

Research article

Flyway-scale migration phenology identifies mismatches between migration timing and European hunting regulations

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ABSTRACT

The study of bird migration timing is pivotal for the identification of the onset of pre-breeding migration, when, according to the European regulatory framework, the hunting seasons should end following Article 7.4 of the EU Birds Directive. Member States may use different data sources, including citizen science platforms, to determine this onset. Here, we used data from eBird, a citizen science platform, to describe the timing of pre- and post-breeding migration of the Song Thrush (*Turdus philomelos*) across the Western Palearctic. For EU Member States, we compared the onset dates of pre-breeding migration we derived from eBird with those obtained from ringing data published in the Eurasian-African Bird Migration Atlas and with those reported in the EU Key Concepts Documents (KCD). We found high agreement between eBird and Atlas estimates, but substantial differences between KCD-defined onset dates and those identified in the Atlas and this study. This suggests that, in many EU Member States, hunting remains open after the onset of pre-breeding migration, with potential negative effects on breeding populations. This mismatch highlights the limitations of current country-specific definitions and the need for harmonized flyway-scale assessments of migration timing. As required by current EU legislation, hunting closure periods should rely on up-to-date scientific evidence and transparent national data-collection mechanisms. The systematic application of the method presented here to citizen science or ringing data provides a reproducible and standardized approach that can be adopted at the EU level, easily upgradeable as new data become available.

1. Introduction

Seasonal migration towards more favourable environments is a widespread phenomenon among birds (Hahn et al., 2009). Timing (phenology) of migration refers to the ability of birds to coordinate their preparation for migration, arrival and departure times with the seasonal shifts in resource availability along the migration route and at the migration destination (Åkesson et al., 2017; Both et al., 2010; Bourski,

2026; Redlisiak et al., 2021). In addition, the onset and duration of migratory movements significantly influence the conditions birds encounter during migration, as well as upon arrival at breeding or non-breeding sites (Bauer et al., 2016; Sinelschikova et al., 2007), with immediate and carry-over consequences on breeding success, energy demand, and survival (Bell et al., 2024; Briedis et al., 2020; Jenni and Kéry, 2003; Kanerva et al., 2020; La Sorte et al., 2015; Lerche-Jørgensen et al., 2018; Smith and Moore, 2005). Therefore, for

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migratory species, the timing of migratory movements is of outmost importance.

Various types of data are typically used to study migration timing, each with its own advantages, limitations and constraints. Tracking devices provide precise location and timing of records for tagged birds (McKinnon and Love, 2018). However, they are financially costly, logistically challenging, and may affect bird survival and behaviour (including timing of migration) depending on the species (Brlík et al., 2020). The study of migration phenology also relies on ringing data, a long-standing method dating back to 1899 that involves marking birds with metal rings bearing unique alphanumeric codes (Preuss, 2001). This method remains invaluable in ornithological research due to its cost-effectiveness, applicability across all bird species, and suitability for extensive, large-scale studies of bird life histories, including migration routes (Spina et al., 2022), the identification of stopover sites (Cattray et al., 2004), population dynamics (Baillie and Schaub, 2009), and phenology (Hinchcliffe and Tkaczynski, 2025), with insights for conservation planning (Anderson and Green, 2009; Baillie, 1995). However, its effectiveness is limited by highly variable sampling effort and recovery rates across regions and time periods (Korner-Nievergelt et al., 2010). Furthermore, ringing data often provide limited individual information, typically restricted to one marking location and a single re-encounter location. Remote-sensing approaches, particularly weather surveillance radar, can provide broad-scale information on the timing and intensity of migratory movements (Dokter et al., 2018; Van Doren and Horton, 2018). However, weather radar generally detects assemblages of airborne animals, and its taxonomic resolution below broad biological groups remains limited (Matthews et al., 2025). Therefore, radar data alone are not currently suitable for characterizing species-specific migration phenology. Finally, in recent years, there has been growing interest in leveraging public participation via the collection of scientific data through citizen science platforms (Passarotto and Costanzo, 2024). Historically, biodiversity observations have also been collected through bird counts, naturalists' field notes, atlases, and other records, but these datasets often suffer from strongly inconsistent sampling effort, non-random survey locations, and a lack of standardized or quantitative methodologies (Alderson and Sander, 2022; Anderson and Ramirez-Reyes, 2026). Conversely, modern citizen science initiatives allow the collection of vast amounts of data that would otherwise be cost-prohibitive or time-intensive to collect (Bonney et al., 2009; Heim et al., 2020; Weisshaupt et al., 2021). However, common challenges include species misidentification, observer bias toward certain species (Troudet et al., 2017; Tulloch et al., 2013; Tulloch and Szabo, 2012), and spatial and temporal biases in observation locations (Botts et al., 2011; Dennis and Thomas, 2000; Hijmans et al., 2000; Kadmon et al., 2004; Mair and Ruete, 2016). Among existing citizen science platforms, eBird (Sullivan et al., 2009) is one of the most widely used by ornithologists worldwide and provides a globally standardized bird observation database with near-global geographic coverage and free access to data. It enables citizens to report bird sightings, along with details such as species, number of birds, location, age, sex, behaviour, and observation date and time (Wood et al., 2011).

