EURASIAN-AFRICAN BIRD MIGRATION ATLAS

Executive Summary

EURING
The European Union for Bird Ringing
CMS
MINISTERO DELL'AMBIENTE

Eurasian-African Bird Migration Atlas - Executive Summary

This is an Executive Summary for the online Eurasian African Bird Migration Atlas. Visit https://migrationatlas.org to view interactive migration maps for 300 species together with full results of the four research modules.

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ACKNOWLEDGEMENTS AND CONTRIBUTIONS

This project was undertaken by EURING with support from CMS and funding from the Government of Italy. We would particularly like to thank Juan Arizaga (Spain), Davor Cikovic (Croatia), Henk van der Jeugd (Netherlands), Dorian Moss (UK), Didier Vangeluwe (Belgium), Justin Walker (UK), Sarah Davidson (USA), Mark Hammond (UK), Daniel Higgins (UK), William Skellorn (UK), Olatz Azipura (Spain), Frederic Jiguet (France) Boris Nikolov (Bulgaria), Henk Levering (Netherlands), Jacquie Clark (UK), Ian Woodward (UK), Tom Romdal (Denmark), Frank Mattig (Germany) and Marco Barbieri (CMS) for their contributions. The project would not have been possible without all of the EURING Ringing Schemes and Movebank tracking studies who supplied the data. Full acknowledgements and pages on each of the contributing Ringing Schemes are available at https://migrationatlas.org/contributors

SUGGESTED CITATION:

Spina F, Baillie SR, Bairlein F, Ambrosini R, Fattorini N, Fiedler W, Franks S, Funghi C, Thorup K, (2022). Eurasian-African Bird Migration Atlas - Executive Summary. 44 pages.

LAYOUT

Dunia Sforzin, CMS Secretariat

COVER IMAGE:

White Stork in flight © pixabay.com

ISBN: 978-3-937429-38-0

Copies of this publication are available from the CMS website:
https://www.cms.int/en/publication/eurasian-african-bird-migration-atlas-executive-summary

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1. Introduction

1.1 Migration and the Conservation of migratory species

Migration is an adaptive response to the variations in time and space of the ecological conditions that migratory species are dependent on. Each migrant will track such conditions regardless of the distance to be covered in order to reach suitable sites and habitats. Migration is a vital component of a migrant's annual cycle and successful completion of long-distance movements is often a pre-condition for individual survival. Migration can only be accomplished when animals are able to access the different sites and habitats they are adapted to rely upon along their pathways, from the breeding quarters, through the passage and staging areas, to the non-breeding sites. Through their fascinating journeys, migratory animals connect continents, countries, sites and habitats. They ignore political boundaries and only follow the routes that meet their ecological requirements, leading them through sites and habitats that are often distributed across many different countries.

1.2 CMS and international cooperation for the conservation of migratory species

Conservation and management of migratory species is particularly challenging given the geographical scale of their movements so international cooperation and coordination across the migratory range is generally required. Each component of a migratory system is important, from breeding, to passage, staging and feeding areas; the loss or degradation of any of these different components will affect the migratory cycle and potentially the demography and conservation status of the populations concerned. A shared responsibility in the conservation, management and sustainable use of habitats and sites, as well as of populations, is therefore key to ensuring the survival of migratory species. Effective international governance of the conservation and management of migratory species is therefore required to properly take into account their spatio-temporal distributions and to identify and implement the most efficient policies ensuring their survival and that they retain a favourable conservation status.

The Convention on the Conservation of Migratory Species of Wild Animals (CMS) is a global multilateral environmental agreement that addresses the conservation and sustainable use of migratory animals and their

Picture 1. Common Kingfisher (Alcedo atthis) caught for ringing at Redgrave and Lopham Fen, UK. An intra European migrant with some resident populations for which knowledge of movements is based mainly on ring recoveries. © Stephen Baillie

habitats. CMS brings together the States through which migratory animals pass, the Range States, and lays the legal foundation for internationally coordinated conservation measures throughout a migratory range. Decisions and actions under CMS are based on the best available science. From this perspective, with a view to improving and making readily available knowledge of the different migratory systems and patterns across the groups of species of relevance for the Convention (including terrestrial and marine mammals, birds, marine and freshwater fish, aquatic reptiles and insects), the CMS Conference of the Parties called for the development of a Global Atlas of Animal Migration (GAAM). This is indeed a complex task, given the huge diversity of patterns of movement across taxonomic groups and the different level of knowledge of migratory systems across geographic areas. With such diversity in mind, and with a view to taking advantage of specific opportunities for collaboration with researchers and research institutions, the GAAM is being developed using a modular approach, delivering individual modules for specific groups of animals and geographic regions.

1.3 The Eurasian-African Bird Migration Atlas

The Eurasian-African Bird Migration Atlas (Atlas) is a major effort to contribute to the GAAM based on the opportunity represented by the unique data on a large number of species, which has not previously been synthesized in a single analytical product at this scale. Efforts to make this atlas a reality have been in the making for many years, but have taken a long time due in part to the huge complexity of the task. The project was finally made possible by the generous support of the Government of Italy, with a pledge of 1M Euros to CMS granted in 2017 by the Ministry of the Ecological Transition (formerly Ministry of the Environment, Land and Sea). The Atlas has been developed and compiled by the European Union for Bird Ringing (EURING). It involved work by researchers from 10 different institutions and data gathered by over 50 different organizations.

1.4 Birds as symbols of animal migration and unique examples of movement ecology studies and citizen science

Thanks to their vast distribution across virtually any habitat on Earth, their beauty, colours and melodious songs, birds are the most popular and best-known group of migratory species, with millions of citizens enjoying birding around the world. Many volunteer ringers and birdwatchers also collect large-scale and long-term data on migratory bird populations. In terms of movements,

Picture 2. Ringed European Turtle Dove (Streptopelia turtur) marked with an Argos satellite tag on Comino Island, Malta. Knowledge of movements is based on a combination of ring recoveries and tracking data. © Nicholas Galea

birds offer unique opportunities to admire migration in action across the globe, with bottleneck passage areas crossed by diurnal migrants and amazing concentrations of individuals staging at key sites on all continents. Birds also provide a unique demonstration of how large-scale marking of individuals can be used to describe migration strategies and document movement patterns. For over 120 years, leg rings have been used to mark hundreds of millions of individuals and discover, through subsequent encounters of single birds (usually referred to as recoveries), the movements and life histories at the level of individuals, populations and species. Bird ringing (or banding as it is known in the Western Hemisphere) represents a very positive example of largely Citizen Science based research that operates on a global scale. The first bird (a Starling, *Sturnus vulgaris*) was ringed by Hans Christian Cornelius Mortensen in Viborg, Denmark on June 5th 1899. Ringing is generally organized by national bird ringing schemes, and since 1963 schemes operating in Europe have been coordinated by the European Union for Bird Ringing (EURING). In another unique achievement at the global level, EURING defined and published the EURING Exchange Code in 1966, allowing easy data transfer between schemes and facilitating data analysis. The EURING Data Bank (EDB) was established as a central repository for European ringing recovery records in 1977. Over the last three decades, many European Ringing Centres within EURING have published national migration atlases, analysing data on the migrations and movement of birds encountered within individual countries.

1.5 Atlas scope and contents

This is the first attempt to produce a migration atlas covering the huge geographical area represented by two continents, encompassing the whole flyway between Eurasia and Africa. Movements in time and space of millions of birds are mapped and analysed, each based on ringing and recovery locations, with the results drawing on data gathered over more than a century. Another unique feature of the Atlas is that it complements movement data provided by ring recoveries with detailed migration patterns of individual birds provided by a range of recent tracking technologies. Similar to the EURING Data Bank and hosted by the Max Planck Institute of Animal Behavior, since 2007 Movebank has provided an online platform that helps researchers and wildlife managers worldwide to manage, share, analyze and archive animal movement data. For over 100 species in this Atlas, the online mapping tool overlays movement patterns based on large numbers of ringed individuals, each documenting only a part of the migratory journey, with tracks offered by electronic devices, principally satellite transmitters, GPS-GSM tags or geolocators, providing the most complete information available on the migration routes of individuals. In this way, the atlas complements the contents of the EURING databank ("traditional" ringing method, offering information from an extremely large array of species, huge numbers of marked individuals, most extended geographical scope, key related information on conditions and circumstances of recovery, long historical coverage of data), with detailed data on migratory movements from Movebank (smaller number of species and individuals and smaller and less intensively sampled geographical scope). This complementarity represents a unique feature of this atlas and a positive example that could potentially be applied to different taxonomic groups within the context of the CMS GAAM.

Another key feature of this atlas is represented by the results of analyses addressing different aspects of bird migration and relationships between man and birds, provided by four research modules. These modules provide practical examples of the many potential policy-relevant applications of the Atlas as an information source. In particular, in terms of bird migration patterns, strategies and adaptations, one module concentrates on migratory connectivity and another on long-term changes in migration patterns, that could be caused, for example, by global climate change. Looking at interactions between man and migratory birds, with reference to key aspects of sustainable harvesting, one module reports on innovative modelling of the onset of return migration of hunted species across Europe in relation to the EU Birds Directive, while a large-scale and long-term analysis of patterns of intentional killing of birds is the subject of a further module.

