Secondly, (1) a step change in the pattern of occurrences of non-breeding migrant bird species, and (2) an increase in the ringing data of migrant species were found to correlate with a step change in temperature in 1987–1988. These results indicate that, for migrant bird species, the impact of a sudden change in temperature can be as important as any long-term monotonic trend, and we suggest that the impact of step change events merits further investigation on a wider range of species and across a greater geographical range.

Keywords Migratory birds · Western Europe · Phenology · Climate variables · Step change

Introduction

Recent climate change due to human activity has resulted in increasing temperatures on a global scale (Parry et al. 2007). Bird species phenology and distribution are known to be correlated with changes in temperature (Turner et al. 1988; Thomas and Lennon 1999; Sparks et al. 2005). Recent records show that bird migration phenology is changing throughout Europe with widespread observations of earlier arrival times (Hüppop and Hüppop 2003; Lehikoinen et al. 2004; Sparks et al. 2005). In addition, it has been shown that there is considerable spatial variability in the observed changes in the timing of arrival (Jonzén et al. 2007). It has also been demonstrated that the likely causes of a shift towards earlier bird migration dates are changes in climatic conditions (Sparks et al. 2005; Cotton 2003), but that not all species respond to temperature in a similar way (Sparks and Trylanowski 2007). Northward shifts in bird breeding ranges across both North America and Great Britain have also been linked with recent climate change (Thomas and Lennon 1999; Hitch and Leberg 2007). However, while the impact of global warming on ecosystems requires quantification, the effect of natural variability in climate must also be borne in mind. This natural variability in the North Atlantic region includes changes in climatic conditions associated with the large-scale, natural climate phenomenon known as the North Atlantic Oscillation (NAO). As noted by Chavez et al. (2003), large-scale, naturally occurring variations must be taken into account when considering the impacts of human-induced climate change.

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The recent increase in spring temperatures in mid-latitudes (Parry et al. 2007) has been found to be an important driver of the observed altered phenology of many plant and animal species (Walther et al. 2002). Across Ireland, average air temperature has increased by 0.5°C (McElwain and Sweeney 2003) during the past century which is in line with the global increase of 0.7°C (Parry et al. 2007). This increase in temperature has been associated with a change in plant phenology in the form of earlier leafing of trees in Ireland (Donnelly et al. 2006).

Even in the absence of anthropogenically-driven increasing temperatures, phenology would be expected to respond to natural variability in climate. The climate in Western Europe is dictated in part by the NAO (Hurrell 1995). In northern Europe, a positive NAO is correlated with warm and moist winters, while a negative NAO is associated with cold and dry winters (Hurrell 1995). The NAO is also characterised by decadal oscillations and longer predominantly positive and negative phases (Hurrell 1995). The beginning of the present positive phase of the NAO has been linked to a significant step change in air temperature across Europe in 1987–1988 (Beaugrand 2004; Fealy and Sweeney 2005; Hari et al. 2006). This type of abrupt change in climate is often associated with step changes at ecosystem level which are generally referred to as regime shifts. A well-documented regime shift occurred in the North Pacific Ocean region in the late 1970s (Hare and Mantua 2000), while the 1987–1988 change point in Europe has been associated with a regime shift in the Baltic, North Sea and Wadden Sea ecosystems (Beaugrand 2004; Weijerman et al 2005). In both cases, these shifts have been linked to declines in populations of the kittiwake *Rissa tridacyla* (Hunt and Byrd 1999; Fredriksen et al. 2004). The regime shift in 1987–1988 was also apparent in a range of biological variables, including numbers of dark-bellied brent geese *Branta bernicla bernicla* (Weijerman et al. 2005). This change point has further been associated with abrupt changes in lake phytoplankton populations in northern Germany (Gerten and Adrian 2000) and an increase in the incidence of disease in brown trout *Salmo trutta* in Switzerland (Hari et al. 2006).

The increase in the winter (December–February) NAO index over the past 20–30 years has contributed significantly to the increase in the average winter temperature across Europe (Hurrell 1995) and seems to explain the earlier spring arrival times of migrant birds to Denmark, Sweden, Germany and Finland (Forchhammer et al. 2002; Jonzén et al. 2002; Hüppop and Hüppop 2003; Vähätalo et al. 2004; Stervander et al. 2005). Based on analyses of a long-term (1960–2003) dataset of migratory birds (~24 species) in Germany, van Noordwijk (2003) proposed three possible mechanisms that might explain the earlier passage of long-distance migrant birds. Firstly, the departure time from Africa has not changed, but migration through continental Europe proceeds more quickly. Secondly, if the weather in Africa is correlated with the NAO index, then the birds might leave earlier because the seasons there are also changing. Thirdly, the climate in Africa has not changed, but natural selection has altered migratory cues. More recently, Saino et al. (2007) and Saino and Ambrosini (2008) proposed that long-distance spring migrants to Europe may be able to predict meteorological conditions in their breeding grounds, as the authors have shown a strong correlation between temperature anomalies in sub-Saharan Africa and Europe.