Regardless of the data type, obtaining accurate and reliable information on broad-scale migration timing at the population level throughout the annual cycle is pivotal for effective conservation and management. The Birds Directive (Council Directive 79/409/EEC, now Directive 2009/147/EC) adopted by the European Union (EU) requires EU Member States to prohibit the hunting of migratory birds during their reproductive period, encompassing not only the reproductive season but also their return to the breeding grounds, the occupation of breeding sites, and the post-fledging dependency period of juveniles. In particular, the Court of Justice of the European Union clarified that, in order to ensure full compliance with the Directive, the closing date of the hunting season “*must be fixed in accordance with a method that guarantees complete protection of those species during the period of prenuptial migration*”, therefore ensuring full protection also to early migrants (European

Commission, 2025).

In this context, in 2001 the European Commission published the Key Concepts Document (hereafter KCD), in which each Member State defined the onset of pre-breeding migration for each of the 70 migratory species included in the European list of huntable birds (Annex II of the Birds Directive). The onset of migration is expressed in the KCD using 10-day periods (defined as “decades” in the KCD), corresponding to the first (days 1–10), second (days 11–20), and third (days 21–end) parts of each month. Accordingly, EU Member States identified the 10-day period during which pre-breeding migration was considered to begin for each game species. Large Member States could indicate different 10-day periods for up to three parts of their territory. Only Finland and Spain used this option: Finland divided its territory into North and South, while Spain divided it into North, South, and the Canary Islands. Since 2001, the KCD has been updated and amended several times based on data provided by each Member State. The last version was published in 2025 (European Commission, 2025). However, the current country-by-country approach has produced discrepancies and inconsistencies in the definition of pre-breeding migration onset among neighbouring Member States, as acknowledged in the KCD itself (European Commission, 2025). This suggests that a better coordination of conservation policies across Member States requires the identification of migration periods at the flyway scale rather than at the national scale (Andreotti et al., 2023). An initial step in this direction is reflected in the recently published “Migration Seasons of Hunted Species” scientific module of the Eurasian African Bird Migration Atlas (Bairlein et al., 2022; Spina et al., 2022). In this work, ringing-recovery data were analysed to identify “migration zones”, defined as areas where the first 5% of individuals are actively migrating within the same 10-day period, which was considered as a conservative proxy of the onset date of pre-breeding migration (Andreotti et al., 2023). While this data-driven approach was innovative and offered several advantages, it was limited by its reliance solely on capture-recapture data from the EURING database, which only includes birds captured at least twice during their lifetimes. Therefore, these results should also be checked against different data sources, such as citizen science data (European Commission, 2025). A recent national-scale study focused on the Song Thrush (*Turdus philomelos*) across Italy showed that migration timing estimates obtained from ringing data and citizen science observations were highly consistent (Ambrosini et al., 2023). This agreement between two independent datasets suggests that robust and comparable estimates of migration timing can be obtained from different data sources. These findings provide a basis for harmonizing the definitions of pre-breeding migration onset across EU Member States, including in areas where migratory and resident populations overlap or intermix. They also support a transition from the current country-specific assessments, where migration periods are defined independently by each Member State, toward a flyway-based approach, better suited to account for the trans-boundary nature of bird migration.

The present study aims to describe the timing of migrations of the Song Thrush across the Western Palearctic using data from the eBird platform and to assess whether citizen science data can provide robust large-scale estimates of migration phenology. Specifically, we first modelled the timing of pre- and post-breeding migration of the Song Thrush across its Western Palearctic range. We then compared the estimated onset of pre-breeding migration with the periods reported by individual EU Member States in the KCD and with those identified in the Eurasian-African Bird Migration Atlas (Spina et al., 2022), based on the EURING Data Bank, to evaluate the consistency among alternative data sources.

We selected the Song Thrush because it is by far the most intensively hunted migratory species in Europe (Hirschfeld and Attard, 2017). Furthermore, it is abundant, widespread and with a wide overlap of breeding and wintering ranges, making it particularly suitable for a detailed analysis of migration timing. In addition, the migration timing of this species remains a topic of intense debate. The coexistence of

wintering, resident, and partially migratory populations may hamper the detection of the actual onset of pre-breeding migration in some areas (Andreotti et al., 2022), potentially contributing to inconsistencies among Member States in the timing of migration reported in the KCD (European Union, 2025). Moreover, neighbouring countries often rely on different analytical approaches to identify the onset of the Song Thrush pre-breeding migration and consequently determine the closure of the hunting season. Finally, the Song Thrush may serve as a reference among morphologically similar thrush species that can be misidentified in the field during hunting activities. Under the precautionary principle, the onset of pre-breeding migration of the Song Thrush might be used as the basis for determining hunting season closure dates for such species, although current KCD definitions assign different pre-breeding migration periods to some of them. Therefore, improving our understanding of Song Thrush migration has implications that extend beyond the focal species and may contribute to the management of other thrush species as well.

2. Methods

2.1. Model species

The Song Thrush is a small to medium size, partially migratory passerine bird of conservation and management interest because it is huntable for recreational purposes in most of the EU countries within its wintering area, including Cyprus, France, Greece, Italy, Malta, Portugal, Romania, and Spain. Partial hunting bag data from the hunting season 2014/2015 revealed an annual harvest exceeding 5 million birds in the EU (Hirschfeld et al., 2019). The species is listed in the IUCN red list and in the European red list of birds as 'least concern' (BirdLife International, 2021). In Europe the breeding population has been stable in the last 10 years (PECBMS, 2025) and is estimated at 47–78 million individuals (BirdLife International, 2021). It is a polytypic species belonging to the Turdidae family (Rafinesque, 1815) that includes two sedentary subspecies: *T. p. clarkei* (found in the British Isles, Ireland, north-west of France, Belgium and the Netherlands) and *T. p. hebridensis* (found in the Hebrides and the Island of Skye). There is also a third subspecies, *T. p. philomelos*, the nominate subspecies, breeding in the Palearctic, which is partially migratory (Cramp, 1988). For the post-breeding migration, different breeding populations follow distinct migration routes towards different wintering areas, with the proportion of migrating individuals increasing from south-west to north-east across the breeding range. Populations in Fennoscandia and in north-western Russia migrate to a wide area, spanning from the north-western coast of western Europe to southern France and Spain and till North-west Africa. Populations in central Europe winter in the western and southern Mediterranean and in Italy, while populations in eastern Europe winter on the eastern coast of the Mediterranean as far as Iran (Milwright, 2006; Spina et al., 2022). Conversely, the pre-breeding migration routes of the different breeding populations have not yet been well described, except for the loop migration route described for the central-western Mediterranean (Andreotti et al., 1999). Nevertheless, similarly to the post-breeding migration, different breeding populations are expected to follow distinct migration routes, potentially characterized by different migration phenologies.