This executive summary aims to provide an overview of the contents of the Atlas, and considers how the scientific information and tools provided can support the work under CMS and the various conservation instruments developed under the Convention.

2. Migration and movements of European bird populations

2.1 Bird ringing data and their use for studying migration

Scientific bird ringing involves the marking of birds with metal rings inscribed with a unique serial number and a reporting address. Subsequent reports of the birds from qualified ringers or members of the public provide information about movements, survival and other aspects of their biology. Many birds are ringed as nestlings or chicks which has the advantage that all records of these individuals are of known age. However the majority are ringed as full-grown after being captured in traps, mist-nets, cannon-nets or other appropriate devices by qualified bird ringers. Most such birds are aged, at least as to whether they are juveniles, first years or adults, and if possible their sex is also determined. Thus in this Atlas it is in most cases possible to distinguish first-year, immature and adult age categories, and to present maps that distinguish males and females. In addition to standard metal rings many individuals also carry various forms of colour marks that allow them to be identified by observers in the field, greatly increasing the amount of information generated. However, not all data from colour marking is held by national ringing centres. Nowadays a small proportion of birds are fitted with electronic tracking devices that allow their movements to be studied in great detail (see section 2.2 below).

This Atlas, in common with the many National Migration Atlases which have been published previously, is based primarily on ring recoveries. These comprise all records of ringed birds that are subsequently found dead or injured by members of the public or by ringers. They also include all live encounters more that 10km from the place of ringing, many of which involve recaptures by other ringers (sometimes referred to as controls). They do not normally include local recaptures by ringers or local resightings by those undertaking detailed studies of populations or behaviour. While many of these local resightings are now held in computerised form by national ringing centres, such developements are relatively recent and datasets are far from comprehensive. When recovery records are received and processed by national ringing centres they are coded using a standard scheme that is used throughout Europe (du Feu *et al.* 2020). There are many codes that can be used to record the cause of recovery as reported by the finder. It is important to consider such causes when interpreting movement maps based on ring recoveries as different recovery causes will be subject to different temporal and spatial biases. For example, hunted recoveries can only be recorded in locations and times of year when hunting takes place, although this many not always follow exactly what would be expected from the hunting regulations. The categories of recovery causes used on the Atlas maps are shown in Table 2.1.

The first modern bird ringing took place in Denmark in 1899. The first national ringing schemes developed over the following 20 years and there are now some 49 European Ringing Schemes that are members of EURING. Ringing Schemes co-ordinate ringing within their countries, organizing the training of ringers, the issuing of rings and the processing and storage of ringing and recovery data. Many coordinate projects operating at national and European levels and also undertake research on the resulting data.

EURING was founded in 1963 to co-ordinate the activities of Ringing Schemes accross Europe, and only three years later the first EURING exchange code was published. The EURING databank (du Feu *et al.* 2016) that aims to hold copies of all European ring recovery data was founded at the Netherlands Institute of Ecology

Table 2.1 Grouping of recovery causes used in this Atlas.

Recovery	Definition
Dead, shot	Self explanatory, nearly all are shot by hunters
Dead, intentionally taken	Taken by other means such as trapping or poisoning
Dead other or sick/injured	Dead or occasionally sick birds reported by the public or ringers
Alive, ringing recovery	Captured alive by ringers away from the ringing place
Alive, identified by other means	Resightings of colour marked birds, reading metal rings in the field
Alive, other	Live recoveries from other causes. e.g entered building
Unknown	No cause of recovery reported

in 1977 and in the early 1980s large-scale computerization of these data was undertaken with grants from the European Community. In 2005 the EURING databank was re-organized and moved to the British Trust for Ornithology where it is still based. The database infrastructure established at that time and developed subsequently underpins this Migration Atlas. The EURING databank now holds of over 25 million encounter records, providing an amazing resource for studying migration at continental and flyway scales. Many bird species cover vast distances during their annual cycles, exemplified by Barnacle Geese that move from the United Kingdom to Svalbard, Manx Shearwaters that breed in Britain and winter off South America, Ruff that move from breeding grounds in Eastern Russia to winter in West Africa and Arctic Terns that move from the Baltic to winter off South Africa. Thus this online Migration Atlas provides a critical tool for visualising the annual movements of some 300 species. Thanks to modern technology it is not a book that will soon be out of date but an online resource that will receive semi-automated updates as more data become available.

2.2 Tracking data

The miniaturisation of a range of electronic devices over the last 30 years has made it possible to track the migrations of individual birds in amazing detail (Geen *et al.* 2019). These techniques are highly complementary to classical bird ringing. The advantages of ringing are the greater geographical and temporal coverage, the higher number of individuals, the lower costs and the minimal effect on the birds. In contrast, electronic devices provide many more data points per individual and do so even from areas where the probability of obtaining a ring recovery is very low.

Thanks to such developments in tracking technology, our knowledge of the migration routes and migratory behaviour of many bird species has increased considerably in recent times. However, information from tracking studies and data from bird ringing are not equally accessible to the general public. While a powerful and robust system of which data are collected and managed where, and how it is coded and made accessible, has evolved in bird ringing for over a hundred years, an equivalent system has yet to be fully developed in relation to tracking studies. Much tracking data is difficult to access and is not standardised by the people who have collected it. The collection of tracking data often incurs considerable financial costs, and therefore researchers may be reluctant to share it with others, at least until all possible published outputs have been produced.

Picture 3. Barn Swallow (Hirundo rustica) a European African migrant for which our knowledge of migration routes is based mainly on ring recoveries (Figure 2.2). © Canva.com

Picture 4. Song Thrust (Turdus philomelos), an intra-European migrant for which knowledge of movements is based mainly on ringing recoveries (Figure 2.11) © Canva.com

Movebank is a database and online toolset designed to store and make available locational data and related parameters from other sensors collected from live animals by means of electronic devices. Movebank aims to provide effective online tools that enable researchers carrying out tracking studies to easily manage and analyse their data. It also enables the public to view much of the data and it facilitates further analysis by other scientists, authorities or conservation organisations in a timely manner, but also decades later. The nature, extent and timing of such data sharing is determined wholly by the study owner. This multiple use of data, which arises as an ethical obligation from the fact that animals are "used" for human knowledge gain, has been standard in bird ringing for a long time and is increasingly being used in the electronic tracking of animals and in other scientific research. The intention of Movebank is thus to facilitate the best possible use of tracking data collected using wild animals. At the beginning of 2022 Movebank contained more than 6900 tracking studies from more than 3200 users with more than 3.3 billion localisations of nearly 1200 different animal species. A detailed description is given by Kays *et al.* 2022. Besides Movebank, other online databases for bird tracking data exist, including the Seabird Tracking Database operated by BirdLife International and the Satellite Tracking database operated by BirdLife Hungary.

A special aspect of the Atlas is that for the first-time tracking data are presented on a large scale in combination with classical ring recovery data. This has been made possible by the data owners of several hundred tracking studies held in Movebank, who agreed to contribute their data for use in the atlas maps. The technical requirements for this have been met via the data interface provided by Movebank, which had been adapted to support the atlas project. All owners of tracking studies in Movebank, which contained tracking data on the bird species covered by the atlas, were contacted by us with a request for cooperation. Data use was directly permitted by owners of almost 300 studies, in some cases written agreements were arranged to assure the study owners that their data would only be used for specific purposes. In a few cases, it also turned out that the data were not suitable for the atlas for various reasons or that not all project participants agreed to the use of the data outside their own project at this stage. Data already published in Movebank via Creative Commons licences or in the Movebank Data Repository were directly available.

As the list of telemetry studies generating data relevant for the Atlas continues to grow rapidly, it is planned to add links to more such studies to the atlas over time. Also, the datasets within the linked projects may grow if the tagged birds are still alive. Thanks to the automated link between Movebank and the Atlas such new data will be added to the Atlas on a regular basis.

The sometimes very high temporal resolution of the telemetry data is not necessary for the continental scale maps presented in this atlas. Therefore, higher resolution data were reduced to one location per day before it was transferred from Movebank, which still allows the large-scale migrations to be represented very clearly. The presentation of the tracking data is similar to that of the ringing data by connecting the known localisations with straight lines in chronological order. For reasons of clarity, however, the point signatures themselves are not shown in the default presentations of the tracks.