Migratory birds are particularly vulnerable to global climatic changes as their complex annual cycle involves breeding, moult and two migration events (Pulido et al. 2001). Long-distance migrant birds may be constrained in their plastic responses to climatic changes by endogenous rhythms that control migration, as migration onset is unlikely to be linked to climate in the breeding grounds (Visser et al. 1998; Cotton 2003; Jonzén et al. 2006). It is unclear whether the changes in migratory behaviour that have been attributed to climatic variability are due to phenotypic plasticity or whether they are as a consequence of adaptive evolution (Pulido et al. 2001; Jonzén et al. 2006). The existence of phenotypic plasticity allows birds to adjust their behaviour according to real-time environmental cues, which they experience at wintering grounds, or during migration (Hüppop and Hüppop 2003; Vähätalo et al. 2004).

Bird phenological phases that have been shown to be affected by changes in climate include variations in the timing of migration and egg-laying dates (Both and Visser 2001; Both et al. 2006). Recent datasets, from the UK county bird reports (1942–1996) and coastal bird observatories (1960–1996), have shown a significantly earlier arrival date of many migratory species including the cuckoo *Cuculus canorus* and barn swallow *Hirundo rustica* (Sparks 1999). The author suggested an increase in temperature along the migration route was a possible contributing factor to the early arrival of these birds to the UK. These recent data sets indicated that the arrival of the barn swallow was 1.6–1.8 days earlier with every 1°C increase in temperature. However, in the Netherlands, a study of the pied flycatcher *Ficedula hypoleuca* did not show an earlier arrival date even though temperature increased significantly over the 20-year period (1980–2000), suggesting that day-length in the wintering grounds was the overriding trigger for migration (Both and Visser 2001).

The objectives of this paper were to determine if any long-term trend or step-change was apparent in either the first arrival dates, annual occurrences of rare migrants or ringing records of migrant bird species, and to establish if any identified trends or step-changes were related to changes in climate. We examined 31 years of arrival dates of 11 long-distance migrant bird species and in relation to temperature variables at the places of departure and arrival. We correlated the arrival dates with the winter (DJF) North Atlantic Oscillation (NAO) and spring temperature in eastern Ireland. In addition, we investigated the occurrence of the 1987/88 step-change in both the climatic and bird data sets.

Materials and methods

Bird phenological data

Three bird datasets were compiled for the period 1969–1999 from Irish local and national bird reports and ringing reports. These datasets were (1) a regional dataset for eastern Ireland of the first arrival dates for 11 summer migrant species, (2) a national dataset of the occurrence of two rare non-breeding migrants, and (3) a national ringing dataset for 12 regular summer migrants which breed in Ireland. Although the sightings of common spring migrants extracted from local bird reports and rare migrants from national bird reports used in this study rely on volunteer observers, the data collected are considered representative of bird movements within the respective areas. Care must be taken when publishing first arrival dates as records may be influenced by changes in numbers of observers, large random variance, atypical behaviour (i.e. individual birds responding independently to external stimuli), visibility and bird population size (Lehikoinen et al. 2004; Sparks et al. 2001, 2005). However, in the current study, observer numbers remained relatively constant at 70–80 over the 31-year period under investigation.

1) The date of arrival of spring migrant bird species to Eastern Ireland (Counties Louth, Meath, Dublin & Wicklow) was extracted from local bird reports over the 31-year period 1969–1999 (Cummins et al. 1970, 1972–1974; Hutchinson et al. 1971; Moore 1975–1976; Mullarney 1976; Cooney et al. 1981–1998, 2000). Irish Bird Reports from 1969–1999 were also examined but only one record was extracted from the 1970 issue (Irish Bird Reports 1970–2000). These dates were then converted to Julian Days. Statistical analysis was performed on observations of arrival dates of 11 terrestrial bird migrant species. The species selected for analysis were those that had a minimum of 18 years for arrival date over the 31-year period (1969–1999). In addition, the species selected were common long-distance transcontinental migrants to the Western Palaearctic whose wintering grounds are in sub-Saharan Africa (Table 1).
2) Two non-breeding migrant species that are rare to Ireland were selected for analysis to establish whether there were any trends in their occurrences. The annual total number of birds for each species was extracted from annual Irish Bird Reports 1969–1999 (Irish Bird Reports 1970–2000). Hobby *Falco subbuteo* and osprey *Pandion haliaetus* were selected as they are rare but regular non-breeding migrants to Ireland and have different summer breeding ranges in Europe. Both also winter in sub-Saharan Africa. The purpose of investigating regular and rare non-breeding migrants to Ireland was to establish whether species with different ecologies and different summer distributions in Europe showed (1) any changes in their patterns of occurrences in Ireland, or (2) whether there was a pattern to any changes observed.
3) National ringing data for 12 regular breeding sub-Saharan migrants were obtained from Irish Ringing Reports 1975 (first year of publication) to 1999 which were published with the Irish Bird Reports (1970–2000). Eight common passerine species (mainly juveniles/

