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ORIGINAL PAPER

Long-term trends in first arrival and first egg laying dates of some migrant and resident bird species in northern Italy

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Abstract Climate change is affecting the phenology of seasonal events in Europe and the Northern Hemisphere, as shown by several studies of birds' timing of migration and reproduction. Here, we analyse the long-term (1982–2006) trends of first arrival dates of four long-distance migratory birds [swift (*Apus apus*), nightingale (*Luscinia megarhynchos*), barn swallow (*Hirundo rustica*), and house martin (*Delichon urbicum*)] and first egg laying dates of two migrant (swift, barn swallow) and two resident species [starling (*Sturnus vulgaris*), Italian sparrow (*Passer italiae*)] at a study site in northern Italy. We also addressed the effects of local weather (temperature and precipitation) and a climate index (the North Atlantic Oscillation, NAO) on the interannual variability of phenological events. We found that the swift and the barn swallow significantly advanced both arrival and laying dates, whereas all other species did not show any significant temporal trend in either arrival or laying date. The earlier arrival of swifts was explained by increasing local temperatures in April, whereas this was not the case for arrival dates of swallows and first egg laying dates of both species. In addition, arrival dates of house martins were earlier following high NAO winters, while nightingale arrival was earlier when local spring rainfall was greater. Finally, Italian sparrow onset of reproduction was anticipated by greater spring rainfall, but delayed by high spring NAO anomalies, and swift's onset of reproduction was anticipated by abundant rainfall prior to reproduction. There were no significant temporal trends in the interval between onset of laying and arrival in either the swift or the barn swallow. Our findings therefore indicate that birds may show idiosyncratic responses to climate variability at different spatial scales, though some species may be adjusting their calendar to rapidly changing climatic conditions.

Keywords Avian phenology · Climate change · First arrival date · Italy · North Atlantic Oscillation

Introduction

Recent climatic changes occurring worldwide are having strong impacts on ecosystems (Walther et al. 2002; Schnoor 2005; Hansen et al. 2006). Long-term shifts in phenology,

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defined as the timing of seasonal activities such as leafing or reproduction, are among the most studied phenomena, and there is compelling evidence of significant temporal modifications at different ecological levels (Walther et al. 2002; Parmesan and Yohe 2003; Root et al. 2003; Lehikoinen et al. 2004; Ahas and Aasa 2006; Menzel et al. 2006). In the Northern Hemisphere, the onset of spring has advanced considerably in recent decades due to increasing spring temperatures and milder winters (Stöckli and Vidale 2004; Schwartz et al. 2006). This is matched by long-term advances in the timing of migration and spring arrival of birds throughout Europe and North America (e.g. Butler 2003; Cotton 2003; Hüppop and Hüppop 2003; Jonzén et al. 2006a; reviewed in Lehikoinen et al. 2004). Moreover, laying dates of both resident and migratory bird species have also advanced (Crick et al. 1997; Winkler et al. 2002; review in Dunn 2004). On the whole, these trends indicate that birds are trying to track climatic changes, though the temporal patterns of change may vary between species and even between populations of the same species, thus suggesting that not all populations are equally adapted to face rapid climate modifications, or that different species/populations are not experiencing the same changes in ecological conditions (Visser et al. 2003; Both et al. 2004, 2006).

Interannual variability in phenology is often directly related to short-term variability of environmental and ecological conditions at different spatial and temporal scales (Stenseth et al. 2002). At the widest scale, regional climatic conditions can influence phenology of seasonal events, as exemplified by the effects of the North Atlantic Oscillation (NAO) on timing of spring events in Europe (Stenseth et al. 2002). The NAO is a large-scale hemispheric oscillation defined as the difference in sea-level pressure between the subtropical centre of high surface pressure and the subarctic centre of low surface pressure, expressed as the anomaly over the long-term mean (Hurrell 1995). The NAO profoundly affects ecological conditions over vast areas of the Northern Hemisphere throughout the year, though the greatest interannual and decadal variability is observed during winter (Hurrell 1995; Stenseth et al. 2003; Forchhammer and Post 2004). Positive winter NAO anomalies are associated with milder and wetter conditions in continental Europe, causing earlier plant leafing and arthropod emergence in spring (e.g. Sparks and Carey 1995; Post et al. 2001; Stenseth et al. 2003), but drier than average conditions over southern Europe and the Mediterranean area (Hurrell 1995; Stenseth et al. 2003). As a consequence, earlier timing of spring migration and arrival of birds in northern Europe, as well as timing of breeding, are generally associated with positive winter NAO anomalies (e.g. Forchhammer et al. 1998, 2002; Sanz 2003). Several studies have suggested that favourable weather conditions and high spring temperatures may lead to faster progression of migration and earlier than average arrival, as they are generally associated with improved foraging conditions, while unfavourable weather, such as cold spells and head winds, may slow down the progression of migration (Sparks and Braslavska 2001; Huin and Sparks 1998, 2000; Hüppop and Hüppop 2003; Zalakevicius et al. 2006; see review by Lehikoinen et al. 2004). Hence, weather conditions both at the local scale and along the migration route may affect the phenology of arrival and breeding of migratory birds. Indeed, there are high mortality risks associated with early arrival, so that selection for optimal arrival date is predicted to be strong (Jonzén et al. 2007). Milder than average temperatures in spring also lead to earlier breeding, mainly because of earlier onset of vegetation green-up and peaks in food sources (e.g. McCleery and Perrins 1998; Crick and Sparks 1999; Both et al. 2004; review in Dunn 2004).

