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Long-term citizen science program of the first arrival of Barn Swallows *Hirundo rustica* in Italy: a preliminary study on how the climate affects spring migration across the Mediterranean

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ABSTRACT

This study aims to present and analyze the spring migration of Barn Swallow *Hirundo rustica* data collected by a network of Italian birdwatchers in collaboration with a Research Institute in the framework of a citizen science project. More than 500 observations of the first sightings of Barn Swallow's arrival in Italy were collected from 2004 to 2019 throughout the country. Percentile indices were calculated for each year and four regional subdivisions of the Italian territory: Northern, Central, Southern Italy, and the main islands (Sicily and Sardinia). Our analysis showed that the first spring sightings were significantly advanced (from 1 to 1.2 days/year) during the study period. Our data also describe the progression of migration across Italy with first arrivals documented in the main island and progressing from South to North of Italy first in Sicily and Sardinia, then along the Tyrrhenian and Adriatic coasts and from there to the major mountain chains (Apennines and Alps). Analysis of climate data (February temperature) of Europe and Africa showed a recurrent pattern of years of late arrivals linked to a negative temperature anomaly over the Mediterranean and North Africa and years of early arrival with a positive temperature anomaly in the same area. First sightings were significantly correlated with December, winter and January-to-March average

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temperatures at a stopover site in North Africa. Our study demonstrates that analyses based on a large environmental dataset can investigate complex phenomena such as bird migration and that a high volume of data combined with statistical indices may mitigate the limitations linked to a citizen science approach.

Keywords: Bird migration, Barn swallow, NAO, Climate, Citizen science

INTRODUCTION

Understanding the great phenomena of nature has always been a challenge for humankind. Bird migration, in particular, is a complex phenomenon, that has been widely studied (Alestarm 2011, Bertold 2001) using various models and methods, including some citizen science data. However, there are some concerns about obtaining large-scale unbiased data, since non-ornithologists should be educated and recruited to collect standardized records. This is feasible if the study involves a well-known species that is easy to identify. The Barn Swallow *Hirundo rustica* has been selected (Sparks & Braslavskà 2001, Sparks & Tryjanowski 2007) since it is a common and easily detectable bird especially while in active flight and foraging.

The Barn Swallow is a small passerine undertaking a long migration between Europe and Africa. Each year migrants embark on a journey estimated to be at least 3000 km long between the two continents (Turner 2006). Along the route that passes through Italy, the Barn Swallows encounter important geographical barriers including the Sahara Desert and the Mediterranean Sea. Some tracked birds have been reported to regularly cross the equatorial rain forest to reach South Africa and return (Klvaňa et al.2017, Liechti et al.2014, Pancerasa et al. 2022). In Europe, Barn Swallow spring migration begins as early as February though its timing varies from year to year sometimes by several weeks. Traditionally, people associate the arrival of the first Barn Swallow with the onset of warmer spring temperatures, but factors determining the timing of Barn Swallow migration are debated and not yet properly quantified. Changes in temperature, food supply and day length have been hypothesized to influence trans-Saharan migrants (Berthold 1996, Berthold 2001, Gordo et al. 2005, Møller et al. 2010, Rubolini et al. 2002). The timing of migration is influenced by the photoperiod (Berthold 1996) as arrival time is highly synchronized to ensure successful pairing and reproduction (Coppack & Both 2002). Variations in Barn Swallow arrival to the breeding grounds in Europe appear to be linked either with meteorological conditions at their destination (Pancerasa et al. 2018) or to environmental changes both in stopover and wintering areas (Balbotin et al. 2009, Sicurella et al. 2016). However, weather conditions that trigger early- or late spring arrivals at breeding sites in Northern Europe may differ from those experienced by birds actively migrating, particularly when crossing major barriers such as the Mediterranean Sea and the Sahara Desert (Saino et al. 2004). It remains unclear whether warmer springs accelerate the migration process due to improved travelling conditions en route, or if large-scale meteorological variations and climatic changes across the continent play a role. This question is challenging to address as it requires significant resources (in time and costs) to monitor such large-scale phenomena both spatially and temporally. Tools like geolocators (Alex et al. 2013, Pancerasa et al. 2022) which track the migration routes of single individuals or radar systems which identify migration patterns of large numbers of birds (Kranstauber et al. 2020, Nilsson et al. 2018) may help to describe the temporal and spatial variation of bird migration. However, these tools do not provide detailed information on biological parameters, such as fitness, that may affect migration timing and routes (Ambrosini et al. 2014, Pancerasa et al. 2022). Direct observation and ringing remain the most used monitoring methods. Ringing schemes (e.g. EURING databank, http://www.euring.org) use capture and recapture methods to track individuals' locations and migration timing along their migratory routes or during their stay in the wintering and breeding grounds. The high cost of monitoring bird migration can be mitigated by long-term citizen science programs involving large numbers of volunteers, guided by experts, who can cover extensive areas such as an entire nation, over multiple migratory seasons for several years (Newson et al. 2016). When properly designed, these programs not only enhance scientific knowledge but also build participants' scientific skills and environmental awareness (Roche et al. 2020). In this study, we report the experience of a citizen science project conducted in Italy and the findings of a 16-year study (2004-2019) led by non-scientist members from the birding association EBN Italia. The Barn Swallow was selected as a target species for two reasons: first, the arrival of this species has always been associated with the beginning of spring in the boreal hemisphere; second, it is a species easy to identify, not secretive in behaviour and not easily confused with others. Birdwatchers in collaboration with the National Research Council of Italy (CNR) were asked to report the first spring sighting of a Barn Swallow and data were analyzed to further address whether there is any trend in spring arrival timing on Italian coasts and if this change might be affected by climate changes.

METHODS

This citizen science study is based on the first sighting of Barn Swallows collected over the Italian territory (from 35° 29′N to 47° 5′N latitude and 6°37′E and 18°31′E longitude) from 2004 to 2019. These data were found as part of the citizen science project "GILIA – Signs of Spring" that was set up by the CNR and aimed to involve all stakeholders who carry out recreational or professional activities in the environmental sector in this campaign: e.g. voluntary and cultural associations, administrators and operators of parks and protected areas and university researchers.