Table 1 Results of Mann-Kendall analysis for arrival dates of common summer migrants to Ireland

Species	*n*	MK-Stat	*p* value
Common cuckoo *Cuculus canorus*	23	1.113	0.266
Common swift *Apus apus*	30	−0.751	0.453
Sand martin *Riparia riparia*	25	−2.221	0.026
Barn swallow *Hirundo rustica*	31	−2.792	0.005
Common house martin *Delichon urbicum*	19	−3.575	0.000
Whinchat *Saxicola rubetra*	23	−1.787	0.074
Northern wheatear *Oenanthe oenanthe*	30	−3.005	0.003
Common grasshopper warbler *Locustella naevia*	21	−1.913	0.056
Sedge warbler *Acrocephalus schoenobaenus*	18	1.221	0.222
Common whitethroat *Sylvia communis*	18	−2.136	0.033
Willow warbler *Phylloscopus trochilus*	26	−0.332	0.740

MK-stat describes the trend. *p value* indicates level of statistical significance.

adults ringed throughout the year) were chosen as representative samples of terrestrial insectivorous species. Four tern species (mainly pulli, ringed during the summer months) were chosen as representative samples of the coastal marine environment. The terrestrial species were sedge warbler *Acrocephalus schoenobaenus*, willow warbler *Phylloscopus trochilus*, chiffchaff *Phylloscopus collybita*, spotted flycatcher *Muscicapa striata*, reed warbler *Acrocephalus scirpaceus*, blackcap *Sylvia atricapilla*, common whitethroat *Sylvia communis* and common grasshopper warbler *Locustella naevia*. The marine species were common tern *Sterna hirundo*, arctic tern *Sterna paradisaea*, sandwich tern *Sterna sandvicensis*, and roseate tern *Sterna dougalii*.

In this study, we treat sightings and ringing data as metrics of changes in bird abundance.

Climate data

Climate data were taken from two synoptic weather stations, which were situated within the eastern Irish counties covered by the local bird reports. These stations were located at Dublin airport and Casement aerodrome and are maintained by Met Éireann, the Irish meteorological service. Average monthly air temperatures (January–April, inclusive) at both stations were calculated to give an average for the study area. In addition, average monthly air temperatures (1969–1999) from 13 synoptic weather stations (Table 2) were calculated for use with the national bird datasets. Data for the winter (December–February) NAO were obtained from (http://www.cru.uea.ac.uk/cru/data/nao.htm/) which corresponded to those of Hurrell (1995). Mean winter surface air temperature anomalies for Africa (latitude 6°N to 35°S and longitude 6°W to 42°E) were obtained from the National Climatic Data Centre (USA) (http://www.ncdc.noaa.gov/gcag/gcag.html/).

Statistical analysis

The trends in arrival dates of the birds were analysed independently for each species. Long-term trends were analysed using the MULTMK/PARTMK program for the computation of univariate Mann-Kendall tests which are non-parametric tests for the detection of trends in a time series (Libiseller and Grimvall 2002). This method is widely used in environmental science because it is simple, robust and can cope with missing values. Arrival dates were correlated with average monthly spring air temperatures on the east coast of Ireland, the North Atlantic Oscillation (NAO) index and the mean winter surface air temperature anomalies for Africa (latitude 6°N to 35°S and longitude 6°W to 42°E) using Spearman's rank correlation analysis.