2.2. Datasets

2.2.1. eBird

From the eBird Basic Dataset (eBird, 2021; accessed on 20 December 2025), we retrieved records of the Song Thrush in the Western Palearctic region, encompassing the area between 18°W and 66°E longitude, and 15°N to 72°N latitude, spanning the years 1900 to 2025. Only reviewed data were retrieved, and no further filtering was applied, as we were interested in the location and date of observations of Song Thrushes, regardless of whether they came from a complete checklist or occasional

observations and whether birds were classified as moving or not, as this classification is not always reliable.

The number of observed individuals was considered whenever the record included this information. Records indicating only the presence of the species were conservatively considered as reports of one individual only. To remove potentially duplicate records from different observers reporting the same birds, the latitude and longitude of all records were rounded to two decimal places. When multiple observations occurred at the same rounded coordinates on the same date, only the record with the highest number of individuals observed was retained. This step reduced the original dataset from 1,588,049 to 1,321,421 records. Importantly, eBird allows users to enter the observation of multiple individuals in the same record, which, in our dataset, resulted in up to 8000 Song Thrushes recorded in a single observation. Such a substantial number of individuals observed in a single day may bias the results of these analyses (McKinlay et al., 2025). To limit this potential effect, we adopted the same method used in McKinlay et al. (2025), and allowed a maximum value of 100 individuals per observation for the analyses. In practice, whenever the number of observed individuals entered in a record of the eBird dataset was larger than 100, it was set to 100. Previous analyses showed that this arbitrary threshold has only a negligible effect on the estimated minimum onset date of pre-breeding migration (McKinlay et al., 2025). The final dataset used for the analyses included 2,990,671 individual observations of Song Thrushes.

2.2.2. Eurasian African Bird Migration Atlas

The 10-day period of pre-breeding migration onset was obtained from the scientific report "Timing of migration of huntable species" (Bairlein et al., 2022), available in the Eurasian African Bird Migration Atlas (Spina et al., 2022). In this report, the ringing data from the EURING databank were analysed with the same analytical method that we used in the present study (described below). While the map in the report covers most countries within the European Political Community (EPC), for our comparisons we only focused on data from the EU Member States.

2.2.3. Key Concept Document

The 10-day period of pre-breeding migration onset of the Song Thrush for each Member State was obtained from the last version of the KCD published by the European Commission (European Union, 2025).

2.3. Procedure for the analyses of the timing of the pre- and the post-breeding migration on eBird data

The method builds upon the approach initially introduced by Ambrosini et al. (2014), later adapted to suit partially migratory species by Ambrosini et al. (2023) and further refined by McKinlay et al. (2025). The approach is based on modelling the seasonal accumulation of records within spatial cells. For fully migratory species, individuals are assumed to be absent from a cell before migration begins; therefore, the onset of migration can be estimated on the calendar date at which a predefined proportion of records is reached (Ambrosini et al., 2014). For partially migratory species, including those whose non-breeding range overlaps the study area, this assumption does not hold because some individuals may already be present before migration starts. In these cases, migration timing is inferred from changes in the rate of accumulation of records, assuming that detection probability is approximately constant when birds are stationary, and increases during migratory movements (Ambrosini et al., 2023; McKinlay et al., 2025). Consequently, the onset of migration is identified as the date at which the observation rate at a cell departs from that observed under stationary conditions, regardless of whether this reflects the arrival of new migrants or the departure of local individuals (Ambrosini et al., 2023; McKinlay et al., 2025). In the present study, the study area was divided into 3° by 3° latitude-longitude grid cells. Cells with fewer than 20