In this study we investigate the long-term trends in first arrival dates of four long-distance migratory bird species, as well as first egg laying dates trends of two resident and two migrant species, at a site in northern Italy over the period 1982–2006. The study area is contained within the Po river plain, where mean temperatures have increased by ca. 1°C per century in the last two centuries, a change similar to that observed in the rest of the Italian peninsula (Brunetti et al. 2006). This trend was shown to be highly consistent even on a seasonal basis (Brunetti et al. 2006). On the other hand, the Italian annual precipitation amount has decreased by ca. 5% per century, mainly because of a decrease in spring rainfall, without pronounced regional differences (Brunetti et al. 2006). Concerning the connections between the Italian weather and the NAO, previous studies highlighted consistent but weak negative correlations between rainfall and winter NAO south of the Alps and in the Po river plain, and positive temperature anomalies following high NAO winters (Hurrell 1995; Schmidli et al. 2002; Tomozeiu et al. 2002; Bojariu and Giorgi 2005). The role of the NAO in driving climatic changes in mainland Italy is, however, poorly understood, though simulations under climate change scenarios suggest that NAO trends may not be the key contributor to changes in winter temperatures and rainfall over the Mediterranean region (and Europe in general) (Stephenson et al. 2006).

All the species analysed in this study are strictly or mostly insectivorous during the breeding season, and it is therefore likely that they may adjust timing of arrival and breeding to prevailing or predicted ecological conditions. Thus, besides quantifying the long-term trend, we analysed the concomitant effects of local weather (temperature and rainfall) and NAO index on phenological events. Specifically, milder local temperatures and positive NAO anomalies were predicted to result in favourable conditions during migration and/or at arrival, and earlier food peaks, so that earlier arrival or breeding could be expected in years when the winter NAO index or spring temperatures are high (see e.g. Bellot et al. 1991 and Sanz et al. 2003 for studies of the effect of temperature and climate change on timing of breeding in the Mediterranean region). On the other hand, the effects of local rainfall are difficult to predict, and could vary among species, though it could be expected that abundant rainfall might lead to earlier breeding (see Crick and Sparks 1999; Dunn 2004).

To the best of our knowledge, no recent analyses of standardised time series of egg laying and arrival dates have been published for Italy, with the exception of the long-term dataset of spring migration dates of the island of Capri (southern Italy; see Jonzén et al. 2006a,b; see also Moltoni 1950 and Maranini 1991 for older time series of first arrival dates of swifts).

Materials and methods

Study species, study area and field protocols

We analysed trends in first arrival date of swift (*Apus apus*), nightingale (*Luscinia megarhynchos*), barn swallow (*Hirundo rustica*), and house martin (*Delichon urbicum*). Trends in first egg laying dates over the same period were analysed for swifts, barn swallows, and two resident species, the starling (*Sturnus vulgaris*) and the Italian sparrow (*Passer italiae*) (see Töpfer 2006 for a discussion of the taxonomic status of *P. italiae*). Though the use of first dates to describe annual events has some caveats, as these represent extreme observations that can be influenced by e.g. population size (Sparks et al. 2001, 2005), such data are often the only available (Lehikoinen et al. 2004). In the present study, biases due to factors such as observer effort or visibility are likely to be negligible, as the data have been collected within a limited study area by the same experienced observer (M.C.) adopting the same protocol every year.

Phenology and breeding data were collected at two nearby sites in central-eastern Lombardy (Italy), Cascina S. Paolo (Borgo S. Giacomo, Brescia) (80 m a.s.l; 45°23′ N - 10°01′ E), and Marcita Alpi (Borgo S. Giacomo, Brescia) (69 m a.s.l.; 45°21′ N - 10°00′ E). The former is a large old farm typical of the agricultural landscape of the Po river plain, hosting breeding colonies of swifts (ca. 30 pairs), barn swallows (ca. 45 pairs), house martins (ca. 30 pairs), starlings (ca. 35 pairs), and Italian sparrows (ca. 100–200 pairs), while the latter is a 1,600 ha farmland area with cultivations, hedges and remnants of a riparian woodland, hosting ca. 15 nightingale singing males. The breeding populations of barn swallow, house martin and Italian sparrow declined during the study period, whereas those of swift and starling were relatively stable (no accurate census data were available for nightingales) (M.C. and P.B., unpublished data). Therefore, any trend towards earlier phenology should not be confounded by increases in population size (Sparks et al. 2001), given that populations of the study species were stable or decreasing. Observations were made from February onward every year. Nesting sites of barn swallows were represented by stables, while swifts, sparrows and starlings nested in special buildings, locally called “sparrow houses”, built specifically to favour nesting of colonial birds. After recording the first arrivals or activities at the colonies, nesting areas were checked regularly for the appearance of newly laid nests and eggs. We recorded first arrival dates, i.e. the day on which the first individual of the migrant species was observed or heard at the breeding site, whereas we could not measure this variable for the two resident species, as they were regularly wintering in the area. Nests were checked every 3rd day. If more than one egg was found simultaneously in a nest, we assumed that females laid one egg per day (Cramp 1998), and back calculated the day of laying of the first egg. This assumption could not be valid for the swift (Cramp 1998), which lays at 2–3 days intervals, though in this species, no nests with two or more eggs were found first. The day of appearance of the first egg in the colony was recorded for swifts, barn swallows, starlings and sparrows, whose nest sites and nests in the “sparrow house” could be easily accessed.