Phenology data

Data collection began in 2004 in the framework of GILIA, a collaboration between EBN Italia and the former Institute of Biometeorology, now the Institute of BioEconomy of the National Research Council (IBE-CNR) aimed to map the timing of the first Barn Swallow's arrival across Italian provinces and to investigate its relationship with climate change. Over the years, EBN Italia members and volunteers have contributed to citizen-science research (Di Febbraro 2023), concerning also the Common Crane *Grus grus* migration routes (Mingozzi et al. 2013), Short-toed Snake-eagle *Circaetus gallicus* autumn circuitous pattern migration (Ruggieri et al. 2007) and other local bird research initiatives.

EBN birdwatchers were asked to report any initial sighting of Barn Swallows in spring, including time and location, by email to the association's mailing list. From 2007 to 2013 IBE developed a dedicated webpage for easy collection of geolocated data. Observers recorded data by selecting the exact position on a map and filling out a form with the relevant information: timing, number of individuals, and weather conditions. Emailed data were processed and collected in a geo-database. Between 2014 and 2019 additional georeferenced data were also gathered from platforms managed by birdwatchers and ornithologists: Ornitho.it (www.ornitho.it) and Ubird (https://ubird.ebnitalia.it). From this extensive database, containing more than 24.000 observations, the authors extracted the earliest record of a Barn Swallow for each of Italy's 106 provinces. This filtering process prevented multiple and duplicate counts from nearby locations, reports from different observers on the same day, or repeated sightings of the same individual at the same site. The refined dataset included 576 records for further analysis.

The timing of each observation was recorded as the Julian day of the year (doy), for example, January 1st is doy 1, February 28th is doy 59 and so on. Studies using the first arrival dates can sometimes overestimate changes in phenology, while the use of median and percentile observation dates within the same year allows a more detailed understanding of shifts in spring migration timing (Maggini et al., 2020). Therefore, to minimize the impact of outliers, we calculated the following indicators: 25th percentile (P25), median (P50) and 75th percentile (P75) of the first arrival dates per province in each year.

Climate data

The analysis of phenology in relation to climate was conducted by using large-scale climate indices and monthly temperature data. We selected the North Atlantic Oscillation (NAO) as a major climate index. The NAO index is calculated as the difference of the surface sea-level pressure between the Azores High and the Subpolar Low (Hurrel 1995). Positive and negative phases of NAO are associated with large-scale weather conditions over the North Atlantic that result in different patterns of temperatures and precipitations over North America and Europe. Previous studies have already detected a correlation between the NAO index and spring migration timing of some bird species (Hüppop & Huppop 2003, Rubolini et al. 2007). Monthly NAO data were obtained from the Climate Prediction Center of the National Oceanic and Atmospheric Administration (CPC-NOAA). To assess temperature patterns across Europe and Africa during years of late and early arrivals we used monthly temperature data retrieved from the ERA5 re-analyses dataset (Hendricks et al. 2010) provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) with a spatial resolution of 30 km x 30 km. For each grid cell and each study year, the February temperature anomaly was calculated as the difference between each year and the average monthly temperature in 1980-2010. Maps showing anomalies for three late-arrival years and three early-arrival years were presented and discussed.

Statistical analyses

Observations were tested for potential weekend biases using the Mann Whitney's and Pearson's chi-squared test for binomial variables and no significant bias was found regarding weekdays and weekends. The 25th percentile (P25), median (P50) and 75th percentile (P75) of the sightings were calculated on the complete dataset (ITA), as well as separately on four Italian geographical subsets (regions) based on latitude: Northern Italy (NI, latitude higher than 44°N), Central Italy (CI, latitude between 41.5 °N and 44°N), Southern Italy (SI, latitude lower than 41.5°N), and the main Islands of Sardinia and Sicily (ISL). Since Barn Swallows may be also a resident species in Central and Southern Italy, a few observations recorded before February 1st were excluded from the analysis.

Then, temporal trends in annual P25, P50 and P75 values were examined using regression analyses. Differences among years were assessed by one-way analysis of variance (ANOVA), followed by Tukey's HSD test with a significance level set to $p < 0.05$. Regional differences in P25 values among regions (NI, CI, SI and ISL) were also tested by ANOVAs followed by Tukey's HSD tests.

Regression analysis was also used to investigate the relationship between first sightings, as the dependent variable, and year and region (four-level factor) as independent variables. The reference value for the factor region was CI.

To map the temporal progression of bird migration, we calculated the anomaly of each observation date relative to the average date in the same year. Then, the 25th percentile (P25), median (P50) and 75th percentile (P75) of all anomalies were mapped to illustrate the geographical distribution of early and late observations.

We also investigated the relationship between P25, P50, and P75 metrics and both the average monthly and winter air temperatures in a region of Northern Africa (Long: 1.5°E – 11°E, Lat: 35°N – 38°N) that is considered one of the major stopover sites of Barn Swallows migrating through Italy and the Mediterranean Sea (Ambrosini et al. 2011, Sicurella et al. 2016).

The average air temperature for December, January, February and March, and the average winter air temperature (DJF) and the average January to March air temperature (JFM) at a height of 2 m were calculated from the period 2003 to 2019 using ERA 5 re-analysis. Relationships between P25, P50 and P75 and monthly NAO and the other climate variables were assessed by Pearson correlation analyses. Maps of the Pearson correlations between P25 sightings and temperature variables in the previously selected African region were also presented.

RESULTS

A total of 576 sightings of the first arrival of Barn Swallows in spring were used in this study (Tab. 1). The average date for the first spring sightings of a Barn Swallow in Italy was March 6th (doy 65); the earliest sighting occurred on February 4th, 2017 (doy 35) in SI (specifically in Lecce and Caserta), while the latest was on April 12th, 2009 (day 102) in CI (Arezzo). The number of observations collected over the whole studied period ranged from 25 to 7 in NI, CI, and SI and from 8 to 2 in ISL (Tab. 1). Over the studied period, the number of observations (nrec) in NI ($t = -1.14$, $df = 14$, $P < 0.01$) and CI ($t = -0.5$, $df = 14$, $p < 0.01$) significantly decreased. No significant trend was assessed for SI ($t = -0.07$, $df = 14$, $p = 0.62$) and ISL ($t = +0.1$, $df = 14$, $p = 0.29$).