records collected on fewer than 10 different days in a year—the minimum sample size required—were merged with neighbouring cells (detailed information can be found in [Ambrosini et al., 2023](#); [McKinlay et al., 2025](#)). This process resulted in cells of varying sizes inversely related to data density. Preliminarily, spatially isolated records were identified by a geographical clustering algorithm that identifies clusters of records that are less than the minimum sample size required at a cell and are more than 400 km from the nearest record. Those records are then removed to avoid creating excessively large cells. Importantly, records from all years were included, regardless of observation year. The daily number of records at a cell was first converted into the proportion of records per calendar date, then into cumulative proportions for each date and cell. These were modelled using a binomial Generalized Linear Mixed Model (GLMM) with a complementary log-log link function and an exponential spatial covariance structure to account for spatial autocorrelation. Day-of-the-year (centred around its mean) was the only fixed effect, while cell ID served as a random effect, with a random slope for day-of-the-year within each cell (i.e. random intercept and slope model). The choice of the initial day-of-the-year for calculating cumulative numbers of records is pivotal in this procedure, and depends on the Song Thrush annual life cycle. In particular, this choice should target the calendar dates when individuals were mostly stationary in their wintering grounds ([Cramp, 1988](#)). The estimate of the calendar date corresponding to a given proportion of records is possible by inverting the GLMM model. The dates estimated for each cell were then spatially interpolated over a $3^\circ \times 3^\circ$ grid using inverse distance weighting with Shepard's method ([Shepard, 1968](#)), validated via leave-one-out cross-validation to select the best power function for interpolation. This interpolated map was subsequently downsampled to a $0.6^\circ \times 0.6^\circ$ resolution (i.e. five times smaller than the initial resolution) using a bilinear method. Because some parameters in this procedure, including the starting date for data cumulation, were arbitrarily chosen, the analysis was repeated across 27 parameter combinations ([Table S1](#)). This generated 27 maps, each predicting different proportions of arriving migrants (PRED values in the Supporting Information, [Table S1](#)). Conservatively, we defined the onset of pre-breeding migration as the date by which 5% of migratory individuals have been observed, as done in previous works ([Ambrosini et al., 2023](#); [McKinlay et al., 2025](#); [Spina et al., 2022](#)). These maps were then averaged to produce a final map, and a sensitivity map reflecting the effect of parameter choices on predictions was also created. For the analyses of post-breeding migration, calendar dates were determined by counting backward from the time when individuals are stationary. Therefore, this method identifies the dates after which specific proportions of individuals are observed ([Ambrosini et al., 2014, 2023](#)).

Pre- and post-breeding dates of migration are then converted into 10-day period of migration similarly to the KCD, and reported in the maps as isochrones, i.e. areas where the migration date is the same.

All the analyses were performed in R 4.4.3 ([R Core Team, 2025](#)) and the models fitted using the `glmmTMB` package ([Brooks et al., 2017](#)).

2.4. Extraction of migration dates from eBird and from the Atlas maps

To determine the onset and the median dates of pre-breeding migration, we clipped the eBird and the Atlas maps, excluding all marine areas. Using the Python `numpy` module, we then extracted the minimum value from the raster for each country, representing the earliest date when the first 5% of individuals were observed, or the median date of observation of pre-breeding migration. As the modelling of the post-breeding migration was not included in the scope of the Atlas research module, we could apply a similar method regarding post-breeding migration only to the eBird dataset. Therefore, for post-breeding migration, we clipped the eBird raster maps showing the date when 50% or 5% of individuals are still expected to be migrating. In this case, we extracted the median and the maximum value from the raster, representing the median and the end date of post-breeding

migration, respectively. We then converted the selected migration dates into the corresponding 10-day period. To assess the range of standard errors for both migration periods, we clipped the respective standard error maps, removed sea areas, and extracted the maximum values from the standard error layers.

2.5. Repeatability analysis of pre-breeding migration onset across the eBird, Atlas and KCD datasets

We assessed the repeatability of the modelled dates of pre-breeding migration onset based on the eBird and the Atlas maps with an ANOVA-based repeatability analysis ([Nakagawa and Schielzeth, 2010](#)). We used the same approach to estimate the repeatability of the 10-day periods of pre-breeding migration onset, first with those derived from eBird and KCD and then with the ones from Atlas and KCD. All analyses were performed in R 4.4.3 ([R Core Team, 2025](#)).

3. Results

3.1. Pre-breeding migration timing according to the eBird dataset

The timing of pre-breeding migration of the Song Thrush across Europe modelled using the eBird dataset is presented in [Fig. 1a](#) and [b](#), representing the calendar dates when 5% and 50%, respectively, of encounters of migratory individuals are expected to occur during this phase. Maps relative to different proportions of encounters (1% and 10%) are available in [Fig. S1](#).

Broadly, pre-breeding migration progresses from the south and south-west towards the north direction ([Fig. 1a](#)). In particular, the onset of migration begins in the first 10-day period of January (JAN1) in Afghanistan, Arabian Peninsula (except Bahrain), Canary Islands, Cyprus, Eritrea, France (including Corsica), Greece, Iran, Iraq, Israel, Italy, Jordan, North Africa, Palestine, Portugal, South Spain, Malta. In the second 10-day period of January (JAN2), migration onset progresses to Albania, Andorra, Bahrain, Lebanon, Northern Spain, Syria, and Turkey. The last country where the onset of migration takes place is Finland, where the migration occurs in the last 10-day period of March and the first 10-day period of April in the South and the North of the country, respectively.

The maps of pre-breeding migration onset ([Fig. 1a](#)) also shows a band, from FEB1 to FEB3, where isochrones are denser, dividing the oceanic and Mediterranean areas from the continental areas in the northern part of the Western Palearctic. These two areas show two different migration phenologies. In the first one, characterized by milder winters, the Song Thrush starts migrating between JAN1 and JAN3, while in the second one, where winters are harsher, the migration onset is much later, between MAR1 and MAY1. The maximum standard error in all 74 countries ranged from 0.12 days (Estonia) to 3.68 days (Russia).

Similarly to the onset of pre-breeding migration, the median date of migration—defined as the date when 50% of individual encounters occur—is first reached in JAN3 in Oman, Saudi Arabia, and Yemen. This is followed by Afghanistan, Egypt, Greece, Iran, Iraq, Italy, Kuwait, Morocco, Portugal, Southern Spain, and United Arab Emirates. Finally, the latest countries to experience the bulk of migration are Estonia, Latvia, Lithuania, and South Finland, where it occurs during APR3, and, lastly, North Finland, where it occurs in MAY1. The maximum standard error in all 74 countries ranged from 0.02 days (Estonia and South Finland) to 1.86 days (Russia).