Climate and local weather variables

As indices of local spring meteorological conditions that could affect phenological events, we considered in the analyses mean monthly temperatures (°C) and the total monthly amount of rainfall (mm) of the month of mean first arrival or laying of each species (March or April, see Table 1), and of the preceding month. In addition, as indicators of general climatic conditions over wider spatio-temporal scales, we considered both the winter NAO index ($\mathrm{NAO_W}$) (mean of December–March values, Hurrell 1995) and a mean spring NAO index ($\mathrm{NAO_S}$) (mean of March–May values). The correlation between NAO indices and the local spring weather variables considered in our study is shown in Table 2. We decided to consider these two NAO indices in order to investigate both the long- and short-term effects on bird phenology of climatic conditions mediated by large-scale circulation patterns (see Stenseth et al. 2003 for a comment on the use of seasonal NAO indices). During the study period, the NAO indices were very weakly correlated with local spring weather conditions, though in a direction similar to previous studies as far as $\mathrm{NAO_w}$ is concerned (positive for temperature and negative for rainfall, at least in February and March; see Hurrell 1995; Schmidli et al. 2002;

Table 1 Mean values (SD) and ranges of first arrival and first egg laying dates

Species	Mean [Date][a] (SD)	Min (Year)[b] [Date][a]	Max (Year)[b] [Date][a]
First arrival date			
Swift	4 Apr [93.6] (5.1)	23 Mar (1998) [82]	12 Apr (1994) [102]
Nightingale	9 Apr [99.1] (3.4)	2 Apr (1989) [92]	17 Apr (1995) [107]
Barn swallow	21 Mar [79.6] (5.3)	7 Mar (2003) [66]	29 Mar (1985) [88]
House martin	18 Mar [77.6] (6.5)	3 Mar (1982) [62]	30 Mar (1998) [89]
First egg laying date			
Swift	30 Apr [119.6] (2.9)	21 Apr (2001) [111]	4 May (1994) [124]
Barn swallow	18 Apr [108.4] (3.6)	10 Apr (2003) [100]	26 Apr (1985) [116]
Starling	30 Mar [89.0] (2.9)	25 Mar (1989) [84]	3 Apr (2003) [93]
Italian sparrow	8 Apr [98.0] (4.6)	28 Mar (2005) [87]	19 Apr (2003) [109]

[a] Numbers in square brackets refer to dates expressed as progressive days (with 1 January = day 1)

[b] Year in which a given value was recorded

Tomozeiu et al. 2002; Bojariu and Giorgi 2005). In any case, NAO indices may provide a better representation of climatic effects than any single weather variable measured at the local scale, because they can be regarded as a synthesis of several interacting weather parameters (see Stenseth et al. 2003; Forchhammer and Post 2004). Winter and spring NAO indices were weakly positively correlated (r=0.37, P=0.07, n=25 years), suggesting that they may indicate different climatic conditions.

Meteorological data (monthly mean values) were recorded at Ghedi Military Airport (the weather station closest to the study area, ca. 25 km east), and were obtained from the Centro Nazionale di Meteorologia e Climatologia Aeronautica of the Italian Aeronautica Militare for the years 1982–2004. Meteorological data recorded in the same weather station for the years 2005–2006 were obtained from the website of the Ufficio Centrale di Meteorologia Agraria of the Italian Ministero delle Politiche Agricole e Forestali (http://www.ucea.it). NAO indices were calculated from monthly NAO values downloaded from the website of the Climate Prediction Centre (CPC) of the National Oceanic and Atmospheric Administration (NOAA) of the United States Government (http://www.cpc.noaa.gov/products/precip/CWlink/pna/nao_index.html). This is a principal component (PC)-based NAO index, where monthly values are calculated as the mean of daily indices obtained by projecting the daily 500 mb height anomalies over the Northern Hemisphere onto the loading pattern of the NAO (see Barnston and Livezey 1987 and the CPC website for further details). The advantage of PC-based NAO indices over traditional station-based indices is that they provide a more realistic representation of the full spatial NAO pattern (Stenseth et al. 2003). In addition, PC-based methods are appropriate for assessing a seasonally varying signal, because the pressure system is subject to a seasonal shift. Thus, our spring PC-based index is accurate in that it takes into account the seasonal shift of the centres of action of the NAO (Stenseth et al. 2003).