Differences among years were significant according to ANOVA analysis ($F = 22.1$, $df = 15{,}560$, $p < 0.001$). The first arrival was significantly late in 2005 (mean = 77 doy, CI = 64-87 doy), in 2008 (mean = 72 doy, CI = 57-87 doy) and in 2009 (mean = 71 doy, CI = 61-96 doy), and significantly advanced in 2017 (mean = 54 doy, CI = 39-73 doy), 2016 (mean = 57 doy, CI = 47-67 doy) and 2019 (mean = 58 doy, CI = 43-73 doy) (Fig. 1). The largest significant difference in P25 first sightings was found between 2012 and 2019 ($|t| \geq 2.235$, $df = 63$, $p \leq 0.029$),

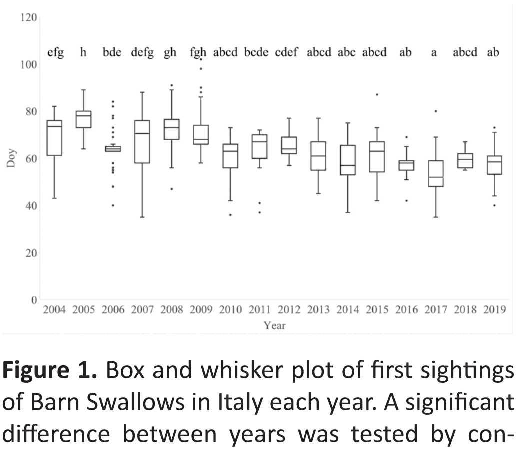

Figure 1. Box and whisker plot of first sightings of Barn Swallows in Italy each year. A significant difference between years was tested by conducting a one-way ANOVA followed by a Tukey HSD test. Different letters indicate significant differences ($p < 0.05$) between groups.

Table 1. Percentage and number of annual observations of the first sighting of Barn Swallows in North (NI), Central (CI) and South Italy (SI) and Italian Islands (ISL). Annual mean, confidence interval, median, 1st and 3rd quartile (Q.) of day (day of the year) of observations collected in Italy

Year	N. Rec	NI	CI	SI	ISL	Mean doy (conf. int.)	1st Q. (doy)	Median (doy)	3rd Q. (doy)
2004	48	52% (25)	31% (15)	10% (5)	6% (3)	69 (48-82)	61	74	76
2005	45	56% (25)	27% (12)	11% (5)	7% (3)	77 (64-87)	73	78	80
2006	33	36% (12)	36% (12)	12% (4)	15% (5)	64 (46-82)	63	64	65
2007	28	43% (12)	29% (8)	14% (4)	14% (4)	67 (38-81)	58	71	76
2008	79	49% (39)	25% (20)	16% (13)	9% (7)	72 (57-87)	68	73	77
2009	53	45% (24)	28% (15)	15% (8)	11% (6)	71 (61-96)	66	68	74
2010	41	44% (18)	24% (10)	22% (9)	10% (4)	61 (42-71)	56	63	66
2011	28	29% (8)	39% (11)	25% (7)	7% (2)	64 (40-71)	60	67	70
2012	31	45% (14)	26% (8)	23% (7)	6% (2)	65 (57-76)	62	64	69
2013	25	44% (11)	28% (7)	12% (3)	16% (4)	61 (46-72)	55	61	67
2014	27	41% (11)	26% (7)	15% (4)	19% (5)	58 (38-74)	53	57	66
2015	28	32% (9)	18% (5)	29% (8)	21% (6)	61 (44-78)	54	63	67
2016	25	52% (13)	32% (8)	8% (2)	8% (2)	57 (47-67)	55	58	59
2017	25	28% (7)	36% (9)	20% (5)	16% (4)	54 (39-73)	48	52	59
2018	26	27% (7)	27% (7)	23% (6)	23% (6)	59 (55-67)	56	60	62
2019	34	32% (11)	26% (9)	18% (6)	24% (8)	58 (43-73)	53	59	61
Total	576	43% (248)	28% (161)	17% (98)	12% (69)	65 (42-87)	58	65	73

while the lowest not significant was found between 2010 and 2017 ($t \leq 0.542$, df = 64, $p \geq 0.059$).

The trend for the first spring sightings showed a significant advancement for P25 (1.02 ± 0.24 SE day/year, t = - 4.334 df = 14, $p < 0.001$, R^2=0.57), P50 (1.24 ± 0.20 SE days/year, t = - 6.071 df = 14, $p < 0.001$, R^2 = 0.72) and P75 (1.15 ± 0.20 SE days/year, t = - 5.648, df = 14, $p < 0.001$, R^2 = 0.69) across the studied period (Fig. 2).

Observations are spread throughout Italy with some hotspots in NI, the Ligurian and Tyrrhenian Sea, the southern Adriatic Sea and Sicily (Fig. 3a). Early sightings (below P25) and late sightings (over P75) are shown in Fig. 3b and 3d respectively while sightings between P25 and P75 in Fig. 3c. The distribution of Barn Swallow first sightings indicates that the first migrants are generally seen both on the main islands, Sicily and Sardinia (ISL) and along