The data originate from four different families of electronic tracking devices:

1. Solar geolocators (see for example Ringed Plover, Alpine Swift, Collared Flycatcher, Sand Martin): these are very small devices that record the times of sunrise and sunset. From this information, it is possible to determine, at least roughly, the position from which the transmitter (and thus the bird) must have experienced these sunrise and sunset times. The accuracy of the localisations depends on numerous factors and is often only in the range of a few hundred kilometres. However, since these loggers are very small and can be carried even by small songbirds, they provide rough results, but in many cases this is the first information at all about migration routes and wintering areas outside Europe. Such tracks must be interpreted with caution and should not be taken as exact migration routes. A further limitation is that the data can only be retrieved when a marked bird is recaptured and the device is removed for analysis. Thus, most studies are of individuals marked on their breeding grounds and recaptured after successfully completing their migration a year later. For more informaion see Lisovski *et al.* (2019).
2. Radio tracking (see for example Little Owl, Dunnock, Blackcap): with this classical tracking method, the device on the animal transmits a radio signal, which can then be detected by a receiving station. This can be done by handheld antennas carried by humans or vehicles or by automatic receiving stations such as the MOTUS system. The positions are determined by cross bearings of the transmitter or by bringing the transmitter and receiver closer together (“homing in” or sensing proximity). Tracked individuals can be distinguished by different modulations of the radio signal. Depending on the system or the way the receiver works, the localisations can be very accurate or only accurate to a few kilometres. For more information see Fuller et al. (2005).
3. Argos doppler system (see for example Eurasian Teal, Eleonora’s Falcon, Quai)l: as with the previous system, the transmitter on the animal sends out a radio signal, which in this case is received by satellites (https://www.argos-system.org) and then transmitted back to a ground station. The approximate positions of the transmitters can then be determined from this data using the Doppler effect. The accuracy of the localisations is usually in the range of a few tens of kilometres. For more information see Soutullo *et al.* (2007), Witt *et al.* (2020).

Table 2.2 Map types provided in the migration Atlas and their function.

Map type	Function	Data type
Overall connectivity	Show overall migration routes and connectivity between different regions	Ring recoveries and tracking layer if available
Connectivity by age	Show any differences in overall connectivity patterns between first year, immature and adult birds	Ring recoveries
Connectivity by sex	Show any differences in overall connectivity patterns between males and females	Ring recoveries
Correctivity by condition	Show differences in connectivity between different recovery causes	Ring recoveries
Connectivity by month and by region	For any of the eight focal regions connectivity maps showing months of ringing and recovery	Ring recoveries
Seasonal movements	For any of the eight focal regions animated maps showing recovery locations by 10-day periods	Ring recoveries

4. GPS telemetry (see for example Cory's and Scopoli's Shearwaters, Black and White Stork, White-fronted Goose, Red Kite and many others): In this latest generation of loggers, the devices on the bird determine their position themselves using a GPS or similar system and then transmit this data, often together with other sensor data, to a receiving station. This data transmission can take place via a radio link to a base station, via the mobile phone network directly to a server or via a connection to a receiver in space, which in turn forwards the data to an earth station. This data is often accurate to within a few metres, although mismeasurements can occur due to various interferences, leading to "peaks" in the tracks shown, which then should not be over-interpreted. GPS loggers are usually used on larger birds from thrush size upwards, although there are now also models that are only a few grams in weight, making them suitable for some smaller species. For more information see for example Bouten *et al.* (2013).

2.3 Migration and movements of species covered by the Atlas

The core content of the Atlas is an online migration mapping application providing maps of the movements of 300 species, based on ring recoveries and tracking data. At the time of publication ring recoveries were available for all species while tracking data were provided for 102 species. The dynamic feed from Movebank means that more tracking data will be added as the number of studies continues to increase and be made available to the Atlas.

The online Atlas has six main map types (Table 2.2), many of which contain options for turning parts of the dataset on and off. The first map displayed when a species is selected shows overall connectivity based on eight regions to which initial encounters are assigned (Figure 2.1). Data for each of these focal regions and the tracking layer if available can be turned on and off, which is particularly helpful when there are many focal regions with large amounts of data. Connectivity maps by age (separating first year birds, immatures and adults) and by sex are also available.

Patterns of ring recoveries are often affected by recovery causes. So for hunted species particulary high concentrations of records may occur in areas of intense hunting activity, while if many of the data arise due to recaptures by ringers then the maps are likely to be influenced by patterns of ringing activity. Even patterns of recoveries simply reported as "found dead" are likley to be affected by human population density and by cultural issues that may influence the proportion of found birds that are reported. The connectivity by recovery condition map type allows these patterns to be explored, helping users to make sensible interpretations of the data.

Figure 2.1 Encounter regions of origin used in the Migration Atlas.

Table 2.3 Supporting tables and figures available for each species. All information can be downloaded as images of the graphs and as tables.

Titles	Contents
Summary of records	Numbers of records, individuals and recoveries for total dataset and for mapping dataset (movements >= 50 km)
Pie charts of recovery categories	For all years, pre-1960, 1961-1990 and 1991-present. Available for the whole dataset and for each of the eight focal region
Histograms showing distance moved	Available for the whole dataset and for each of the eight focal regions
Histogram of encounters by region	Number of encounters by region for all regions combined and for each of the eight focal regions
Histogram of number of encounters by 10-day period/month and by sex	Bars for male, female and unknown sex. Either 10-day periods or months are used depending on data volume
Histogram of number of encounters by 10-day period/month and by age	Bars for first year, after first year, immature, adult, unknown but full grown and unknown. Either 10-day periods or months are used depending on data volume
Histogram of number of encounters by year	Shows how the number of records has changed over time
Histogram of number of encounters by 10-day period/month	Shows seasonal distribution of encounters

The connectivity by month and by region maps allow the nature and timing of year round movements to be explored in more detail for one focal region at a time. The user selects a single focal region and the map then shows movements from that region, with encounters colour coded by month. Data for individual months can be turned on and off so, for example, the user can quickly select a map of recoveries from the winter period only. If further detail is required then the final map type, seasonal movements, shows encounters of birds from a selected region by 10 day period as an animated map. This is particularly useful where there is interest in exploring migration timing for species with reasonably high volumes of data.

In addition to the maps the Atlas also provided a set of eight types of tables sumarising the data for each species, which can be viewed by clicking the statistics button (Table 2.3). Any of these can be downloaded as an image or text file. It should be emphasised that the main purpose of these tables is to aid interpretation by providing more information about the dataset. Some of the patterns shown on the Atlas maps arise from variation in ringing effort and reporting probabilities and it is therefore important that users wishing to explore the data in detail should understand these aspects of the dataset.

All species have a written species text comprising an introduction together with sections on overall connectivity patterns, recoveries by condition, connectivity by month and annual movements. These correspond to the main map types, with variation by age and sex being covered under overall connectivity. Text sections are displayed using the analysis button and the references via the bibliography button. Thus the species texts have been carefully designed to aid interpretation of the online maps.

In the rest of this section we present a set of examples of the online maps illustrating some of the movement patterns shown by the Atlas. Most of the species shown are relevant to particular CMS initiatives. Due to space constraints we focus on the overall connectivity maps which generally provide the best overview of the movements of particular species.

First we consider the Barn Swallow (*Hirundo rustica*), a European African migrant which has been extensively ringed throughout Europe. Most birds are ringed at breeding colonies or at premigratory autumn roosts. Records show strong connectivity between different regions of Europe and the African wintering grounds (Figure 2.2). While birds form Britain and Ireland winter mainly in Southern Africa those from central Europe winter further north in central Africa. Connectivity maps by age and sex are also available but they do not show any strong patterns in this species. The map of connectivity by month (Figure 2.3) show that as expected the birds are in Europe during the summer and in Africa in winter. More detailed examination of the map shows, for example, passage through the mediterranean in April and May.

Migratory geese are an important focus for CMS in relation to AEWA and the European Goose Management Plan. Fortunately such movements are well documented due to good quality sets of both ringing and tracking data. Barnacle Geese wintering in Western Europe show three very clear flyways (Figure 2.4). Birds wintering in Britain breed in both Iceland/Greenland and in Svalbard, while those wintering in Belgium, the Netherlands and surrounding countries breed in Northern Russia and Siberia. Adding tracking data to the map (Figure 2.5) confirms this pattern and provides evidence that a higher proportion of the eastern population breeds in Siberia. This is no doubt because human population density in Siberia is very low so ring recovery probabilities will be small, while tracking data are not subject to this bias. Most of the population of Greater White-fronted Geese wintering in Europe breeds in Siberia, as is shown by both ringing and tracking data (Figure 2.6). The much smaller population of Greenland White-fronted Geese, which are a separate sub-species, winter in Ireland and the West of Scotland and breed in South-west Greenland. Pink-footed Geese provide another example of strong connectivity, in this case based entirely on ring recoveries (Figure 2.7). Birds wintering in Britain and Ireland breed mainly in Iceland while those wintering in Belgium, the Netherlands, Germany and Denmark breed in Svalbard.

Understanding the movements of Teal and other migratory duck species is important for population mamagement in relation to hunting (see section 5 below). Most of these birds breed in Northern Europe and Russia, including Siberia, and winter in Western Europe (Figure 2.8). There is considerable population mixing on the wintering grounds and extensive within winter movements are observed, particularly in relation to severe weather. Tracking data from northern Italy show that in spring this population migrates in a north-easterly direction to breeding grounds in Siberia.

There is an interesting contrast between the movements of the two Kite species that are of interest in relation to the CMS raptors MoU. Red Kites breeding in Britain, a population that was restored through a reintroduction programme, are largely sedentary and only move relatively short distances (Figure 2.9). Those breeding in Central Europe move South-West to winter in Iberia. A few birds move to the Western Mediterranean and there are just two recoveries in Africa. In contrast European Black Kite populations mainly winter in West Africa, as shown by both the ring recovery data and tracking data from Northern Italy (Figure 2.10).