The air temperature data, non-breeding migrant data, ringing data and migrant arrivals dates were analysed for the presence of step changes using the cumulative deviations test (Buishand 1982) (TREND V1.0.2). Only 4 (swift, barn swallow, wheatear and willow warbler) of the 11 long distance migrant datasets were suitable for step change analysis as data were not available for all species for all years. All datasets were checked for normality and serial correlation using the Ryan-Joiner test and Durbin Watson test respectively (MINITAB 13.1). The common tern, arctic tern, osprey and reed warbler data had non-normal distributions, while the reed warbler, sedge warbler and blackcap data showed serial correlation at a 1-year lag. To compensate for deviations from assumptions of normality and independence, significance levels for the Q statistic (Buishand 1982) were based on bootstrap resampling using

Table 2 Results of cumulative deviations test for average spring air temperature at 13 meteorological stations together with station name and location

Station name	Latitude	Longitude	Q statistic	*p*
Belmullet	54°13′40″ N	10°00′25″ W	1.71	<0.01
Birr	53°05′25″ N	07°53′25″ W	1.55	<0.01
Dublin Airport	53°25′39″ N	06°14′42″ W	1.37	<0.01
Casement Aerodrome	53°18′20″ N	06°26′20″ W	1.50	<0.01
Claremorris	53°42′40″ N	08°59′29″ W	1.54	<0.01
Clones	54°00′00″ N	07°14′00″ W	1.68	<0.01
Cork Airport	51°50′59″ N	08°29′27″ W	1.60	<0.01
Kilkenny	52°39′55″ N	07°16′10″ W	1.71	<0.01
Malin Head	55°22′20″ N	07°20′20″ W	1.53	<0.01
Mullingar	53°32′14″ N	07°21′44″ W	1.56	<0.01
Rosslare	52°15′00″ N	06°20′05″ W	1.64	<0.01
Shannon Airport	52°41′43″ N	08°29′27″ W	1.67	<0.01
Valentia	51°56′23″ N	08°54′15″ W	1.66	<0.01

In all cases the change point occurred in 1987.

1,000 resamples (Robson et al. 2000), while block resampling was used in the analysis of the reed warbler, blackcap and sedge warbler data to compensate for lag one serial correlation (Robson et al. 2000). The centre of a long-term trend in a time series may be falsely identified as a change point (Rodionov 2004). Where a long-term trend was present in the data, a regime shift detection method based on a sequential version of the partial cumulative sums method combined with a *t* test was also applied (Rodionov 2004). The regime cut-off length was set to 10, while Huber's weight function was set to 1 for the latter test.

Results

Temperature trends

Monthly spring air temperatures (February–April, inclusive) averaged over two meteorological sites (Casement Aerodrome and Dublin Airport) located within the eastern region of Ireland for the period 1969–1999 showed a statistically significant ($p \leq 0.05$) increasing trend (0.05°C per year) towards warmer conditions (Fig. 1a,b).

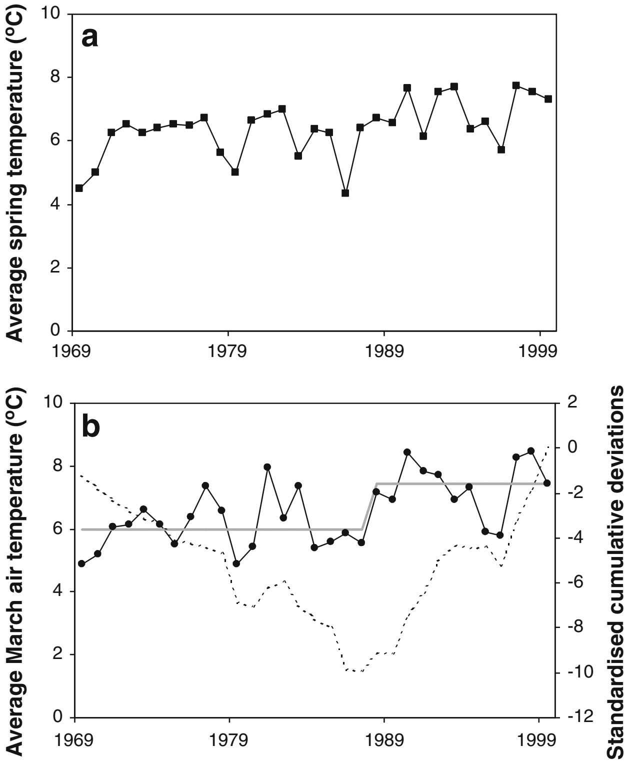

Fig. 1 **a** Average spring temperature (February–April) on the east coast of Ireland for the period 1969–1999 showing an increasing trend ($p \leq 0.05$) ,and **b** average air temperature in March for 13 sites 1969–1999 (*closed circles*), corresponding standardised cumulative deviation functions (*dashed line*), and weighted mean of regimes (*grey line*) before and after the 1987 change point. The average air temperature was 1.5°C higher after this point

A significant step change was identified at 1987 in average March air temperatures based on data from 13 synoptic weather stations across Ireland (Fig. 1b). This change point was significant using both the cumulative deviations test (Table 2) (Q=1.43; $p \leq 0.05$) and the sequential regime shift method (RSI=0.28; $p \leq 0.005$). The step change was most significant for the month of March at all stations (Table 2), but was, however, also apparent in the May datasets. March temperatures increased by an average of 1.5°C after this change point.