3.2. Post-breeding migration timing according to the eBird dataset

The timing of post-breeding migration of the Song Thrush across Europe modelled according to the eBird dataset is presented in [Fig. 1c](#) and [1d](#), representing the calendar dates when 50% and 5% of individuals, respectively, are still on migration to their wintering grounds. Maps relative to different proportions of encounters (10% and 1%) are

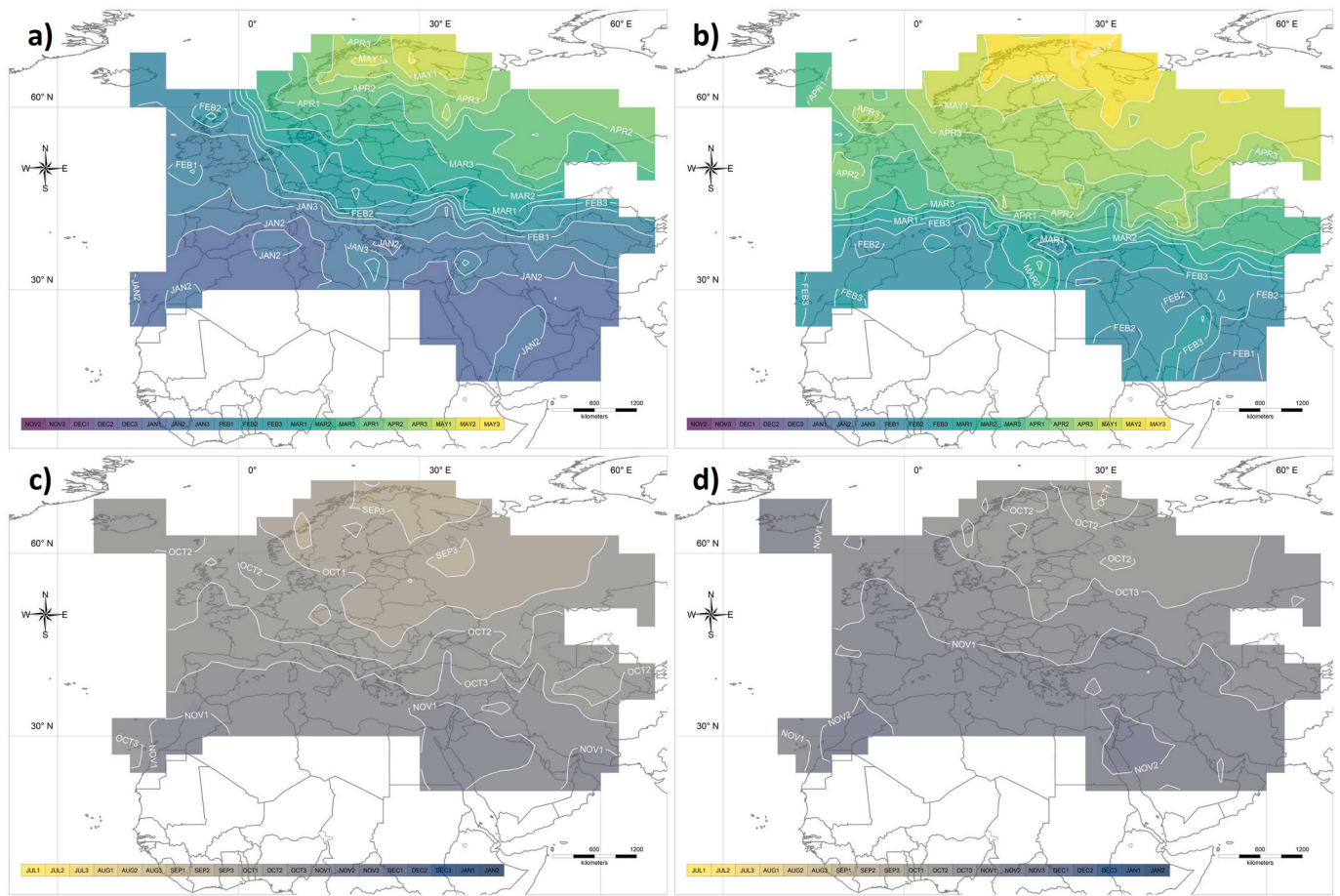


Fig. 1. Migration dates of Song Thrush in Europe as determined from analysis of eBird data. a) onset of pre-breeding migration; dates indicate when 5% of observed individuals are expected to be on migration. b) median dates of pre-breeding migration; dates indicate when 50% of observed individuals are expected to be on migration. c) median dates of post-breeding migration; dates indicate when 50% of individuals are expected to still be migrating. d) end of post-breeding migration; dates indicate when 5% of individuals are expected to still be migrating. Isochrones indicate regions where the average migration date is the same. For example, in map a) in southern Spain, the pre-breeding migration onset date is during the first ten days of January, whereas in northern Spain, it is during the second ten days of January. The months are divided into 10-day periods, or 'decades', as defined in the EU Birds Directive Key Concepts Document (e.g., JAN1, JAN2, JAN3). The labels on isochrones indicate the first day of each decade, so JAN1 means "January 1", JAN2 means "January 11", and JAN3 means "January 21", and so forth.

available in Fig. S1.

Both maps show a general north-to-south pattern. The median date of post-breeding migration across Europe is much more homogeneous than that of the pre-breeding one. Indeed, it shows a gradient from SEP3 in Belarus, Estonia, Latvia, and North and South Finland, to NOV1 in Canary Islands, Cyprus, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, North Africa (except Tunisia and Libya), Oman, Palestine, Saudi Arabia, Syria, and United Arab Emirates. The standard error in all 74 countries ranged from 0.04 days (Estonia) to 2.26 days (Saudi Arabia).