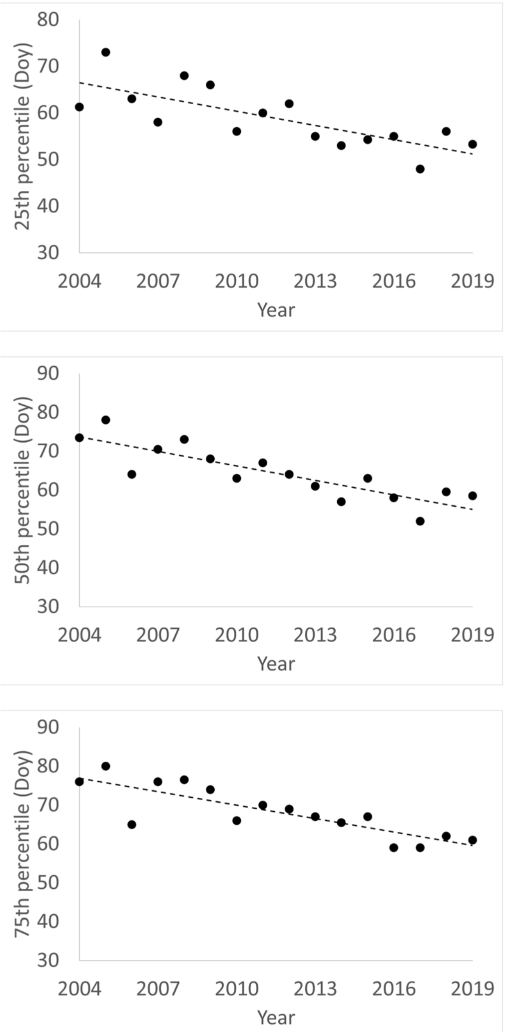

Figure 2. Temporal trend (year) of 25th percentile, 50th percentile and 75th percentile of first sightings (doy) of barn swallows in Italy. The dashed line represents the trend interpolated by the regression analysis.

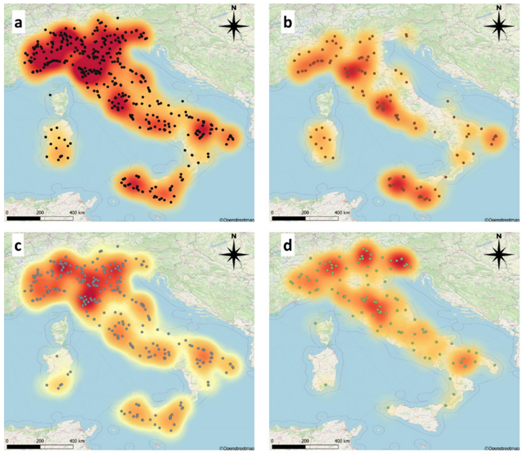

Figure 3. Geographical distribution and concentration of observations of first sightings of barn swallows in Italy for the whole dataset (a), for observation date lower than the 25th percentile (b), between the 25th and 75th percentile (c) and higher than the 75th percentile (d). Concentration is represented in graduated colours with increasing values from white to red.

the Tyrrhenian coast as in Latium, Liguria and Tuscany (Fig. 3b). Late observations are mainly concentrated in the mountain regions of the Alps and Apennines (Fig. 3d).

ANOVA test on first sightings across the four different geographical areas was significant ($F = 16.19$, $df = 3,572$, $p < 0.001$, Fig. 4) and indicated that the first Barn Swallows reached the isles earlier than other parts of Italy.

Multiple regression analysis by year and region (Tab. 2 and Fig. 5) supports the hypothesis that Barn Swallows arrive first in ISL, then, after 5 days, in CI and SI, and finally, after 7 days, in NI.

In the year of latest arrival (2005) we report a large negative temperature anomaly present over the Mediterranean Sea, Italy and North Africa from Mauritania to western Libya with a similar pattern, though weaker, also present in 2009 (Fig. 6). The year with the second latest

Table 2. Regression analysis of first sightings of Barn Swallows as dependent variables and year and region as independent variables. Reference value for the factor variable region was CI (Central Italy) and the other factors were Northern Italy (NI), Southern Italy (SI) and main Islands (ISL). Residuals df are 571

Effect	Coef	SE	t	P
Intercept	2232.205	166.378	13.416	< 0.001
year	–1.078	0.083	–13.025	< 0.001
region ISL	–5.124	1.273	–4.024	< 0.001
region NI	2.063	0.901	2.291	0.022
region SI	0.470	1.148	0.409	0.682

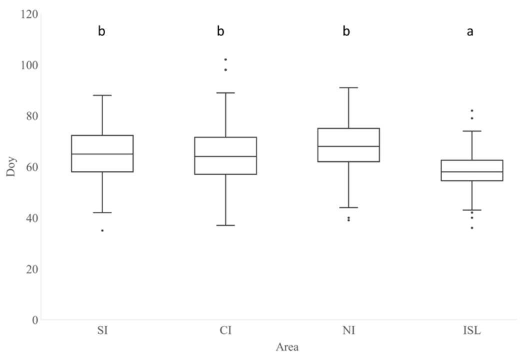

Figure 4. Box and whisker plot of first arrival anomaly per area for the whole study period: Northern Italy (NI), Central Italy (CI), Southern Italy (SI) and main islands (ISL). A significant difference between regions was investigated by conducting a one-way ANOVA followed by Tukey HSD tests. Different letters indicate significant differences ($p < 0.05$) between groups.

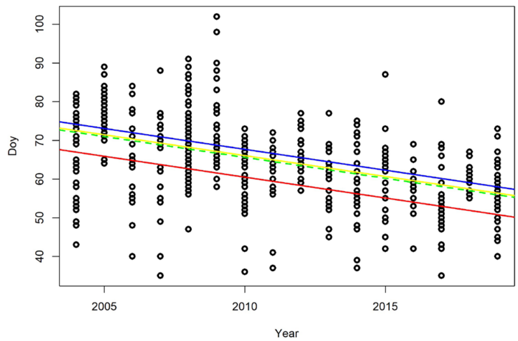

Figure 5. Scatterplot of the day of the year (doy) of barn swallow sightings collected from 2004 to 2019. Regional trend of barn swallow arrival interpolated by the regression analysis are represented with blue line (NI), green dashed line (CI), yellow line (SI) and red line (ISL).

arrival (2008) does not show such pattern even though a negative anomaly is present over Libya.

In contrast, the year of the earliest arrival (2016) showed a large positive temperature anomaly over the Mediterranean Sea with a similar pattern, though of weaker intensity, evident both in 2017 and 2019 (Fig. 6).