Long-distance migrant bird species arrival dates

We tested arrival date against year to establish whether there was a trend for earlier or later arrival. There was evidence of earlier arrival times on the east coast of Ireland for 9 out of the 11 long distant migrant species over the 31-year period 1969–1999 as indicated by the negative values obtained in the partial Mann-Kendall analysis (Table 1). The negative trend was statistically significant ($p \leq 0.05$ or 0.10) for 7 species (Table 1). Figure 2 shows the timing of arrival of barn swallow and common house martin over the 31-year period. No step changes were identified in the first arrival dates of long-distance spring migrants

Table 3 summarises the correlations between arrival dates of individual species and monthly air temperatures for

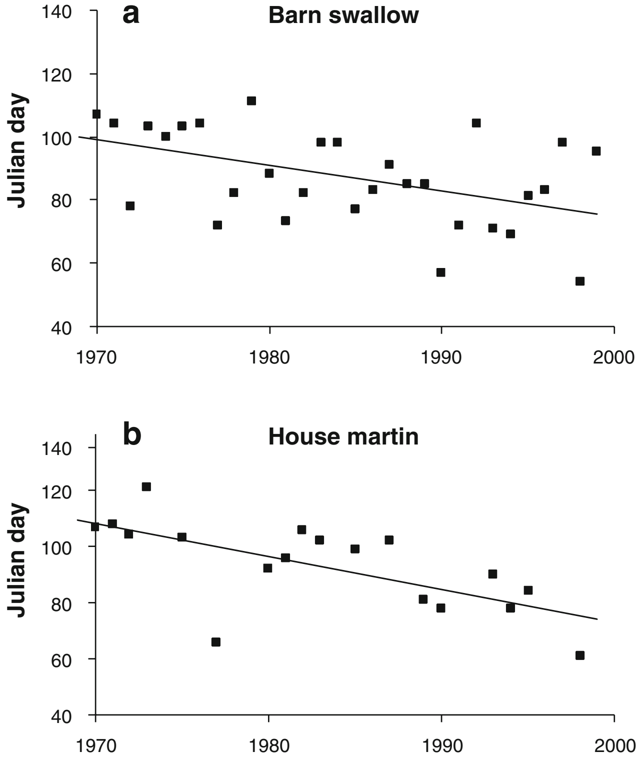

Fig. 2 Date of arrival (Julian day) to the east coast of Ireland for the period 1969–1999 for **a** barn swallow *Hirundo rustica* and **b** common house martin *Delichon urbicum*

Table 3 Correlations between first arrival date of common summer migrants to Ireland and local temperatures for January (*J*), February (*F*), March (*M*), April (*A*), January–April (*J–A*), February–April (*F–A*), African winter temperature anomalies (*A–A*) and North Atlantic Oscillation (*NAO*)

	N	J	F	M	A	J–A	F–A	A–A	NAO
Common cuckoo *Cuculus canorus*	23	0.139	−0.068	−0.001	−0.406*	−0.094	−0.180	−0.280	0.302
Common swift *Apus apus*	30	−0.141	−0.085	−0.106	−0.110	−0.062	−0.054	0.041	−0.021
Sand martin *Riparia riparia*	25	−0.060	−0.191	−0.367	0.054	−0.208	−0.312	0.097	−0.297
Barn swallow *Hirundo rustica*	31	0.021	−0.213	−0.553**	−0.056	−0.227	−0.405*	−0.216	−0.243
Common house martin *Delichon urbicum*	19	−0.063	−0.502*	−0.610**	0.078	−0.387	−0.653**	−0.007	−0.461*
Whinchat *Saxicola rubetra*	23	0.070	0.381	−0.101	0.044	0.211	0.145	−0.136	−0.200
Northern wheatear *Oenanthe oenanthe*	30	−0.267	−0.088	−0.481*	0.153	−0.264	−0.197	−0.188	−0.194
Common grasshopper warbler *Locustella naevia*	21	−0.173	−0.076	−0.388	−0.084	−0.269	−0.290	−0.172	−0.219
Sedge warbler *Acrocephalus schoenobaenus*	18	−0.275	0.397	−0.080	0.143	−0.197	0.378	0.220	0.140
Common whitethroat *Sylvia communis*	18	0.180	−0.156	−0.289	−0.148	−0.114	−0.267	−0.418	−0.273
Willow warbler *Phylloscopus trochilus*	26	−0.373	−0.279	−0.371	0.128	−0.407*	−0.299	0.200	−0.455*