Finally, the last 5% of individuals are still in Estonia, Latvia, and North and South Finland in OCT2, and in NOV2 5% of individuals have yet to arrive in Algeria, Canary Islands, Cyprus, Egypt, Iraq, Israel, Jordan, Lebanon, Morocco, Saudi Arabia, Syria. The standard error in all 74 countries ranged from 0.25 days (Estonia) to 1.59 days (Turkey).

3.3. Comparison of pre-breeding migration timing across the three datasets

3.3.1. eBird vs Eurasian African Bird Migration Atlas

In this analyses, the Canary Islands were excluded due to the lack of data in the Eurasian African Bird Migration Atlas. In addition, Spain and Finland were divided into northern and southern regions according to

the KCD classification. The repeatability between the minimum dates of migration onset in each of the EU Member States estimated from the present analyses and the Eurasian African Bird Migration Atlas (Fig. 2, Table S2) is high (repeatability = 0.944, $F_{28,29} = 34.44$, $P < 0.001$).

3.3.2. eBird vs Key Concepts Document

The comparison of the estimated 10-day period of migration onset based on the eBird dataset and on the KCD (Fig. 3, Table S2) revealed a match in 9 out of 29 Member States or subdivisions thereof (31%). The KCD indicated an earlier onset of migration than the eBird-based onset of migration in three States (or parts of them; 10%). Specifically, the KCD was one 10-day period earlier than our analyses in the northern part of Finland and Hungary, while it was two 10-day periods earlier in Slovakia. Conversely, in 17 out of 29 Member States or subdivisions thereof (58.6%), the KCD reports the onset of migration later than what was indicated by the eBird dataset, spanning from one to six 10-day periods later. Overall, these results indicate a low repeatability in the 10-day period of the migration onset proposed in the KCD vs those calculated on the eBird data (repeatability = 0.491, $F_{28,29} = 2.897$, $P = 0.003$).

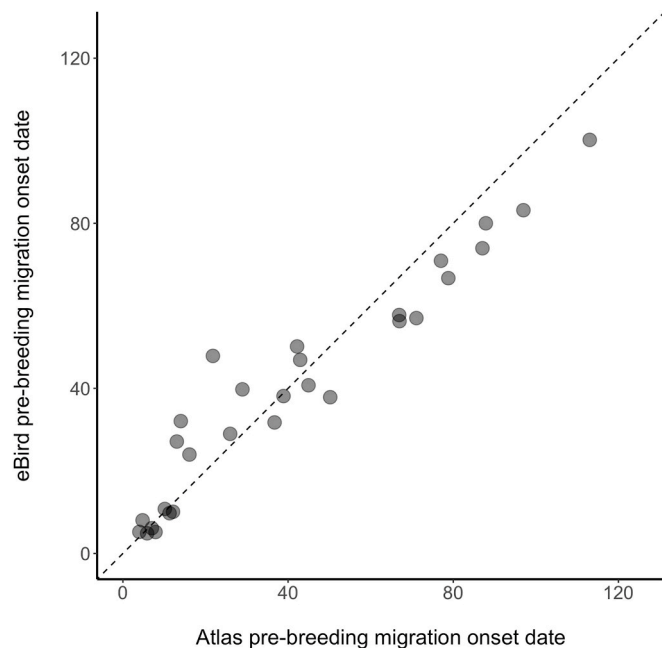


Fig. 2. The onset dates of pre-breeding migration derived from our analyses with eBird (when 5% of individuals are expected to be on migration) is plotted against the onset dates of pre-breeding migration from the Eurasian African Bird Migration Atlas, based on ringing data (when 5% of individuals are expected to be on migration). Dates are reported as days from 1 January (1 January = 1). The dashed line represents the 1:1 relationship.

3.3.3. Eurasian African Bird Migration Atlas vs Key Concept Document

In the following results, Canary Islands were excluded due to a lack of data in the Eurasian African Bird Migration Atlas. The comparison of migration onset based on the EURING dataset and on the KCD (Fig. 3, Table S2) revealed a match in only five out of 29 Member States or subdivision thereof (17.2%). According to the KCD, the Song Thrush starts the pre-breeding migration one 10-day period earlier as compared to the EURING dataset in five States, two 10-day periods earlier in one State, and three 10-day periods earlier in two States (17.2%, 3.4%, and 6.9%, respectively). Conversely, according to the KCD the Song Thrush starts the pre-breeding migration one 10-day period later as compared to the EURING dataset in four States, three 10-day periods later in five States, four 10-day periods later in four States, five 10-day periods later in one State, six 10-day periods later in one State, and seven 10-day periods later in one State (13.8%, 17.2%, 13.8%, 3.4%, 3.4%, and

3.4%, respectively). Overall, these data indicate a low repeatability in the 10-day period of the migration onset proposed in the KCD vs those calculated on the Migration Atlas (repeatability = 0.453, $F_{28,29} = 2.656$, $P = 0.005$).

4. Discussion

This work examined the migration timing of the Song Thrush with the dual goal of providing a reliable estimate of migration timing at the flyway scale and evaluating the potential of large-scale citizen-science data to address questions of relevance for both migration ecology and wildlife management. This represents a particularly challenging task for a species in which resident and migratory individuals coexist across large portions of its range, resulting in substantial spatial and temporal overlap between migratory and non-migratory birds. To address these objectives, we first described the timing of both pre- and post-breeding migration across most of the Western Palearctic using citizen science data. We then focused on the EU Member States to compare the results obtained with the same statistical method from two different datasets: citizen science and ringing data published in the Migration Atlas. Lastly, we compared migration timing estimated from these two datasets with the migration period currently reported in the KCD.