No significant correlation was found between percentiles of first sightings and winter and monthly NAO indices (Tab. 3). Increasing average temperatures in the selected region of North Africa (Sicurella et al., 2016) significantly anticipated the 25th percentile of first sightings: December temperatures (Pearson's r = -0.537,

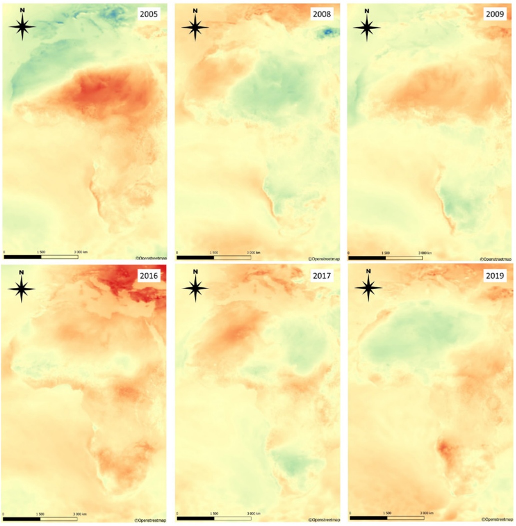

Figure 6. February temperature anomaly over Europe and Africa for the year of late arrival (2005, 2008 and 2009) and of early arrival (2016, 2017 and 2019).

df = 14, p = 0.032), winter (DJF) temperatures (r = -0.577, df = 14, p = 0.019) and JFM temperatures (r = -0.530, df = 14, p = 0.035). No other significant relationships between percentiles of first sightings and temperature indices were found (Tab. 3). The maps of correlation (Fig. 7) show that P25 sightings are also negatively affected by temperatures in the Western part of the selected area in December (Fig. 7a), while later in the season, in February and March, they are more negatively affected by temperatures in the North-Eastern part (Fig. 7c and 7d). This is also confirmed by correlation with the three-month average temperatures: in winter, migration is advanced with increasing temperatures in the whole area (Fig. 7e), while in late winter and early

Table 3. Pearson correlation (r) between 25th percentile (P25), 50th percentile (P50) and 75th percentile (P75) of first sightings of Barn swallow as dependent variables and monthly (Dec, Jan, Feb, Mar) and seasonal (DJF, JFM) average North Atlantic Oscillation (NAO and temperature (TEMP) as independent variables. Significant correlations at $p < 0.05$ are indicated by*. Degrees of freedom are 14 in all cases

	P25	P50	P75
Dec NAO	–0.054	–0.067	–0.045
Jan NAO	0.191	0.027	–0.006
Feb NAO	–0.254	–0.362	–0.344
Mar NAO	–0.35	–0.171	–0.083
DJF NAO	–0.059	–0.16	–0.153
JFM NAO	–0.236	–0.255	–0.21
Dec T	–0.537*	–0.410	–0.423
Jan T	–0.322	–0.182	–0.169
Feb T	–0.474	–0.265	–0.239
Mar T	–0.183	–0.258	–0.329
DJF T	–0.577*	–0.358	–0.342
JFM T	–0.530*	–0.344	–0.341

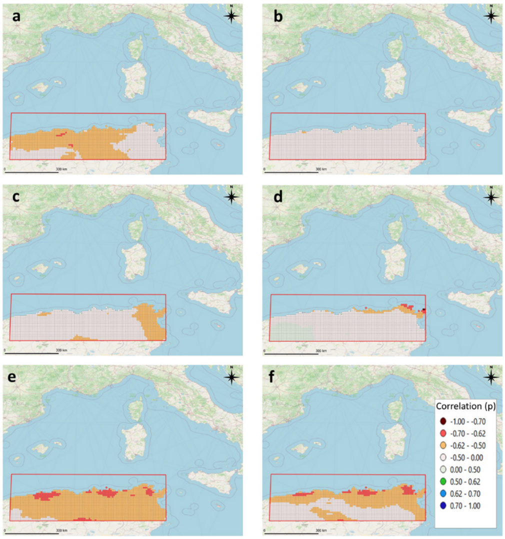

Figure 7. Pearson correlation between P25 sightings of Barn Swallows and December temperatures (a), January temperatures (b), February temperatures (c), March temperatures (d), winter temperatures (e) and January to March temperatures (f) calculated on the ERA 5 reanalysis dataset on an area of Northern Africa (Long: 1.5° E – 11° E, Lat: 35° N – 38° N). Colours represent significance level at $p < 0.05$ (orange), $p < 0.01$ (red) and $p < 0.001$ (dark red).

spring, it advances with increasing temperatures along the coast (Fig. 7f).

DISCUSSION

This study presents 16 years of observations of the first Barn Swallow in spring in Italy. This data was collected through a citizen science project initiated by the CNR to engage all stakeholders involved in recreational or professional activities within the environmental sector, including voluntary and cultural associations, park and protected area administrators and operators, as well as university researchers. However, almost all the data, apart from the first year of the project when also other stakeholders contributed, were provided by volunteers connected to the EBN Italia network association. Participant involvement is always a recurring issue in citizen science as highlighted by other studies (Dickinson et al. 2012). For citizen science projects to be effective, participants must have a strong interest in the project's theme and be willing to dedicate their time to specific activities. In this case, involvement was facilitated by the fact that the participants were already members of a community aligned with the environmental focus of the study. They contributed to the project's objectives simply by performing the required observations as part of their regular hobbies. This approach enabled the collection of a significant number of observations within Italy, a country that lacks a consolidated tradition of engaging citizens in nature observations as seen in other countries (e.g. UK, Germany, USA).

According to our data, the interannual variability of the first sighting of Barn Swallow spring migration in Italy was very high. For instance, P25 was advanced by 25 days in 2017 (doy: 48) compared to 2005 (doy: 73). Our models explained between 57% (for P25) and 72% (for P75) variability, showing a significant trend from 1 (P25) to 1.2 days/year (P50) of first Barn Swallow arrivals (Fig. 2). This temporal shift is consistent with other studies that found an advancement in Barn

Swallow spring migration. Most studies found a lower advancement of the spring migration of this species between 0.1 to 0.3 days/year (Cohen et al. 2018, Lehikoinen et al. 2019, Romano et al. 2022, Usui et al. 2017), while others found a higher significant advancement of the first arrival dates on small islands of the Tyrrhenian Sea (1.7 day/year) from the wintering grounds in tropical Africa (Maggini et al. 2020) and of the arrival date (1.3 days/year) in Badajoz, Spain (Balbontin et al. 2009). However, we acknowledge some limitations of our dataset, particularly the relatively limited length of our data series (16 years) which may have introduced some bias. This is particularly true as later arrivals were concentrated at the beginning of the series and early arrivals towards its end. Our findings should therefore be validated by analysing longer data series.