*$p \leq 0.05$

**$p \leq 0.01$

January, February, March and April. For the majority of species the correlations were negative, with March temperatures showing the strongest correlations, as arrival dates of all species were negatively correlated with temperature during this month. Arrival dates of three species, barn swallow ($p \leq 0.01$), common house martin ($p \leq 0.01$) and wheatear ($p \leq 0.05$), were significantly correlated with average March temperature. The date of arrival of only one species (common house martin) was significantly ($p \leq 0.05$) negatively correlated with average February temperature while the date of arrival of the common cuckoo was negatively ($p \leq 0.05$) correlated with average April air temperature. The average February–April air temperature was significantly correlated with the arrival dates of both barn swallow ($p \leq 0.05$) and common cuckoo ($p \leq 0.01$). Mean winter temperature anomalies (°C) for Africa (latitude 6°N to 35°S and longitude 6°W to 42°E) were negatively correlated with arrival dates on the Irish east coast for 7 species and positively correlated for the other 4 species. However, these correlations were not statistically significant (Table 3).

The timing of spring migration correlated negatively with the winter (December–February) NAO for 9 of the 11 species examined (Table 3). A negative correlation indicates early arrival in those years when the NAO was in a positive phase. The correlations were statistically significant ($p \leq 0.05$) for 2 species (common house martin and willow warbler).

Step changes in non-phenological bird data

There were significant step changes in the late 1980s in the ringing data for three of the four tern species and for two of the eight passerine species examined (Table 4). The step change in the roseate tern data (99.3% ringed were pulli) occurred in 1987 (Fig. 3a) while that in both the common tern (99.7% ringed were pulli) and arctic tern (99.9% ringed were pulli) data occurred in 1988 (Fig. 3b). The step changes in the reed warbler (99% ringed were adult/

Table 4 Bird species for which a significant step-change was identified in ringing data: total number of birds ringed, year of step-change, cumulative deviation Q statistic, and average number of birds before and after step-change

Species	Total ringed No.	Step Year	Q	Before	After
				Average no. year^{-1}	
Roseate tern *Sterna dougalii*	10,147	1987	1.69**	246	579
Common tern *Sterna hirundo*	13,026	1988	1.74**	292	813
Arctic tern *Sterna paradisaea*	3,212	1988	1.66**	36	247
Blackcap *Sylvia atricapilla*	2,901	1987	1.77**	91	143
Reed warbler *Acrocephalus scirpaceus*	2,011	1989	2.02**	21	169

**$p < 0.001$

juveniles) and blackcap (99.9% ringed were adult/juveniles) data occurred in 1987 and 1988, respectively (Fig. 3c,d). There was no step change in the data for the remaining six passerine species, with the exception of a step change in 1989 in the sedge warbler (ringed were 98.8% adult/ juveniles) data which was significant at $p<0.10$.

Significant step changes were also identified in the number of reported sightings of two rare non-breeding summer migrants (Fig. 3e,f). There was a step change in the number of reported sightings of hobby ($Q=2.14$; $p\leq0.01$) between 1986 and 1987 (Fig. 3e). A total of 87 sightings of birds were reported for the period 1969–1999 with 76% of these birds being recorded between 1987 and 1999, after the step change occurred. The mean number of sightings recorded per year increased from 1.2 in the period 1969–1986 to 5.1 in the period 1987–1999. There was also a statistically significant step change in the number of reported sightings of osprey ($Q=2.07$; $p\leq0.01$) between 1988 and 1989 (Fig. 3f). The total number of birds reported from 1969–1999 was 132 with 69% of these sightings being recorded in the period after 1989. The mean number of birds recorded per year increased from 1.9 in the period 1969–1989 to 8.9 in the period 1990–1999 (i.e. after the change point).

Discussion

Our dataset has shown that spring migration phenology of long-distance migratory birds whose wintering grounds are in sub-Saharan Africa to Eastern Ireland has advanced over the 31-year period from 1969 to 1999. This is in agreement with Cotton (2003) who reported earlier arrival of birds in Oxfordshire (UK) over the same time period and for many of the same species. It is notable that the two species (barn swallow and common house martin) for which there are significant correlations with spring temperatures are Hirundines. It has been suggested that recent changes in climate may have resulted in selection for earlier and faster migration in these two species (Sparks and Tryjanowski 2007). There have been reports of changing migratory patterns of birds, typically in the form of earlier spring arrival, over the past 30 years at locations throughout Europe but primarily in northeastern Europe (Sparks et al. 2005). In a recent review, Lehikoinen et al. (2004) reported a significant earlier arrival for 39% of 983 time series of first arrival dates of migratory birds from 10 European countries. In addition, other changes in spring phenology have been widely reported in the literature, such as earlier leafing of trees in Ireland (Donnelly et al. 2006) and across