Statistical analyses

Throughout the study, dates are expressed as progressive days, with 1 January = 1. Year was considered as an independent variable in all analyses. In an exploratory analysis, we tested the effect of year, NAO and weather variables on phenological events by means of simple linear regressions. We then performed stepwise multiple regression analyses (Garson 2006). All regressions were performed for first arrival date and first egg laying date separately, as well as for the interval between laying and arrival (calculated as the difference between first egg laying date and first arrival date, for swifts and barn swallows only).

Table 2 Relationships between winter North Atlantic Oscillation (NAO_W), spring NAO (NAO_S) and local temperature and rainfall in the period of study (1982–2006, n=25 years) (correlation coefficients, r, and associated P-values are shown)

		Year	Temperature			Rainfall		
			February	March	April	February	March	April
NAO_W	r	−0.22	0.29	0.33	−0.01	−0.13	−0.18	0.22
	P	0.30	0.15	0.11	0.97	0.54	0.40	0.29
NAO_S	r	−0.28	0.13	0.02	−0.06	0.28	−0.07	0.21
	P	0.17	0.52	0.91	0.76	0.18	0.74	0.32

The temporal trend of NAO indices is also shown

Arrival date was also included as a predictor in multiple regression models concerning laying date of migrant species (i.e. swift and barn swallow), because arrival timing can influence timing of breeding. The stepwise selection procedure was not biased by multivariate colinearity of independent variables, as suggested by the relatively weak correlations among predictors ($r=-0.62$ in one case, $|r|<0.41$ in all others). In addition, the tolerance of stepwise models was always >0.78 (Garson 2006). Tolerance is defined as $(1-r^2)$ for the regression of a given independent variable on all the other predictors, while ignoring the response variable, and is commonly adopted to identify colinear predictors in multiple regressions (Garson 2006). The higher the intercorrelation of predictors, the more the tolerance will approach zero. Garson (2006) indicates the value of 0.20 as a threshold below which multicolinearity may bias regression performances. Regression analyses were performed with the SPSS 13.0 statistical package.

As dependent variables represent time series, residuals may show temporal autocorrelation. We checked for serial autocorrelation in the residuals by inspection of the plots of the residuals over the predicted values and with the *acf* function of the S-Plus 6.1 statistical package. If the residuals showed large autocorrelation ($|r|\geq 0.40$), we checked for robustness of the fitted model by means of a randomisation process. Briefly, the dependent variable was randomly permutated 1,000 times, at each permutation the final model was fitted and the coefficients of the fitted function were noted. We then calculated the rank of the observed coefficient over the series of coefficients obtained by the randomisation procedure, and the significance of the independent variable was calculated as $1-(|\mathrm{rank}-500|/500)$, i.e. the probability of obtaining a more extreme value than the observed one. Throughout the paper, *P*-values <0.05 were regarded as statistically significant.

Results

February, March and April rainfall, as well as $\mathrm{NAO_W}$ or $\mathrm{NAO_S}$ indices, did not show any significant temporal trend between 1982 and 2006 ($P\geq 0.17$ in all cases; see also Table 2), while February to April temperatures showed a tendency to increase, which reached statistical significance only for April [February: slope=0.09(0.05 SE), $t=1.81$, $P=0.08$; March: slope=0.08(0.04 SE), $t=1.75$, $P=0.09$; April: slope=0.05(0.02 SE), $t=2.13$, $P=0.044$].

Descriptive statistics concerning first arrival and laying dates are reported in Table 1. First arrival dates of swifts and barn swallows showed a significant trend towards earlier arrival, while those of nightingales and house martins did not (Table 3, Fig. 1). Based on the slopes of the linear regressions (Table 3), the models indicate that in 2006 swifts arrived 7.2 days and barn swallows 8.1 days earlier than in 1982. Significant and negative relationships were also found between arrival dates of swifts and April temperatures, arrival dates of nightingales and April rainfall, and arrival dates of house martins and the $\mathrm{NAO_W}$ index (Table 3). Finally, the interval between laying and arrival increased with increasing April temperature in swifts (Table 3).

Table 3 Slopes (SE) from simple linear regressions of first arrival and first egg laying dates in relation to year, local temperature, local rainfall, and $\mathrm{NAO_S}$ and $\mathrm{NAO_W}$ indices

Species	Year	Temperature[a]	Rainfall[a]	$\mathrm{NAO_S}$ index	$\mathrm{NAO_W}$ index
First arrival date					
Swift	−0.30 (0.13)*	−3.84 (1.00)*** [d]	−0.02 (0.03)[d]	2.43 (1.60)	2.07 (1.95)
Nightingale	0.04 (0.10)	−0.59 (0.40)[c]	−0.04 (0.02)* [d]	−1.39 (1.09)	−1.40 (1.31)
Barn swallow	−0.34 (0.13)*	−0.84 (0.63)[c]	−0.01 (0.03)[b]	0.24 (1.76)	−0.92 (2.09)
House martin	0.11 (0.18)	−1.28 (0.76)[c]	0.03 (0.03)[b]	−1.56 (2.13)	−5.79 (2.27)*
First egg laying date					
Swift	−0.20 (0.07)**	−0.95 (0.71)[d]	−0.02 (0.01)[c]	0.49 (0.96)	1.46 (1.11)
Barn swallow	−0.38 (0.07)***	−0.57 (0.42)[c]	−0.02 (0.02)[d]	1.42 (1.15)	0.31 (1.41)
Starling	−0.01 (0.08)	−0.16 (0.35)[c]	−0.01 (0.01)[c]	0.55 (0.95)	−0.79 (1.13)
Italian sparrow	−0.19 (0.12)	−1.69 (1.11)[d]	−0.05 (0.03)[d]	2.94 (1.40)*	1.30 (1.79)
Interval between laying and arrival					
Swift	0.09 (0.14)	2.89 (1.08)** [d]	−0.02 (0.02)[c]	−1.95 (1.57)	−0.61 (1.92)
Barn swallow	−0.04 (0.11)	−0.42 (0.41)[b]	0.01 (0.02)[b]	1.18 (1.25)	1.22 (1.50)