We also compared our findings on the first spring arrival of Barn Swallows on Italian coasts — the first step of their journey to Europe from Africa — as soon as they crossed the Mediterranean Sea. This is of particular interest as the progression of migration was not hampered or altered by atmospheric conditions over the European mainland. We found that the first Barn Swallows reach Sicily and Sardinia earlier compared to other parts of Italy (Fig. 4). Subsequently, the migration in Italy follows a clear SW-NE trajectory (Fig. 3). This is consistent with previous findings of a direct journey across the Mediterranean Sea from wintering grounds with no stopovers in Northern Africa (Rubolini et al. 2007) indicating that some routes involve necessarily a continuous non-stop flight over the sea without resting (Pilastro & Magnani 1997). Progression towards NE in Italy is hampered by crossing mountain ranges (i.e. the Apennines) and the Alpine chain is reached considerably later (9 to 10 days later) (Fig. 4). Moreover, regression analysis performed between sightings and year and region suggested a significantly different arrival time of Barn Swallow in ISL: 5 days earlier than CI and SI and 7 days earlier in NI (Tab. 3, Fig. 5).

It should be noted that our results might be affected by the odd geographical distribution of our observations throughout the years. Indeed, the percentage of observations collected in SI and ISL increased during the study period and the higher rate of observations collected in the South of Italy where Barn Swallows arrive earlier might have contributed to the pronounced trend.

We did not find any strong correlation with NAO, a large-scale climate index. The NAO index has been shown by Vähätalo et al. (2004) to affect the arrival in Finland of some migrant bird species, though not Barn Swallows, and of 23 out of 24 migratory bird species in Helgoland, Germany, (Hüppop & Hüppop 2002) where Barn Swallow was not tested. At the Ottenby Bird Observatory in Sweden, early arrivals of 16 out of 19 long-distance migrants — but not Barn Swallows — correlate with the NAO index (Stervander et al. 2005). These differences may reflect the effect of the NAO index along an East-West gradient (Hüppop & Hüppop 2003, Stervander et al.

2005), as the NAO effect is more pronounced for migrants following western routes. The number of studies that have investigated the effect of NAO on bird behaviour on the one side and temperature and precipitation regime on the other (Gentilucci et al., 2023) along such an important migratory route is still scarce. This work thus adds further evidence to the studies that did not find any influence of NAO on bird migration through the Central Mediterranean Basin (Rubolini et al., 2007).

Both 2005 and 2016 were marked by significant and opposite temperature anomalies over the Mediterranean Sea and North Africa in February: a negative anomaly in 2005 and a positive anomaly in 2016. This is confirmed by the significant correlation between P25 and December, winter and average January to March (JFM) temperatures over a stopover site in North Africa that suggests that marked temperature anomalies in late winter might affect Barn Swallow migration timing (Fig. 6 and 7). Consequently, the relationships between climate conditions and other environmental variables at wintering and stopover sites warrant further investigation.

The influence of climate on the timing of bird migration is still debated in literature, particularly in Europe. For instance, Barn Swallow's arrival and migration progression in Britain has been demonstrated to be influenced by temperatures along the route in continental Europe and in Britain (Huin & Sparks 1998). Other studies indicated that temperatures in NW Africa and SW Iberia affect the arrival dates of 5 different migrant species in Spain, including the Barn Swallow, suggesting that favourable weather conditions could facilitate faster migration (Gordo & Sanz 2005, 2008).

The main limitation of our study is the observation protocol which relied on the voluntary efforts of amateurs motivated by contributing to scientific research. Early sightings (P25) in the Southern part of the Tyrrhenian coast (Campania and Calabria) are less frequent, possibly due to the limited number of observations in these areas which may not be sufficient to accurately capture the timing of Barn Swallow's arrival. This approach does not always ensure a homogeneous and consistent coverage of observations across spatial and temporal scales. However, we sought to limit this aspect by working on aggregated data. We used the P25 statistical index calculated across all observations to assess temporal differences between years and trends, and we used arrival date anomalies to describe the progression of migration across Italy. In studies of this kind, there can be also some concerns about the observer's ability to correctly identify the bird species: we mitigated this by focusing on a well-known and easily recognizable species, especially for skilled and experienced birdwatchers. In several cases, observations were supported by photos that allowed data verification.

The influence of climate change on bird migration is a very interesting and fascinating area of study. However, monitoring such a large-scale phenomenon is challenging and entails high fieldwork costs to collect the necessary amount of data. In addition, climate or environmental indicators made available by earth monitoring systems are still underused in this type of study. Citizen science projects have emerged as an efficient way to collect such data, involving a large number of participants who contribute their observations. This approach is particularly valuable when the events span over a broad geographical area, as is the case for bird migration. Volunteers and skilled participants in these projects not only collected field data but also received scientific feedback addressing fundamental questions and tested the initial hypothesis: Do barn Swallows progressively advance spring migration along Italian coasts? Is this phenomenon correlated to climatic changes or weather anomalies? The answer remains complex, as environmental factors, which can be summarized by different climatic indices (Alerstarm 2011, Berthold 2001, Coppack & Both 2002), are involved in this extensive process, alongside biological and genetic influences (Møller et al. 2004, 2010) which must be understood, to predict Barn Swallow migration patterns.

Conflict of interest

The authors declare they have no conflicts of interest

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Data availability

Data are available in the Electronic Supplementary Materials of this paper.