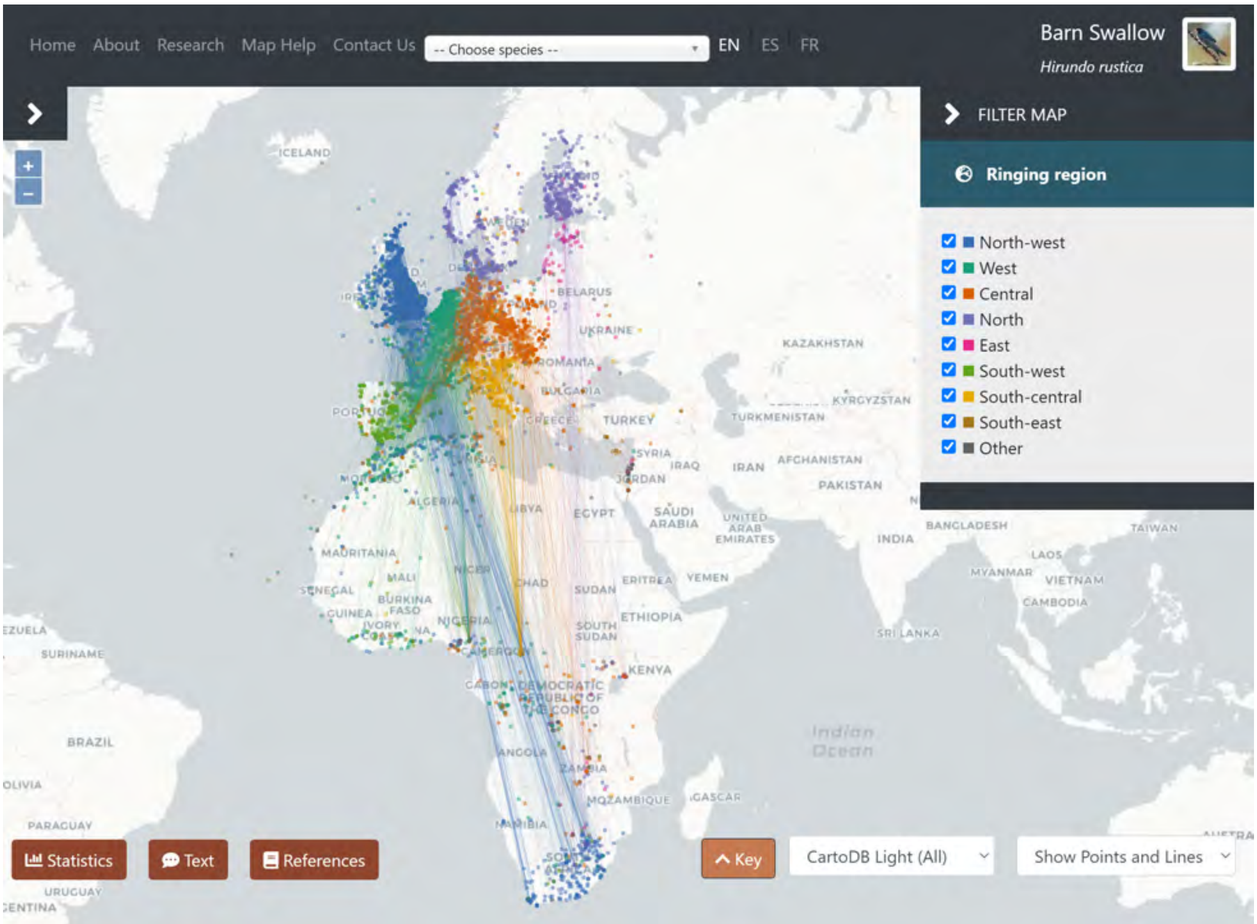

Figure 2.2 Overall connectivity by month for Barn Swallow based on ring recoveries.

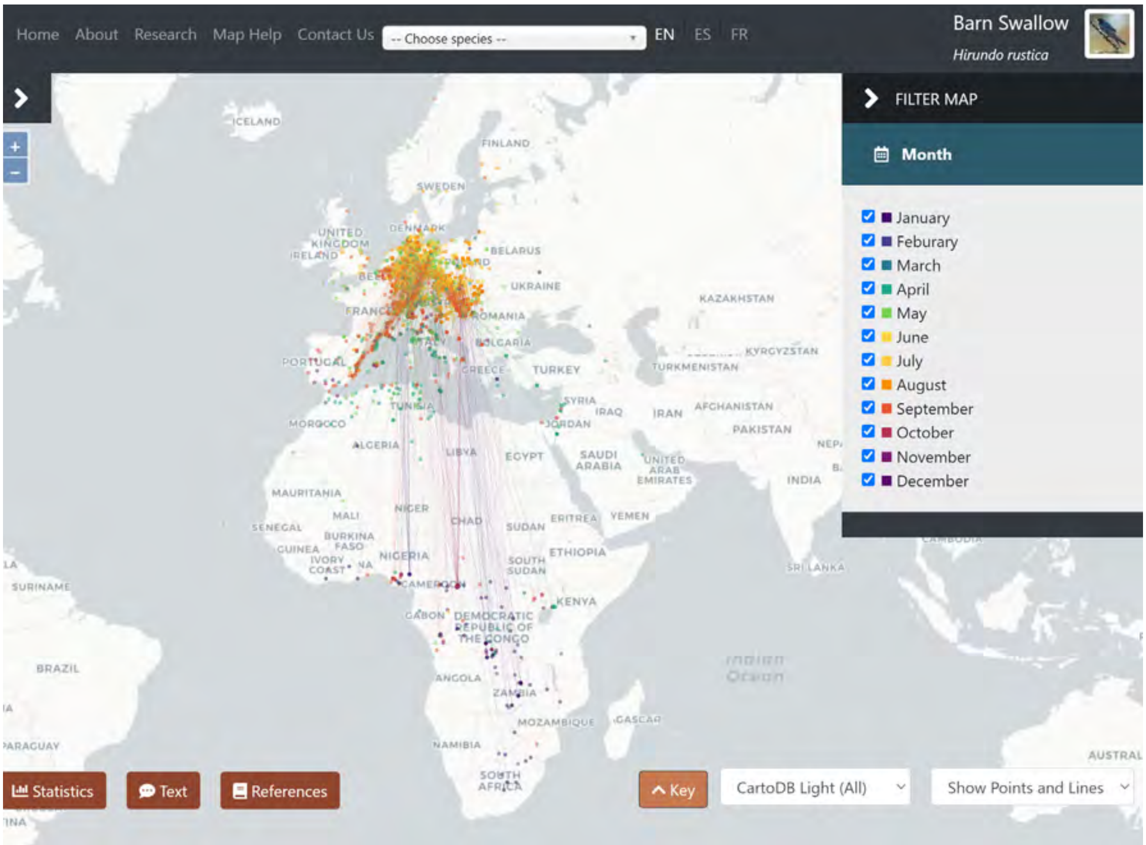

Figure 2.3 Connectivity by month for Barn Swallows from Central region.

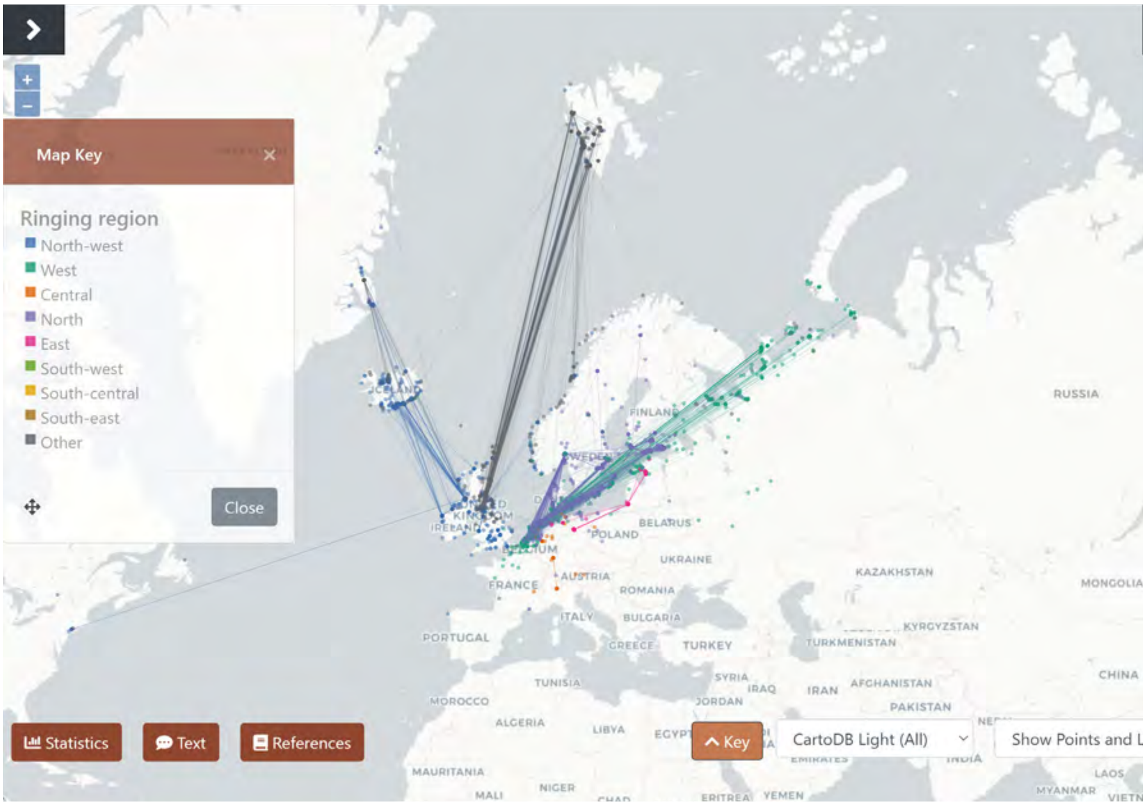

Figure 2.4 Overall connectivity for Barnacle Goose based on ring recoveries.