* $0.01<P<0.05$; ** $0.001<P\leq 0.01$; *** $P\leq 0.001$

[a] For simplicity, statistics refer to the monthly value (chosen between the month of mean first dates and the preceding one, see Materials and methods) showing the strongest (absolute) relationship with the dependent variable.

[b] February temperature/rainfall

[c] March temperature/rainfall

[d] April temperature/rainfall

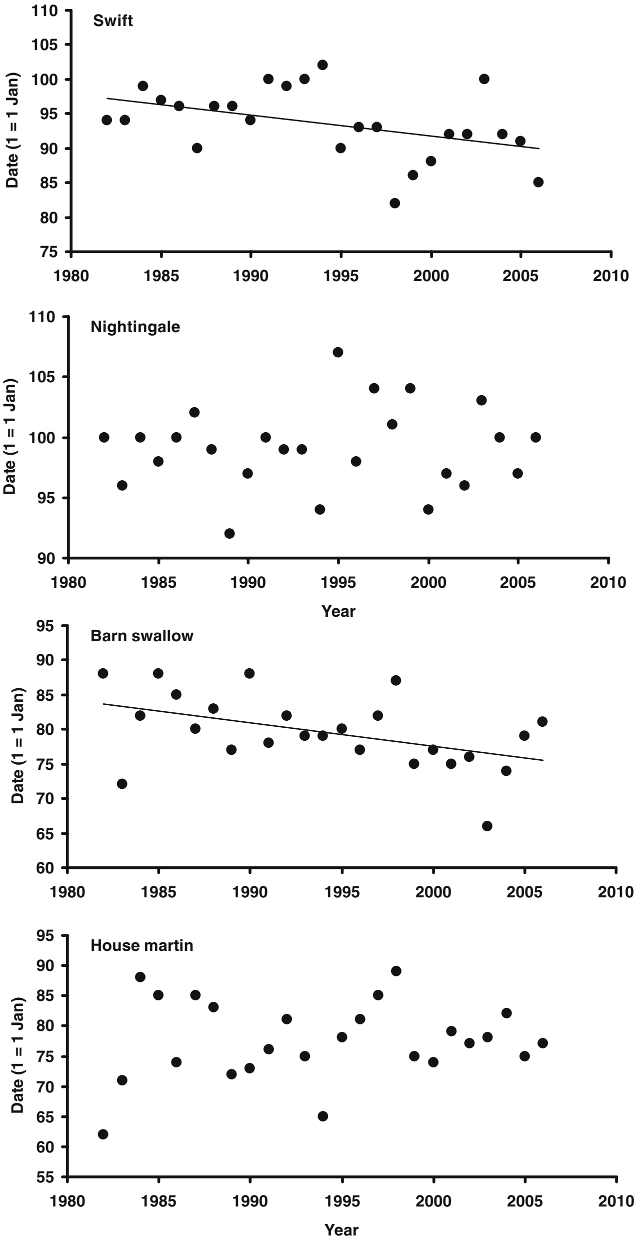

Fig. 1 Temporal trends in first arrival dates of the four migratory study species. Regression lines are shown for significant relationships

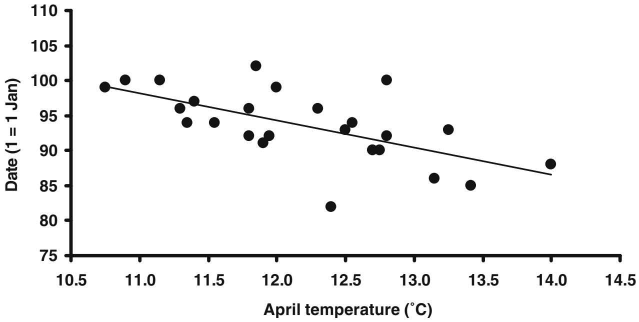

Fig. 2 First arrival date of swift in relation to mean April temperature. The line is the fitted linear regression

In the stepwise multiple regression models, arrival dates of swifts were influenced only by April temperature, with swifts arriving earlier when temperatures are high (Table 4, Fig. 2). The significant temporal trend of barn swallow arrival dates (see Table 4) was not significantly explained by any of the meteorological or climate variables we considered (details not shown). First arrival dates of nightingales and house martins were influenced by meteorological and climate variables, respectively, with nightingales arriving earlier in years with abundant April rainfall and house martins in years with positive NAO_W anomalies, thus confirming the results of the simple regression analyses (Table 4). Residuals of the final models did not show any significant temporal autocorrelation, except in the models of barn swallow, where significant temporal autocorrelations at lags from 1 to 4 years emerged (details not shown). However, the randomisation procedure confirmed that these models were not biased (details not shown).