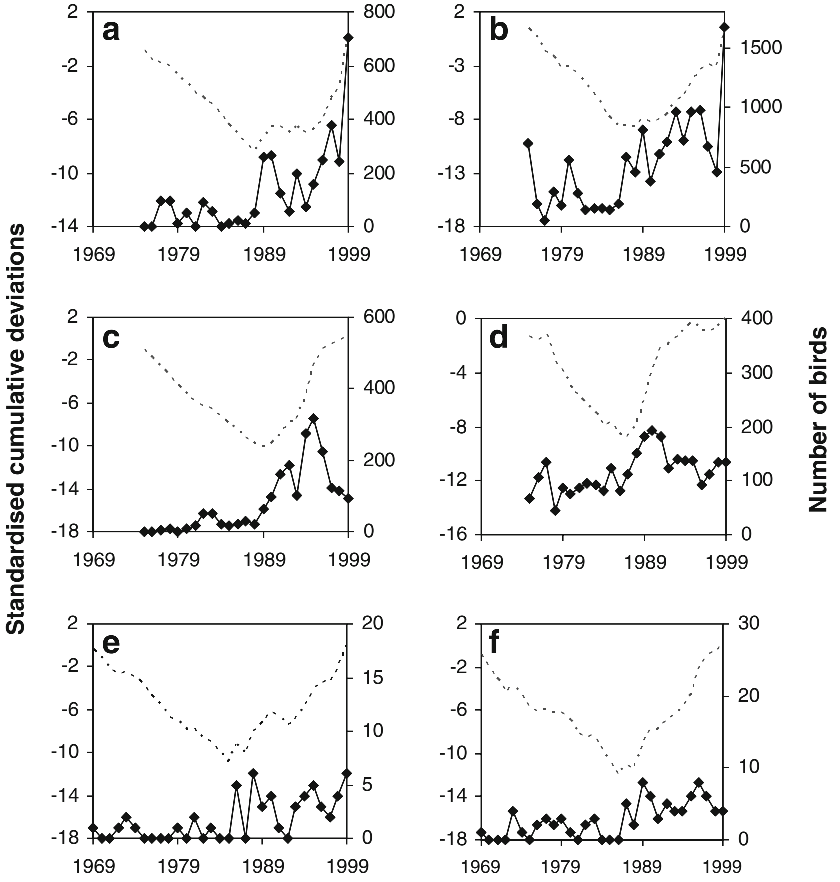

Fig. 3 Annual totals of **a** arctic tern *Sterna paradisaea*, **b** roseate tern *Sterna dougallii*, **c** reed warbler *Acrocephalus scirpaceus* and **d** blackcap *Sylvia atricapilla* ringed in Ireland (*black line*) and corresponding standardized cumulative deviations (*dashed line*) between 1975 and 1999. Annual number (*black line*) of **e** hobby *Falco subbetuo* and **f** osprey *Pandion haliaetus* recorded in Ireland and corresponding standardized cumulative deviations (*dashed line*) between 1969 and 1999

Europe (Menzel et al. 2006), and changes in insect appearance dates and abundance (Walther et al. 2002).

Cotton (2003) has argued that earlier bird migration to Europe in spring is a consequence of changes in environmental conditions in wintering grounds in particular, as an increase in temperature in sub-Saharan Africa has been correlated with earlier departure times of spring migrant species from the wintering grounds and, on average, earlier spring arrival times in the UK. The results presented here show no significant correlation between winter temperature in Africa and arrival dates of spring migrants to Ireland, although the majority of species tended to exhibit a negative trend. This is similar to the results for individual species reported by Cotton (2003).

There have been many reports in the literature of a strong correlation between arrival times of long-distance migrant birds and the winter North Atlantic Oscillation (NAO). A negative correlation has been shown between arrival dates and positive NAO index values in Scandinavia, suggesting that when winters are milder and wetter, spring migrants arrive earlier (Jonzén et al. 2006; Forchhammer et al. 2002; Hüppop and Hüppop 2003; Vähätalo et al. 2004). However, in contrast to this, Jonzén et al. (2006) have reported the opposite trend for southern Italy where a positive NAO appears to delay arrival times and Cotton (2003) found no effect of the NAO on arrival times to the UK. The results for Ireland show that arrival times were negatively correlated with the NAO, but only 2 out of the 9 species showing this trend were statistically significant. The evidence suggests that the NAO may have a stronger influence on migration of long-distance migrant spring arrival times in more northern latitudes of Europe.