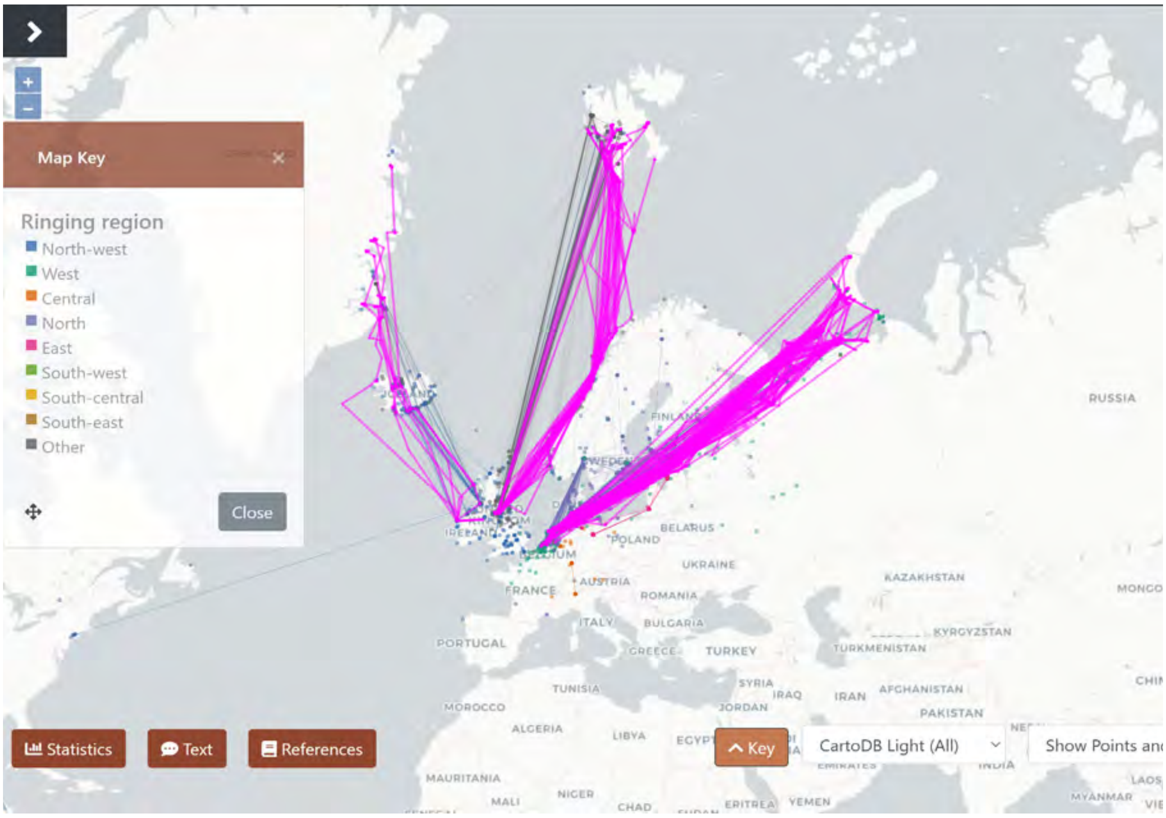

Figure 2.5 Overall connectivity for Barnacle Goose based on recoveries and tracks. Here and in subsequent figures tracks are shown as pink lines.

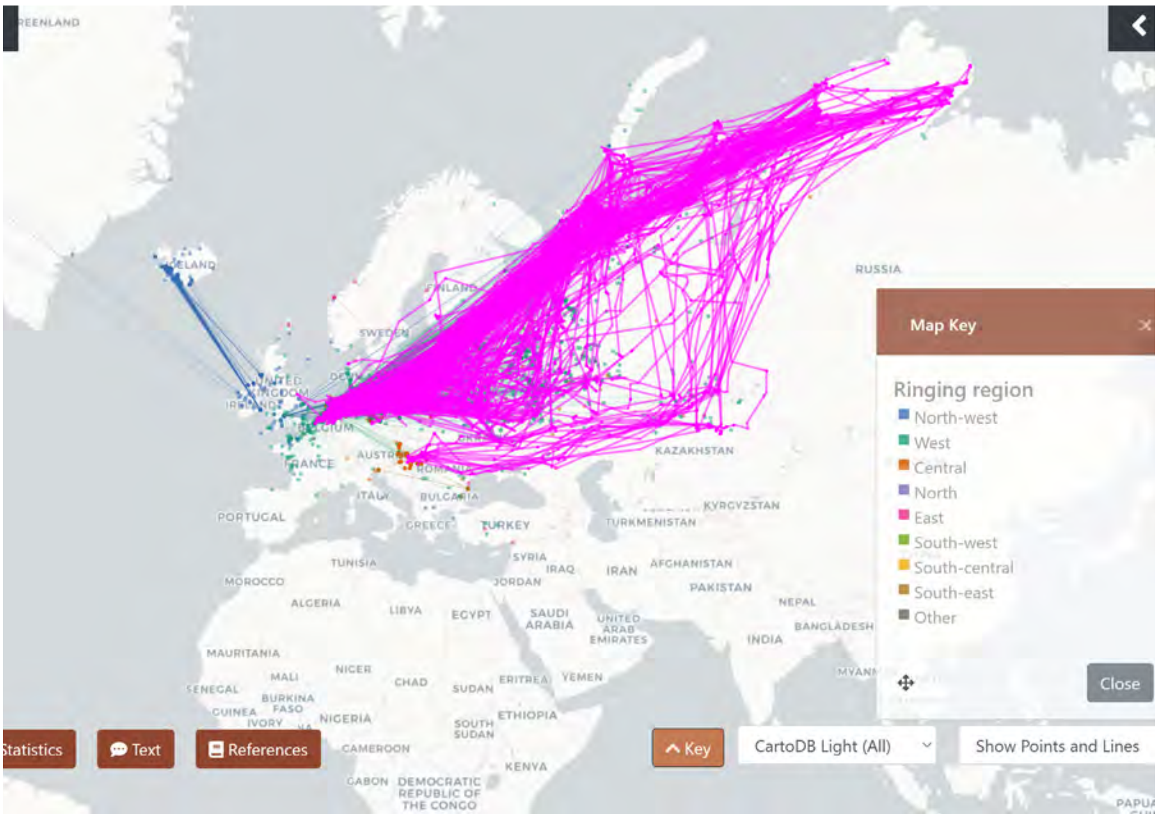

Figure 2.6 Overall connectivity for Greater White-fronted Goose based on recoveries and tracks.