First egg laying dates of swifts and barn swallows showed a clear temporal advance (Table 3, Fig. 3), being 4.9 and 9.0 days earlier in 2006 than in 1982, respectively, based on the slopes of the linear regressions (Table 3). Trends in first egg laying dates of the two resident species, the starling and the Italian sparrow, were not significant, though the sparrow showed a tendency towards earlier onset of reproduction (Table 3, Fig. 3). The onset of reproduction of the Italian sparrow was positively influenced by NAO_S index (Table 3). The stepwise multiple regression analyses showed that, in the barn swallow, arrival date of the first individual positively predicted the date of appearance of the first egg in the colony, and confirmed the significant temporal trend towards earlier laying (Table 4). The model was able to explain as much as 73% of variability in first egg laying dates (effect size, partial η^2: year=0.59; first arrival date=0.14) (Table 4). In the swift, first arrival date did not predict laying date in the multiple regression model (t=0.64, P=0.53). This species showed a clear temporal trend towards earlier onset of reproduction, which was also relatively earlier when rainfall in the month preceding egg laying (i.e. March) was more abundant (Table 4). The onset of reproduction of the Italian sparrow was delayed by positive NAO_S anomalies, whereas abundant April rainfall anticipated breeding (Table 4). These results were similar when an extremely late value (year 2003, see Table 1 and Fig. 3) was excluded from the analyses [effect of NAO_S: slope=3.75(1.04 SE), t=3.61, P= 0.002; effect of April rainfall: slope=−0.06(0.02 SE), t= −2.89, P=0.009]. Finally, none of the variables we considered significantly predicted first egg laying date in the starling (details not shown). Residuals of the final models did not show any significant temporal autocorrelation (details not shown).

The interval between laying and arrival was equal to 25.9 days (0.9 SE, range 17–39 days) for the swift and

Table 4 Stepwise multiple regression analyses of arrival, first egg laying dates, and interval between laying and arrival, in relation to year, local temperature, local rainfall, and NAO_S and NAO_W indices

Species	Predictors	Slope (SE)	*t*	*P*
First arrival date				
Swift[a]	April temperature	−3.84 (1.00)	−3.83	0.001
Nightingale[b]	April rainfall	−0.04 (0.02)	−2.28	0.032
Barn swallow[c]	Year	−0.34 (0.13)	−2.53	0.019
House martin[d]	NAO_W	−5.79 (2.27)	−2.55	0.018
First egg laying date				
Swift[e]	Year	−0.22 (0.06)	−3.42	0.002
	March rainfall	−0.03 (0.01)	−2.46	0.022
Barn swallow[f]	Year	−0.28 (0.06)	−4.56	<0.001
	Arrival date	0.28 (0.09)	3.36	0.003
Italian sparrow[g]	NAO_S	3.62 (1.27)	2.83	0.010
	April rainfall	−0.06 (0.02)	−2.58	0.017
Interval between laying and arrival				
Swift[h]	April temperature	2.89 (1.08)	2.67	0.014

Only statistically significant multiple regression models are shown. Arrival date was also included as a predictor in models concerning laying date of migrant species (see Materials and methods)

[a] $F_{1,23}$=14.7, P=0.001, r^2=0.39

[b] $F_{1,23}$=5.2, P=0.032, r^2=0.18

[c] $F_{1,23}$=6.4, P=0.019, r^2=0.22

[d] $F_{1,23}$=6.5, P=0.018, r^2=0.22

[e] $F_{2,22}$=7.9, P=0.003, r^2=0.37

[f] $F_{2,22}$=29.7, P<0.001, r^2=0.73

[g] $F_{2,22}$=6.1, P=0.008, r^2=0.36

[h] $F_{1,23}$=7.2, p=0.014, r^2=0.24

28.8 days (0.8 SE, range 21–36 days) for the barn swallow. This interval did not show any significant temporal trend in either species (Table 3), while it increased with increasing April temperature in the swift (Table 4). This implies that the lag between arrival and breeding increases when temperatures are high, which is simply due to the earlier arrival of swifts when April temperatures are high (Table 4, Fig. 2). Residuals of the model for swift did not show any significant temporal autocorrelation (details not shown).

Discussion

The main aim of our study was to quantify the long-term trends of first arrival and first egg laying dates in some migrant and resident bird species. To the best of our knowledge, the set of data analysed here represents the only recent long-term phenological information concerning first arrival and first egg laying dates of migratory birds in Italy. In addition, we tested whether variation in timing of phenological events could be explained by local weather conditions and/or large-scale climatic variability, as assessed by the NAO index, that may influence ecological conditions both in Europe and in the sub-Saharan wintering grounds (Oba et al. 2001) of the migratory species we studied. Our study is set in the central Mediterranean context, whose temperatures are changing similarly to the rest of Europe, while precipitation is decreasing (Brunetti et al. 2006). Comparison between our results and those from similar studies conducted elsewhere in Europe may therefore highlight variable and possibly idiosyncratic effects of climate changes on avian phenology.