REFERENCES

1. Alerstam T. 2011. Optimal bird migration revisited. Journal of Ornithology 152 (Suppl 1): S5–S23.
2. Ambrosini R., Rubolini D., Møller A.P., Bani L., Clark J., Karcza Z., Vangeluwe D., du Feu C., Spina F. & Saino
3. N. 2011. Climate change and the long-term northward shift in the African wintering range of the barn swallow *Hirundo rustica*. Climate Research. 49: 131–141.
4. Ambrosini R., Romano A. & Saino N. 2019. Changes in migration, carry-over effects, and migratory connectivity. In: Dunn P.O. & Møller A.P. (eds). Effects of climate change on birds. Oxford University Press, Oxford, UK pp. 93–108. https://doi.org/10.1093/oso/9780198824268.003.0008.
5. Ambrosini R., Borgoni R., Rubolini D., Sicurella B., Fiedler W., Bairlein F, Baillie S.R., Robinson R.A., Clark J.A., Spina F. & Saino N. 2014. Modelling the progression of bird migration with conditional autoregressive models applied to ringing data. PLoS ONE 9(7): e102440. https://doi.org/10.1371/journal.pone.0102440
6. Balbontin J., Møller A.P., Hermosell I.J., Marzal A., Rivierego M. & de Lope F. 2009. Individual responses in spring arrival date to ecological conditions during winter and migration in a migratory bird. Journal of Animal Ecology 78, 981–989
7. Berthold P. 2001. Bird migration—a general survey, 2nd ed. Oxford University Press. Oxford, UK.

8. Berthold P. 1996. Control of bird migration. Chapman & Hall, London, UK.
9. Caprioli M., Ambrosini R., Boncoraglio G., Gatti E., Romano A., Romano M., Rubolini D., Gianfranceschi L. & Saino N. 2012. *Clock* gene variation is associated with breeding phenology and may be under directional selection in the migratory Barn Swallow. PLoS ONE 7(4): e35140. https://doi.org/10.1371/journal.pone.0035140.
10. Cohen J.M., Lajeunesse M.J. & Rohr J.R. 2018. A global synthesis of animal phenological responses to climate change. Nature Climate Change. 8, 224–228. https://doi.org/10.1038/s41558-018-0067-3.
11. Coppack T. & Both C. 2002. Predicting life-cycle adaptation of migratory birds to global climate change. Ardea 90: 369–378. https://doi.org/10.5253/arde.v90i3.p369.
12. Di Febbraro M., Bosso L., Fasola M., Santicchia F., Aloise G., Lioy S., Tricarico E., Ruggieri L., Bovero S., Mori E. & Bertolino S. 2023. Different facets of the same niche: integrating citizen science and scientific survey to predict biological invasion risk under multiple global change drivers, Global Change Biology 29: 5509–5523.
13. Dickinson J.L., Shirk J., Bonter D., Bonney R., Crain R.L., Martin J. Philips T. & Purcell K., et al. 2012. The current state of citizen science as a tool for ecological research and public engagement. Frontiers in Ecology and the Environment 10: 291–297. doi: 10.1890/110236.
14. Gentilucci M., Domenicucci S., Barbieri M., Hamed Y., Hadji R., Missaoui R., Pambianchi G. 2023. Spatial Effects of NAO on Temperature and Precipitation Anomalies in Italy. Water 15: 3727.
15. Gordo O., Brotons L., Ferrer X. & Comas, P. 2005. Do changes in climate patterns in wintering areas affect the timing of the spring arrival of trans-Saharan migrant birds? Global Change Biology 11: 12–21.
16. Gordo O. & Sanz J.J. 2008. The relative importance of conditions in wintering and passage areas on spring arrival dates: the case of long-distance Iberian migrants. Journal für Ornithologie 149: 199–210.
17. Gordo O. & Sanz J.J. 2005. Phenology and climatic change: A long-term study in a Mediterranean locality. Oecologia 146: 484–495.
18. Hendricks E.A., Peng M.S., Fu B. & Li T. 2010. Quantifying environmental control on tropical cyclone intensity change. Monthly Weather Review, 138: 3243–3271. https://doi.org/10.1175/2010MWR3185.1.
19. Huin N. & Sparks T.H. 1998. Arrival and progression of the swallow Hirundo rustica through Britain. Bird Study 45: 361–370.
20. Hüppop O. & Huppop K. 2003. North Atlantic oscillation and timing of spring migration in birds. Proceedings of the Royal Society of London B 270: 233– 240.
21. Hurrell J.W. 1995. Decadal trends in the North Atlantic Oscillation: regional temperatures and precipitation. Science 269: 676–679
22. Klvaňa P., Cepák J., Munclinger P., Michálková R., Tomášek O. & Albrecht T. 2018. Around the Mediterranean: an extreme example of loop migration in a long-distance migratory passerine. Journal of Avian Biology 2018: e01595.
23. Lehikoinen A., Lindén A., Karlsson M., Andersson A., Crewe T.L., Dunn E.H., Gregory G., Karlsson L., Kristiansen V., Mackenzie S., Newman S., Røer J.E., Sharpe C., Sokolov L.V., Steinholtz Å., Stervander M., Tirri I.S. & Tjørnløv R.S. 2019. Phenology of the avian spring migratory passage in Europe and North America: asymmetric advancement in time and increase in duration. Ecological Indicators. 101: 985–991. https://doi.org/10.1016/j.ecolind.2019.01.083.