The onset of pre-breeding migration of the Song Thrush modelled using the eBird dataset is heterogeneous across countries, with different migration patterns suggested by the maps (Ambrosini et al., 2014). The pre-breeding migratory routes of this species have not yet been fully characterized (Andreotti et al., 1999). However, maps show that birds start migrating in JAN2 along the Spanish and French Atlantic coast towards Normandy and then towards southern England and the British Isles. This pattern of advancement of migration can also be observed in the Atlas (Spina et al., 2022). Birds appear also to start migrating in JAN1 in north-west Africa and the Western Mediterranean basin, proceeding then toward the north-east through Sardinia. Finally, migration starts in JAN1 also in Greece and then proceeds towards eastern Europe. This last pattern is not clearly indicated by ring recoveries (Spina et al., 2022), maybe because of the limited ringing effort in areas such as North Africa and the Middle East.

Our results also revealed a high density of isochrones along a band approximately corresponding to the separation between the oceanic and Mediterranean climate areas of Europe from those with a continental climate. Migration timing and distance combined might contribute to shaping this band. Specifically, individuals breeding in southern areas with milder climates may start pre-breeding migration earlier (to obtain better territories) than those migrating to colder northern regions, where the risk of encountering adverse weather earlier in the season is higher. Differences in migratory behaviour among populations could

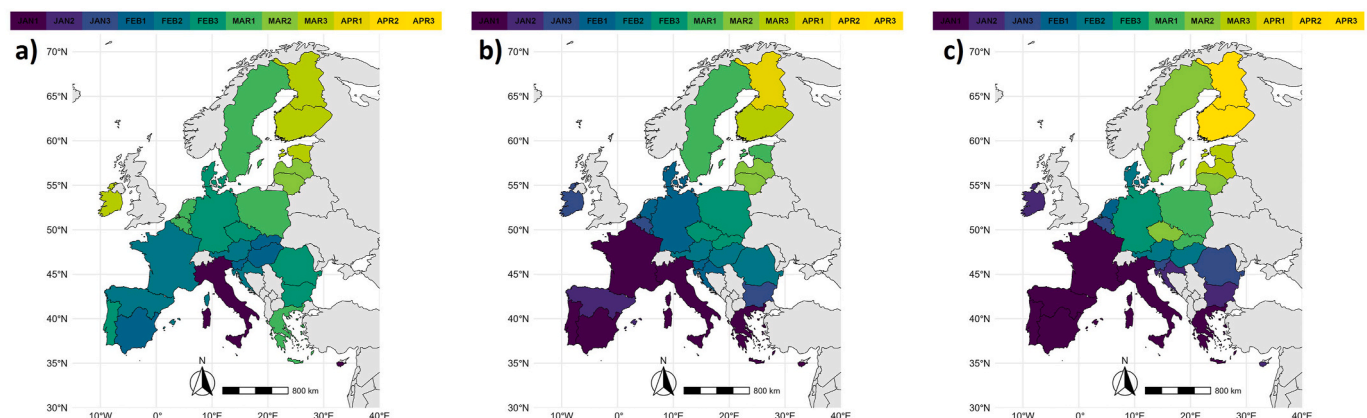


Fig. 3. Onset of pre-breeding migration of the Song Thrush in the Member States according to a) the KCD (European Commission, 2025); b) the eBird dataset (present work); c) the “Migration seasons of hunted species” module (Bairlein et al., 2022) of the Eurasian African Bird Migration Atlas. Finland and Spain are divided into two and three parts, respectively, as reported in the KCD. The Canary Islands are not shown because migration onset is not defined in the KCD.

also explain the presence of this band. Indeed, it may reflect a temporal segregation between wintering populations that move shorter distances within the warmer Mediterranean or Atlantic climates and those migrating longer distances to breed in more continental and colder climates. This hypothesis is supported by the observation that the band approximately coincides with the boundary between areas where the Song Thrush is present all year round, and areas where it only breeds (BirdLife International, 2018).

While the onset of pre-breeding migration spans over a period of 14 10-day periods across the Western Palearctic, the end of post-breeding migration of the Song Thrush is more homogenous across countries, being concentrated within just 5 10-day periods. Indeed, the last post-breeding movements (i.e. when 5% of individuals are still migrating) occur between OCT1 in north-east Europe and NOV2 in northern Africa and the Middle East. Additionally, the band of dense isochrones dividing areas with oceanic/Mediterranean and continental climates is not present in the post-breeding migration map. This homogeneity likely arises because Song Thrushes in different areas tend to leave at the same time, a pattern that might be explained by the fact that post-breeding migration is less tied to a tight schedule compared to pre-breeding migration (Lawrence et al., 2022). Information on post-breeding migration timing may provide important, yet so far overlooked management information. These movements are largely ignored in the regulation of hunting periods, as the current European legal framework (Birds Directive, article 7.4) focuses exclusively on the timing of pre-breeding migration and the overall length of the breeding season. In areas where species are regularly occurring during winter, the interval between the date when 95% of migrants have already arrived from post-breeding migration and the date when the first 5% have departed for pre-breeding migration can be used to define the duration of the stationary wintering period. Such a period is particularly sensitive for this species, as the mortality due to hunting cumulates on stationary populations, and may exceed the quantity that defines a sustainable hunting pressure, i.e. the number of harvested individuals that could be naturally compensated by a reduction in mortality due to other natural factors. For a species that shows moderate to high connectivity (Spina et al., 2022), this mortality, if it becomes excessive, may directly translate into a decline in the corresponding breeding area. This implies that any sustainable harvesting policy should be defined at a supranational level, considering the whole pattern of migratory connectivity of a species and the timing of the different phases of its annual life cycle. A detailed knowledge of post-breeding migration phenology is also crucial to define the onset of the hunting season for species with local breeding populations. Indeed in areas where a partial migrant like the Song Thrush is present year-round, allowing hunting before the arrival of a substantial number of migrants may determine an unsustainable mortality for the local populations, with a consequent decline.