The analysis of long-term trends revealed that two migratory species, the barn swallow and the swift, show a significant trend towards earlier spring arrival. These results are consistent with most studies of arrival dates of these species in central and northern Europe (e.g. Peintinger and Schuster 2005; Zalakevicius et al. 2006), where they have generally advanced their first arrival date in the past 30 years. Conversely, in eastern countries and in Spain trends towards later arrival (barn swallow) or no trends (swift) have been documented (Sparks and Braslavska 2001; Gordo et al. 2005). The absence of a significant temporal trend in arrival dates of house martins is consistent with the findings of a similar study in Spain (Gordo et al. 2005), but differs from what has been observed in central Europe, where a significant advance is apparent at many sites (Peintinger and Schuster 2005). No long-term trend in arrival date was observed in the present study for the nightingale. This is similar to studies from central Europe, where no trend or delayed arrival was observed, but differs from the study in Spain, where

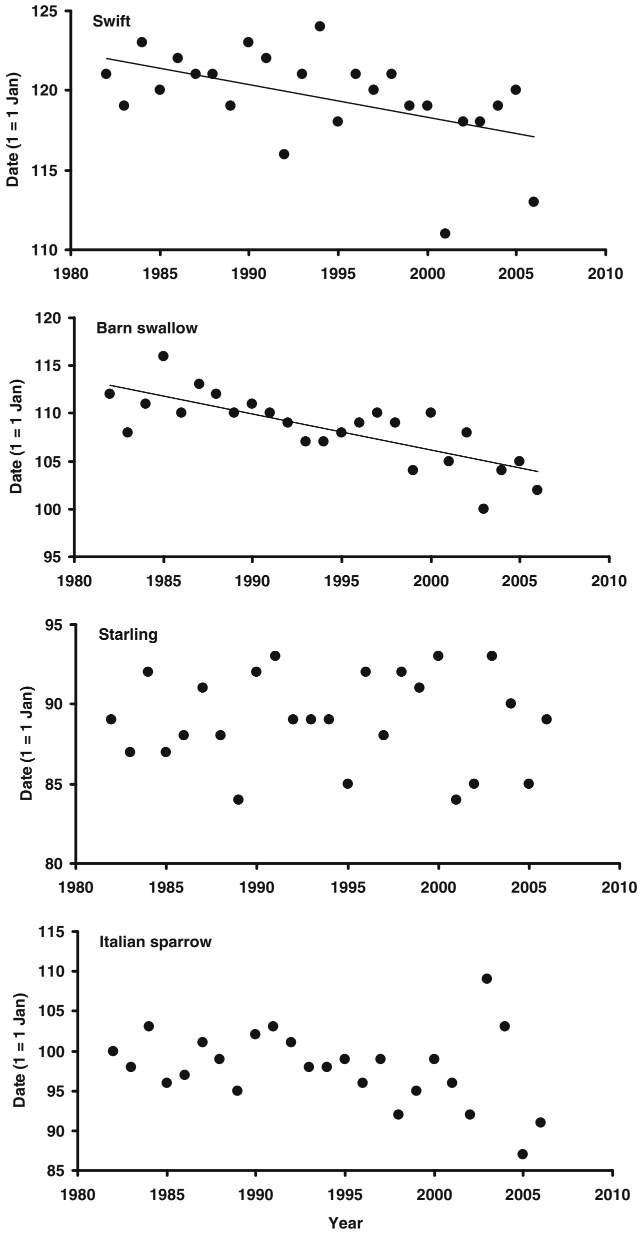

Fig. 3 Temporal trends in first egg laying dates of the four study species. Regression lines are shown for significant relationships

nightingales showed a marked trend towards later arrival (Gordo et al. 2005; Peintinger and Schuster 2005).

The barn swallow and the swift also showed a significant temporal trend towards earlier first egg laying dates, while no long-term trends were detected in first egg laying dates of the two resident species, the starling and the Italian sparrow. There was no significant temporal trend in the lag between onset of laying and arrival in either the barn swallow or the swift. The advance in first egg laying dates is consistent with earlier studies of several species, including some of the ones we studied (Crick et al. 1997; Winkler et al. 2002). Furthermore, it should be emphasised that time-series concerning this important phenological variable are quite rare compared to those documenting changes in arrival date (see review in Dunn 2004).

The second aim of this study was to analyse the effect of large-scale climatic and local weather conditions on both arrival dates and onset of reproduction. Winter and spring NAO indices were significantly correlated with arrival dates of house martins and onset of reproduction of Italian sparrows, respectively. High NAO_W values denote warmer and drier conditions in Italy and the Mediterranean, conditions which may thus enhance the speed of migration through the Mediterranean area. This mechanism may explain the earlier arrival of house martins in years with a high NAO_W index. These results are in line with previous findings showing earlier phenological events in central-northern Europe in years with positive NAO_W anomalies. However, it should be emphasised that high NAO_W is associated with increasing rainfall in central-northern Europe, so that the NAO-influenced ecological processes leading to the previously documented earlier arrival of migrants in northern Europe (see Introduction and Lehikoinen et al. 2004) may differ from those leading to the same pattern in southern Europe. On the other hand, this finding is at odds with a recent study on timing of spring migration of long-distance migrants in southern Italy, which suggested that high NAO_W delays mean migration date, possibly by affecting habitat quality of stopover sites or departure areas of migrants in Africa (Jonzén et al. 2006a). However, this discrepancy should be considered with caution as our study refers to first arrival dates and not to mean migration dates, and the former may not be a good predictor of the latter (Møller and Merilä 2004; Sparks et al. 2005).