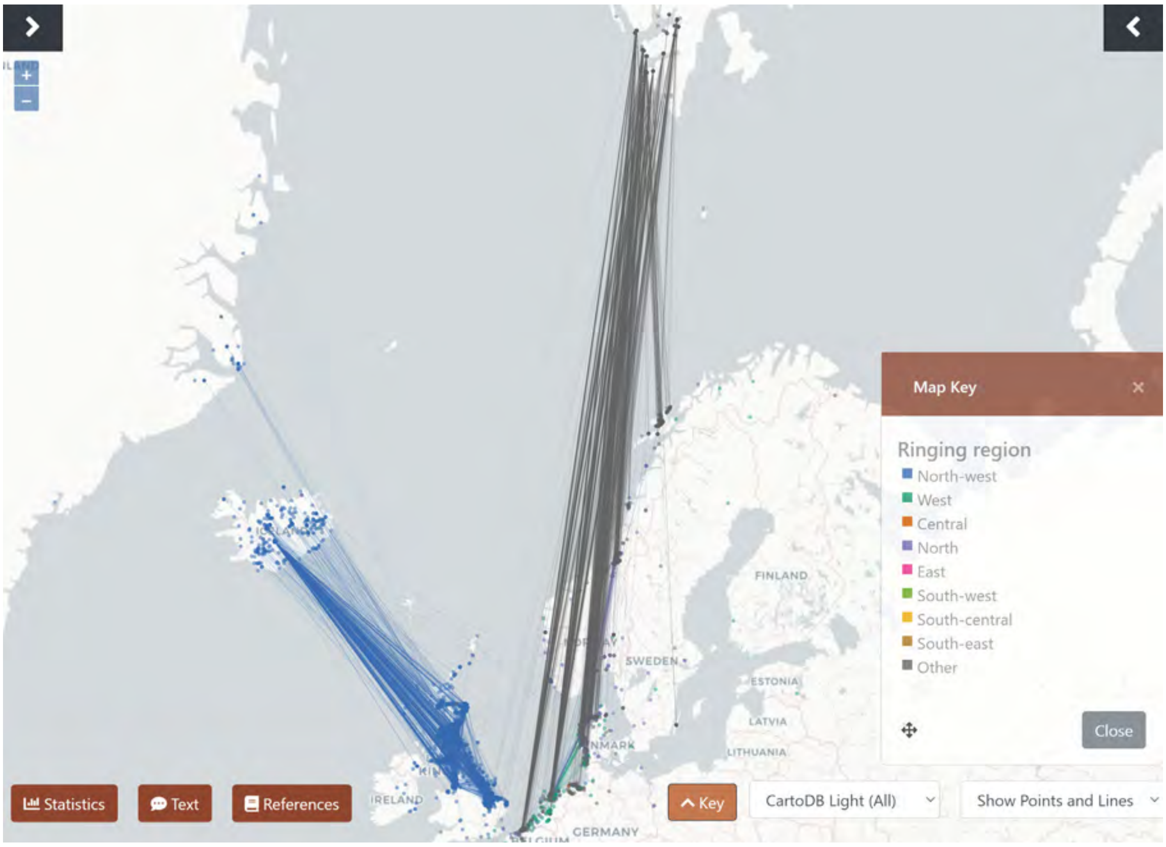

Figure 2.7 Overall connectivity for Pink-footed Goose based on recoveries.

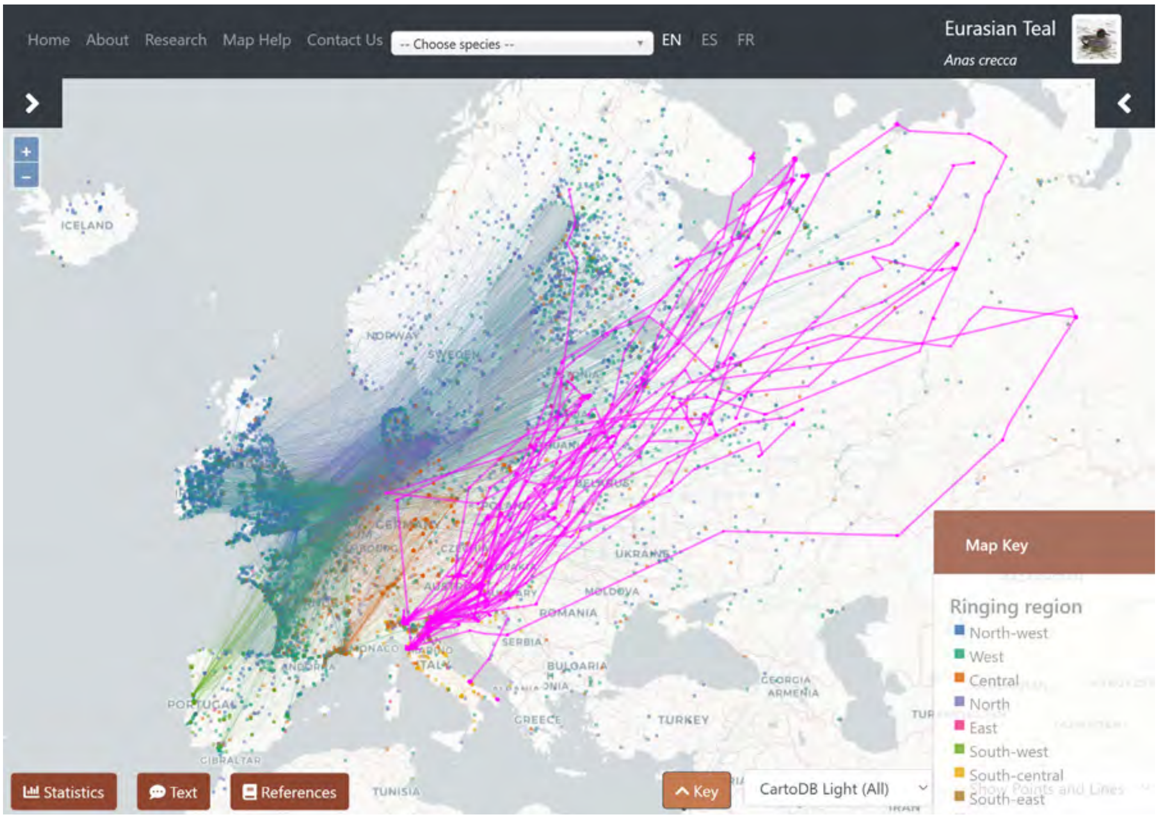

Figure 2.8 Overall connectivity for Teal based on ring recoveries and tracks.

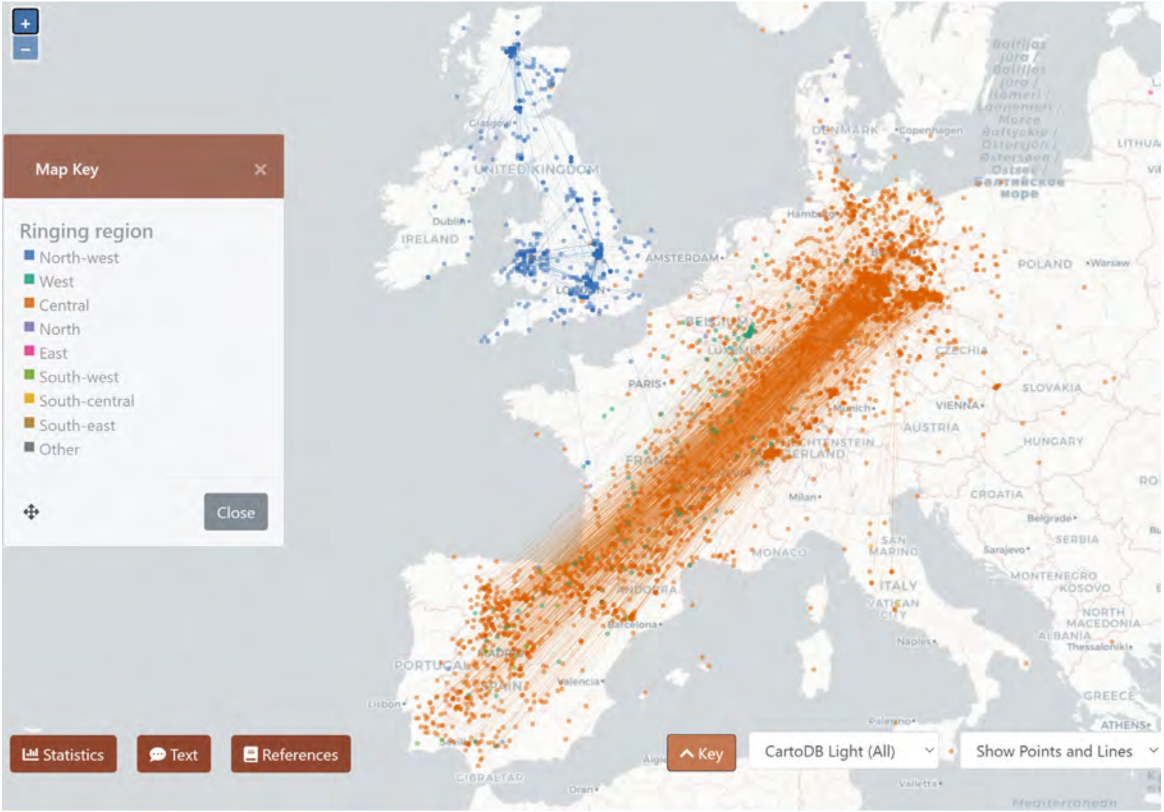

Figure 2.9 Overall connectivity for Red Kite based on ring recoveries.