When we compared the pre-breeding migration onset modelled either on citizen science or ringing data, we found a very high repeatability. This suggests a strong biological pattern reflected by both data sources. The consistency in the timing of migration across two different datasets modelled according to the method proposed by Ambrosini et al. (2023, 2014) has also been demonstrated in a previous study which analysed the migration timing of the Song Thrush and 22 other game species in Italy (McKinlay et al., 2025). Therefore, this study conducted on a broader spatial scale further demonstrates the suitability of citizen science data for assessing migration timing. Indeed, despite the well-known limitations of citizen science data (Gorleri and Areta, 2022), birdwatchers can generate a large volume and spatial coverage of data in a short time and at a low cost. In addition, both citizen science and ringing data are affected by spatial and temporal biases, caused by the uneven distribution of ringing and birdwatching effort. The close match of the estimated timing of migration onset obtained from these two different datasets is particularly important in Europe, where Member States are required to identify the starting date of pre-breeding migration to determine the closing of the hunting season. Following the Birds

Directive, the start of pre-breeding migration can be estimated by comparing different data sources from different regions of the European Union. These data include ring recoveries, tracking and citizen science data. Therefore, our study further confirms that citizen science data are suitable for this goal, since the onset of migration for 86% of Member States does not differ of more than one 10-day period from that derived from the Migration Atlas.

This is not the case when we compared 10-day periods calculated using either ringing or citizen science data with the 10-day periods defined by the KCD (Fig. 3). The migration onset dates defined by the KCD tend to be later than those estimated by the other sources for nearly all countries, especially in the Mediterranean area. Following the revision process carried out in 2021, nine Member States postponed their estimate by one (8 Member States) or two (1 Member State) 10-day periods (Andreotti et al., 2023). This revision resulted in a further increase in the mismatch between the migration onset defined in the KCD and that observed from citizen science and ringing data. This is particularly concerning as analyses based on long-term data collected over the course of 50 years across Europe on adult Song Thrush demonstrated a clear advance in the onset of migration by 19 days in males and 12 days in females (Redlisiak et al., 2021). Remarkably, among the eight Member States where the Song Thrush is listed as a huntable species in the Annex II - Part B of the Birds Directive 2009/147/EC, only Italy and Cyprus indicated KCD dates for the onset of the pre-breeding migration that are coherent with those obtained from citizen science and ringing data analyses. Conversely, in the remaining six countries (France, Greece, Malta, Portugal, Romania, and Spain) the hunting season remains open until a date that is later than the onset of pre-breeding migration as estimated by the present analyses and the Migration Atlas, hence potentially leading to the killing of individuals *en route* towards their breeding quarters. Additionally, in some cases, the references provided by the Member States to justify the reported pre-breeding migration periods are outdated or not reported at all. This is in contrast with the recommendation of a definition of the onset of pre-breeding migration based on the most up-to-date scientific evidence and on transparent national data-collection mechanisms (European Commission, 2025). To overcome this issue, the systematic application of the method described by Ambrosini et al. (2023) to citizen science or ringing data, as proposed in the present paper and the Migration Atlas, can provide a reproducible and standardized approach that can be adopted by any Member State and that can be readily updated on a regular basis as new data become available. Now that information on bird observations is available on electronic centralized databases on a continental scale, rather than in separate physical archives scattered across different countries, this process may be more efficiently conducted directly by the European Commission. This will overcome one of the main criticisms of the application of the information reported in the KCD, i.e. the inconsistency of migration onset dates among neighbouring countries, which may at least partially derive from the different hunting status of the species (Andreotti et al., 2023).

To conclude, the present work, using almost 3 million observations, further demonstrates the suitability of properly analysed citizen science data to address pivotal questions in conservation ecology. Indeed, the proposed method can help define an agreed methodology among different Member States that goes beyond the current national-level approach and towards a flyway-based framework, the latter with a stronger coherence with bird migration as a natural phenomenon that ignores political boundaries. This can ultimately lead to a more biologically coherent and effective protection of birds during their pre-breeding migration, as required by the EU Birds Directive.

CRedit authorship contribution statement

Alessandra Costanzo: Writing – review & editing, Writing – original draft, Project administration, Formal analysis, Data curation, Conceptualization. **Susan Ellen McKinlay:** Writing – review & editing, Writing

– original draft, Formal analysis, Data curation. **Alessandro Andreotti**: Writing – review & editing. **Lorenzo Serra**: Writing – review & editing. **Fernando Spina**: Writing – review & editing. **Niccolò Fattorini**: Writing – review & editing. **Franz Bairlein**: Writing – review & editing. **Stephen Baillie**: Writing – review & editing. **Simona Imperio**: Writing – review & editing. **Roberto Ambrosini**: Writing – review & editing, Methodology, Formal analysis, Data curation, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jenvman.2026.131105>.

Data availability

Data are from publicly available sources. R code is provided as supplementary material.

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