24. Liechti F., Scandolara C., Rubolini D., Ambrosini R., Korner-Nievergelt F., Hahn S., Lardelli R., Romano M., Caprioli M., Romano A., Sicurella B. & Saino N. 2015. Timing of migration and residence areas during the non-breeding period of barn swallows Hirundo rustica in relation to sex and population. Journal of Avian Biology 46: 254–265.
25. Maggini I., Cardinale M., Sundberg J.H., Spina F. & Fusani L. 2020. Recent phenological shifts of migratory birds at a Mediterranean spring stopover site: Species wintering in the Sahel advance passage more than tropical winterers. PLoS ONE 15(9): e0239489. https://doi.org/10.1371/journal.pone.0239489
26. Mingozzi T., Storino G.P., Venuto G., Alessandria G., Arcamone E., Urso S., Ruggieri L., Massetti L. & Massolo A. 2013. Autumn migration of Common Cranes *Grus grus* through the Italian Peninsula: new vs. historical flyways and their meteorological correlates. Acta Ornithologica 48: 165–177.
27. Møller A.P., Fiedler W. & Berthold P., (eds.) 2010. Effects of Climate Change on Birds. Oxford University Press, Oxford, UK.
28. Møller A.P., Rubolini D. & Lehikoinen E. 2008. Populations of migratory bird species that did not show a phenological response to climate change are declining. Proceedings of the National Academy of Science USA 105: 16195–16200.
29. Møller A.P. & Merilä J. 2004. Analysis and interpretation of long-term studies investigating responses to climate change. Advances in Ecological Research. 35: 111–130.
30. Musitelli F., Spina F., Møller, A.P., Rubolini D., Bairlein F., Baillie S.R. Clark J.A., Nikolov B.P: du Feu C., Robinson R.A., Saino N. & Ambrosini R. 2019. Representing migration routes from re-encounter data: a new method applied to ring recoveries of Barn Swallows (*Hirundo rustica*) in Europe. Journal of Ornithology 160: 249–264. https://doi.org/10.1007/s10336-018-1612-6
31. Newson S.E., Moran N.J., Musgrove A.J., Pearce-Higgins J.W., Gillings S., Atkinson P.W. Miller R., Grantham M.J. & Baillie S.R. (2016). Long-term changes in the migration phenology of UK breeding birds detected by large-scale citizen science recording schemes. Ibis, 158: 481–495. https://doi.org/10.1111/ibi.12367.
32. Pancerasa M., Ambrosini R., Saino N. & Casagrandi R. 2018. Barn swallows long-distance migration occurs between temperature-correlated areas. Scientific Reports 8: 12359.
33. Pancerasa M., Ambrosini R., Romano A., Rubolini D., Winkler D.W. & Casagrandi R. 2022. Across the deserts and sea: inter-individual variation in migration routes of south-central European barn swallows (*Hirundo rustica*). Movement Ecology 10: 51. https://doi.org/10.1186/s40462-022-00352-3.
34. Pilastro A., Magnani A. 1997. Weather conditions and fat accumulation dynamics in pre-migratory roosting Barn Swallows *Hirundo rustica*. Journal of Avian Biology 28: 338–344.
35. Roche J., Bell L., Galvão C., Golumbic Y.N., Kloetzer L., Knoben N., Laakso M., Lorke J., mannion G., Masseti L., Mauchline A., Pata K., Ruck A., Taraba P. & Winter S. 2020. Citizen Science, education, and learning: challenges and opportunities. Frontiers in Sociology 5: 613814. https://doi.org/10.3389/fsoc.2020.613814.
36. Romano A., Garamszegi L.Z., Rubolini D. & Ambrosini, R. 2023. Temporal shifts in avian phenology across the circannual cycle in a rapidly changing climate: a global meta-analysis. Ecological Monographs, 93: e1552.
37. Rubolini D., Pastor A.G., Pilastro A. & Spina F. 2002. Ecological barriers shaping fuel

stores in barn swallows Hirundo rustica following the central and western Mediterranean flyways. Journal of Avian Biology 33: 15–22.
38. Rubolini D., Møller A.P., Rainio K. & Lehikoinen, E. 2007. Intraspecific consistency and geographic variability in temporal trends of spring migration phenology among European bird species. Climate Research 35: 135–146.
39. Ruggieri L., Premuda G., Baghino L. & Giraudo L. 2006. Esperienza di monitoraggio su vasta scala della migrazione autunnale del biancone *Circaetus gallicus* in Italia e nel Mediterraneo centrale. Avocetta 30: 76–80.
40. Saino N., Szép T., Romano M., Rubolini D., Spina F. & Møller A.P. 2004. Ecological conditions during winter predict arrival date at the breeding quarters in a trans-Saharan migratory bird. Ecology Letters 7: 21–25.
41. Saino N., Szép T., Ambrosini R., Romano M. & Møller A.P. 2004. Ecological conditions during winter affect sexual selection and breeding in a migratory bird. Proceedings of the Royal Society of London B – Biological Sciences 271: 681– 686
42. Scheifinger H., Winkler H. & Koch E. 2005. Arrival dates of migrating birds in Central Europe and climate variability. Geophysical Research Abstracts 7: 02799.
43. Sicurella B., Musitelli F., Rubolini D., Saino N. & Ambrosini R. 2016. Environmental conditions at arrival to the wintering grounds and during spring migration affect population dynamics of barn swallows *Hirundo rustica* breeding in Northern Italy. Population Ecology 58: 135–145.
44. Szép T., Møller A.P., Piper S., Nuttall R., Szabó Z.D. & Pap P.L. 2006. Searching for potential wintering and migration areas of a Danish Barn Swallow population in South Africa by correlating NDVI with survival estimates. Journal of Ornithology 47: 245–253.
45. Sparks T. & Tryjanowski P. 2007. Patterns of spring arrival dates differ in two hirundines. Climate Research. 35: 159–164.
46. Sparks T. & Braslavská O. 2001. The effects of temperature, altitude and latitude on the arrival and departure dates of the swallow *Hirundo rustica* in the Slovak Republic. International Journal of Biometeorology 45: 212–216.
47. Turner A. 2006. The barn swallow. Poyser, London, UK.
48. Usui T., Butchart S.H.M. & Phillimore A.B. 2017. Temporal shifts and temperature sensitivity of avian spring migratory phenology: a phylogenetic meta-analysis. Journal of Animal Ecology 86: 250–261. doi: 10.1111/1365-2656.12612.
49. Vähätalo A.V., Rainio K., Lehikoinen A. & Lehikoinen E. 2004. Spring arrival of birds depends on the North Atlantic Oscillation. Journal of Avian Biology. 35: 201-216.
50. Visbeck M.H., Hurrell J.W., and Polvani L. 2001. The North Atlantic Oscillation: past, present, and future. Proceedings of the National Acad Sciences. 98 (23) 12876-12877

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