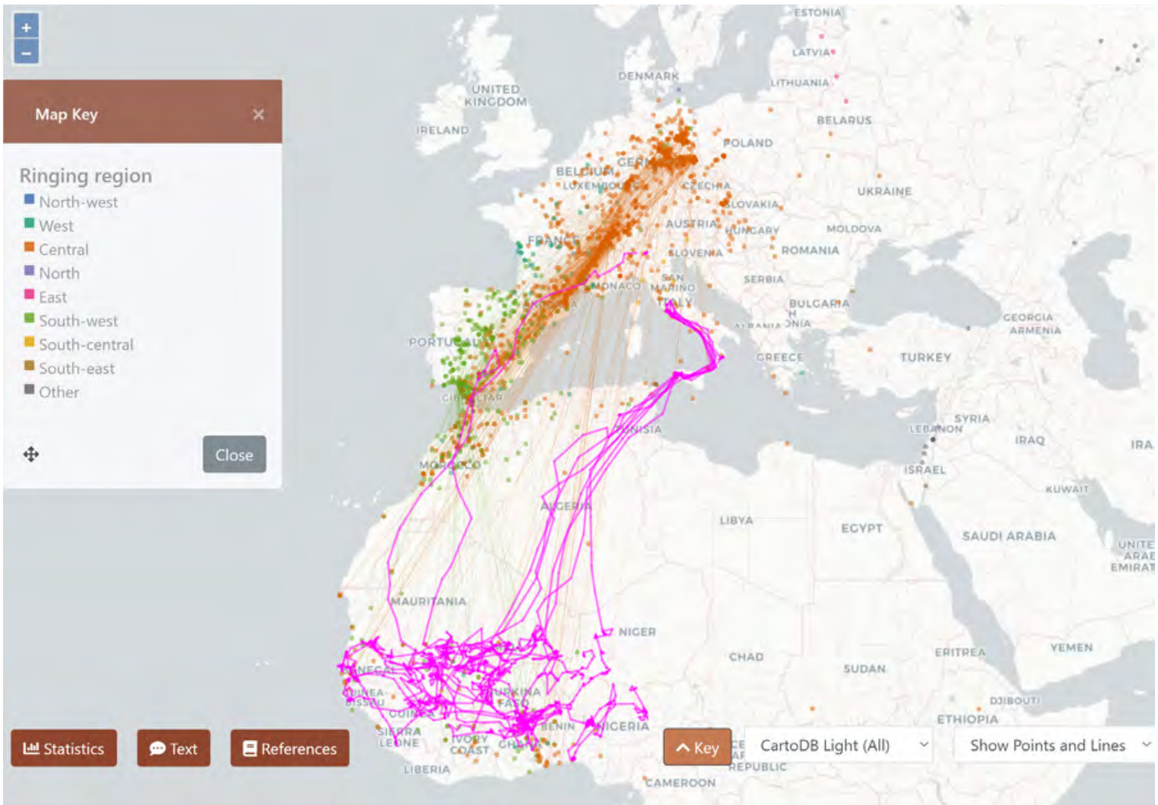

Figure 2.10 Overall connectivity for Black Kite based on recoveries and tracks.

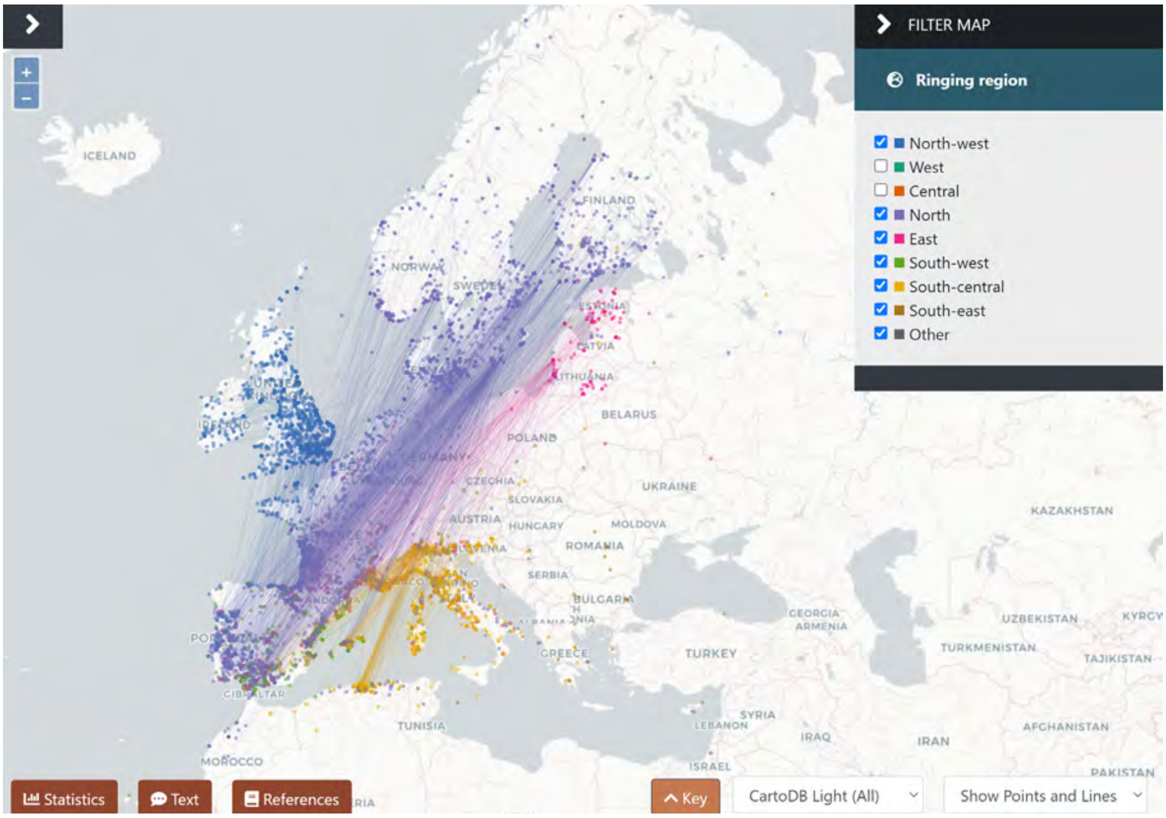

Figure 2.11 Overall connectivity for Song Thrush with West and Central regions turned off.

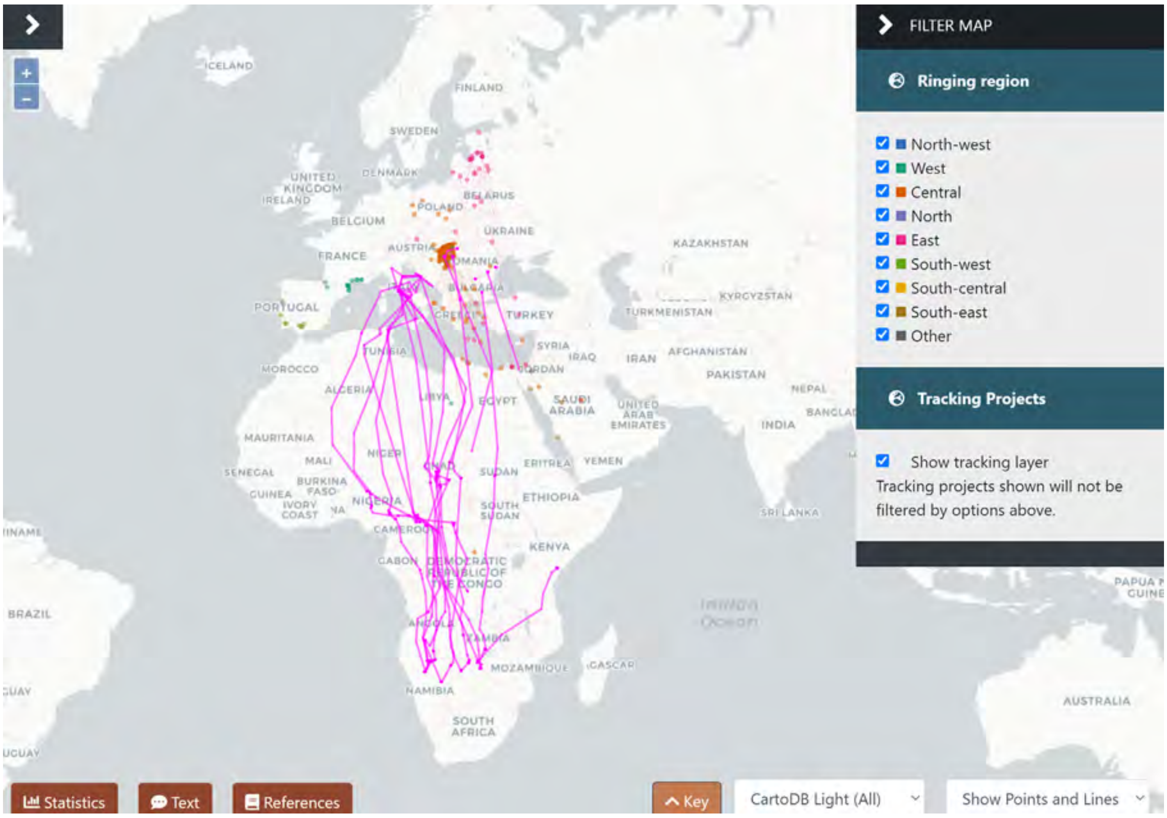

Figure 2.12 Overall connectivity for Roller based on recoveries and tracks.