Local weather conditions affected timing of arrival of swifts and nightingales. Specifically, April temperatures were strongly and negatively correlated with the date of observation of the first swift. Mean April temperatures are increasing in the study area and their effect obscured the long-term temporal trend in arrival dates of swifts, which was thus not significant in the multiple regression model. This suggests that swifts are reacting to increasing April temperatures by progressively advancing their arrival date. Nightingale arrival was earlier when April rainfall was abundant. This finding is difficult to interpret, as the opposite could have been expected based on current knowledge on the effect of weather on migration patterns, and may be biased by the occurrence of transient migrant birds in the study area, which may stop over and sing more frequently when rainfall is more abundant. However, it should be noted that nightingales rely mainly on insects and other ground arthropods, which can emerge earlier in years with abundant spring rainfall. In addition, consistent with our findings, widespread earlier arrival of long-distance migratory birds in wet years has also been reported by Zalakevicius et al. (2006) for the Baltic countries, though this pattern did not apply to aerial feeders (swallows, swifts and martins).

Onset of reproduction of the Italian sparrow was related both to large-scale climatic indices and local weather conditions. High NAO_S, which may denote warmer and drier than average conditions in the Mediterranean (e.g. Stenseth et al. 2003), delayed the onset of breeding of sparrows, which was, in turn, earlier in years with abundant April rainfall. These findings suggests that humidity conditions may influence timing of breeding in this species, possibly by affecting peaks in fundamental nestling food sources (i.e. a wide range of terrestrial arthropods, which constitute 60–99% of nestling diet, Cramp 1998), and is consistent with similar findings for birds in the United Kingdom (Crick and Sparks 1999). Spring rainfall is in fact associated with a bloom in vegetation, which may positively influence the abundance of terrestrial arthropods in agricultural areas (Frampton et al. 2000). In addition, rainfall may positively affect shoots, buds and seeds availability, either in agricultural or natural areas (see Frampton et al. 2000), which may allow adults to increase their energy reserves for reproduction and thus anticipate breeding. It should also be noted that the first egg laying date of sparrows was significantly and positively correlated with that of starlings (r=0.52, P=0.007, n=25), implying that these two species may respond to similar ecological cues for the onset of breeding, though starlings bred ca. 1 week earlier than sparrows, and none of the climate or weather variables we studied seemed to affect onset of breeding in this species. Greater local rainfall in the month preceding reproduction was also associated with earlier onset of breeding of swifts, as shown by stepwise multiple regression models. Such a lagged effect may indicate that increasing rainfall in the month prior to reproduction leads to more favourable breeding conditions, and thus earlier breeding (e.g. Crick and Sparks 1999).

Taken together, it appears evident that the species analysed in our study showed variable patterns of response to the same climate or local weather factors. While differences in ecological attributes of species, as well as differences in migration routes, timing of arrival or migration strategies, may partly account for such variability, it should be emphasised that extreme events (such as those used in our study) may be subject to a large random variance (Sparks et al. 2001; Lehikoinen et al. 2004), which could confound the true underlying patterns.

In conclusion, though our findings cannot be generalised to migrant and resident species as a whole, we showed that two species of migratory birds, the barn swallow and the swift, have significantly advanced the timing of spring arrival and onset of breeding in recent years, whereas two resident species have not significantly advanced the onset of reproduction. While the increase in April temperatures may explain the earlier arrival of swifts, this was not the case for arrival dates of swallows and the timing of breeding of both species. In the barn swallow, timing of spring arrival is also affected by ecological conditions in their winter quarters (Saino et al. 2004; Gordo et al. 2005). Admittedly, we did not consider winter conditions in our study, because we argued that patterns of first arrivals at a single study site should reflect more intensely local conditions or conditions in the late phase of migration compared to conditions in tropical Africa (see also discussion in Zalakevicius et al. 2006). Anyway, recent changes in ecological conditions in winter quarters, such as an increase in winter Sahel rainfall (e.g. Hulme et al. 2001), may have contributed to the pattern of advanced timing of spring arrival of swallows. On the other hand, the advance in onset of breeding may have followed the concomitant increase in late spring temperatures recorded in the study area, when peak fledging periods of the two species take place [increase in May temperature: slope=0.11 (0.04 SE) °C/year, P=0.014; June: slope=0.12(0.03 SE) °C/year, P=0.001)]. Whether these changes represent phenotypically plastic responses to changing selective pressures during breeding, or microevolutionary changes in the timing of spring migration or breeding, remains to be elucidated but our results nevertheless strongly indicate that migratory birds are adjusting their calendar time to the changing spring phenology.

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