McElwain and Sweeney (2003) have reported a significant increase of 0.05°C per year in average spring air temperatures across Ireland from 1960 to 2000. The spring (February–April inclusive) temperature in the east coast region of Ireland has shown the same increasing trend (0.05°C per year) over the period 1969–1999. Air temperatures in March have shown the strongest correlation with arrival times of spring migrant birds indicating that temperatures in this month were more influential for the timing of arrival than any other. Significant negative correlations between average spring air temperature (February–April inclusive) and the beginning of the growing season (as determined by leaf unfolding), for a suite of tree species, over the period from 1970 to 2000 have been reported in Ireland (Donnelly et al. 2006). The authors have shown that, with every 1°C increase in spring air temperature, leaf unfolding advanced by approximately 1 week. Our data (not shown) reveal that the barn swallow and the common house martin are expected to arrive more than a week earlier with every 1°C increase in spring temperature, which is earlier than the ~2-day advance reported by Sparks (1999) for the UK. However, these results confirm the relationship between increasing spring air temperatures and advancing spring phenology for both plants and migratory birds in Ireland.

In contrast to the gradual, long-term change in arrival dates, the analysis of the rare non-breeding migrants and the ringing data of the breeding species indicates that a significant change occurred which influenced Irish birdlife in the late 1980s centreing on 1987. Evidence for this is the sudden increase in the number of hobbys and ospreys recorded in Ireland. Concurrent with these changes were step changes in the numbers of reed warblers, blackcaps, roseate, arctic and common terns being ringed. All of these remarkable events coincided with a significant step change in air temperature in Ireland in 1987–1988. There is evidence that a major change in atmospheric variability occurred in the North Atlantic region at this time which was associated with an abrupt increase in temperature and an increased occurrence of westerly winds (Beaugrand 2004; Fealy and Sweeney 2005). A change point has also been reported in 1987–1988 for air and water temperature in the Alpine region (Hari et al. 2006). These step changes have been attributed to a shift in the NAO into its present extended positive phase (Beaugrand 2004; Fealy and Sweeney 2005; Hari et al. 2006). Ecological impacts of the 1987–1988 event have included changes in lake phytoplankton (Gerten and Adrian 2000) and declines in Alpine brown trout populations (Hari et al. 2006), while a major regime shift, affecting several trophic levels, has been identified in both the North Sea and Wadden Sea and in the Baltic (Beaugrand 2004; Alheit et al. 2005; Weijerman et al. 2005). Our results indicate that this major event also impacted the avifauna from the most westerly fringe of the European continent. The presence of this step change in datasets for species with very different ecologies, e.g. two land-based species, three tern species and two non-breeding summer migrant species, supports the hypothesis that the changes were triggered by a fundamental driver such as temperature.

Shifts in temperature can also trigger more complex changes in bird populations if thresholds are breached (Thomas and Lennon 1999; Hitch and Leberg 2007). Northward shifts in the breeding range of many bird species have been observed in both North America and Europe which are often preceded by an increase in the frequency of occurrence of non-breeding birds, e.g. Mediterranean gull *Larus melanocephalus* (Donald and Bekhuis 1993). Similar northward shifts of species into Ireland have also occurred, for example the recent rapid colonisation of the south and east coast of Ireland by the little egret *Egretta garzetta* (Smiddy and O’Sullivan 1998). Its spread northwards in Europe since the 1970s has been attributed to the absence of severe winters (Voisin 1991). Based on species climate response models, Huntley et al.

(2007) have suggested that Ireland has the potential to gain at least 20 new breeding species over the next 100 years. It is possible that the influence of one or both climatic factors (the slowly increasing temperatures and the step change event) might also be at least partly responsible for other notable changes, particularly the recording of several new nesting bird species in Ireland, for example, reed warbler resumed nesting in 1980 after a gap of 45 years (Smiddy and O'Mahony 1997).

In conclusion, we have presented data to illustrate that climate change is influencing Irish birdlife in two distinct ways. Firstly, the long-term monotonic trends observed in a range of spring migrant arrival dates are gradual changes that appear to be related to increasing spring temperatures. These results confirm that the trends apparent at other European sites are also evident in Ireland, on the western fringe of Europe. Moreover, we present for the first time evidence that a step change in temperature in 1987–1988 may have been the catalyst for (1) a step change in the pattern of occurrences of non-breeding migrant bird species, and (2) step changes in the ringing data for five migrant species that breed in Ireland. This step change in the Irish temperature record was coincident with that identified in Northern and Central Europe in the late 1980s. Our results demonstrate that step changes in temperature can be as significant as monotonic temperature trends for long distance migratory species. We suggest that the impact of step change events merits further investigation on a wider range of species and across a greater geographical range.

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