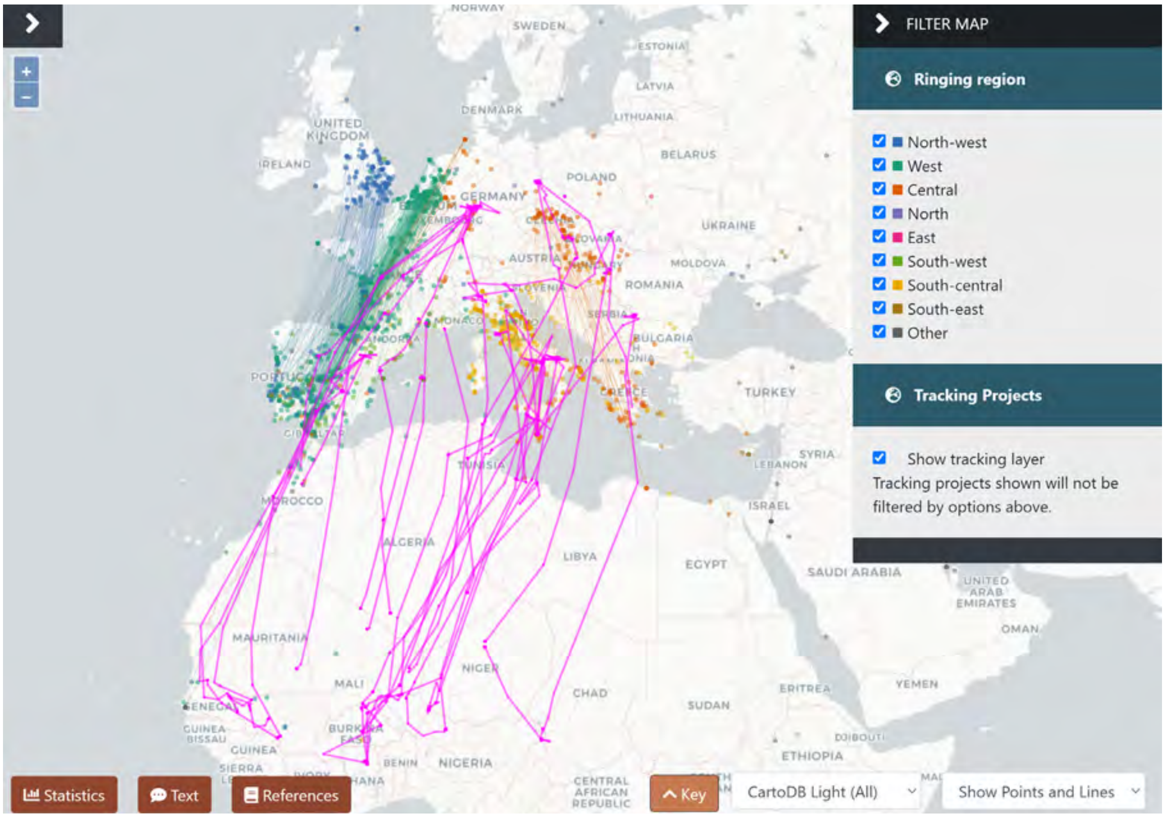

Figure 2.13 Overall connectivity for Turtle Dove based on recoveries and tracks.

Song Thrush is an intra-European migrant with varying movement patterns accross the continent (Figure 2.11). British birds are relatively sedentary while those from Northern and Central Europe move South West in winter to southern France and Iberia. Poulations from southern Europe move shorter distances to winter around the Western Mediterranean and in North Africa. This species continues to be legally hunted in some parts of Europe so details of its movements are of interest in relation to the definition of hunting seasons (section 5).

Finally we show maps for two long-distance migrants of conservation concern for which understanding of movements and habitat use are essential for population management and species recovery. Both have their own species action plans which need to be based on the best available scientific evidence. Recent tracking data show that Rollers breeding around the central Mediterranean winter in Southern Africa (Figure 2.12). In contrast, birds breeding in central and eastern Europe migrate in a south-easterly direction to wintering grounds in north Africa and Saudi Arabia. Turtle Doves continue to decline rapidly. Historically they have only been ringed in moderate numbers and there are relatively few recoveries on their African wintering grounds, although the recovery data does provide a reasonably clear picture of passage movements within Europe. New tracking studies from several areas now show that most Turtle Dove populations move directly south to winter in West and Central Africa (Figure 2.13).

This small set of examples based on just a few of the 300 species included in the Atlas clearly show the huge conservation relevance of this new tool. They also demonstrate the value of combining ringing and tracking data in order to obtain a more complete picture of bird movements. We hope that readers will be encouraged to visit the Atlas website and to explore the information on species that are of particular relevance to their own work.

3. Migratory connectivity

3.1 Background and Objectives

Migratory connectivity is defined as the linkage among individuals between the periods and areas where they spend different phases of their annual life cycle. Various definitions of migratory connectivity have been proposed, depending upon whether it is considered as a property of individuals, populations, areas, or periods of the annual cycle. In this latter meaning, the concept of migratory connectivity extends also to the degree of mixing among individuals during different stages of their annual cycle. Since birds show uninterrupted graduation of migratory movements (from strictly sedentary to fully migratory) not only between different species but also between populations of the same species and even within the same population, a focus on the temporal component of the mixing among individuals allows studies of migratory connectivity to be extended to a wide range of species because the species or populations that show mixed migratory strategies or do not perform proper migratory movements can also be considered.

In this module of the Atlas, we performed migratory connectivity analyses on species breeding within the Palearctic-African migration system. We checked the robustness of the results through sensitivity analyses and by comparing different methods for estimating migratory connectivity. We then summarized the results on individual connectivity in a meta-analysis that allowed us to identify some of the ecological processes that drive the strengths of migratory connectivity observed in different species.

3.2 Materials and Methods

We applied a robust data filtering procedure to all species in the EURING databank and selected only those species with a minimum amount of data. We then performed two different analyses of migratory connectivity. The first one assessed the connectivity of individuals between their breeding and their non-breeding ranges (hereafter, "individual connectivity") according to the method proposed by Ambrosini et al. (2009). Briefly, using the geographical positions of individuals during breeding and non-breeding stationary periods, we estimated the strength of the migratory connectivity as the Mantel correlation (r_M) between the distances among individuals in the breeding and wintering grounds. If this analysis showed connectivity, we further checked whether it was due to the presence of clusters of individuals that stay together during the breeding and the non-

Picture 3. Whooper Swans (Cygnus cygnus) show strong connectivity and strong clustering. © Canva.com

breeding periods (independently of the reciprocal position of individuals within each cluster) or whether individuals show "pattern transference", i.e. they tend to maintain the same reciprocal positions without showing any clustering structure. To check for the robustness of the results when the sample size was small, we rarefied our samples by randomly selecting decreasing amounts of data. We also checked whether the large spatial heterogeneity in the sampling effort that typically affects ringing data may have biased our results by comparing the analyses run separately for individuals whose second (most recent) encounter was either a dead recovery or a live recapture.

The second method measured the connectivity between populations within 15 pre-defined breeding and non-breeding regions encompassing the European and African continents (Europe: 8 regions, Africa: 7 regions) according to the method proposed by Cohen *et al.* (2018). Briefly, each encounter was first assigned to a region. A set of transition probabilities was then estimated as the proportion of individuals assigned to a breeding region that were found during the non-breeding period in another region. An *MC* coefficient that represents the strength of migratory connectivity was then calculated based on the distance among the centres of the areas, the population size of that species in each area, and the transition probabilities. Importantly, it can be demonstrated that also *MC* is a correlation coefficient, and it is therefore comparable to r_M.

Finally, we summarized these species-specific estimates of connectivity in a meta-analysis that allowed us to identify some of the ecological processes that drive the different strengths of migratory connectivity observed in different species. For methodological details of all the analyses see our full report.

3.3 Results

We initially investigated the patterns and strength of migratory connectivity in 137 bird species with at least 20 encounters in both the breeding and the non-breeding areas. We then rarefied our samples and showed that the power of these analyses was reasonable for a sample size of at least 30 individuals. We also compared the values of the strength of migratory connectivity obtained by the two methods applied to the same set of ringing encounters and found that they showed good agreement and repeatability. Finally, we found that analyses run separately for individuals whose second (most recent) encounter was either a dead recovery or a live recapture were generally consistent. The results of the migratory connectivity analyses thus appeared robust to the main problems that usually affect analyses of ringing encounters, and consistent between different estimation methods.

Overall, the strength of migratory connectivity in the European-African bird migration system showed high interspecific variability, but it was significant in almost all (c. 92%) of the species analysed. In addition, the analyses showed that migration strategies varied at the intraspecific level, with most species showing geographically distinct migratory populations (i.e. migratory connectivity derived from a clustering process). Figure 3.1 shows examples of species showing weak connectivity and strong clustering (e.g. *Hirundo rustica*), strong connectivity and strong clustering (e.g. *Cygnus cygnus*), moderate connectivity and weak clustering (e.g. *Bucephala clangula*), and no connectivity (e.g. *Turdus iliacus*). Migratory connectivity maps and detailed results of the analyses for all the 137 species analysed can be downloaded from the species pages on the Atlas website.

The meta-analysis included 129 species with at least 30 encounters in both the breeding and non-breeding staging areas, 42 of which were resident, 24 partial migrants, and 63 full migrants. The forest plot in Figure 3.2 summarizes the results of this meta-analysis. Migratory connectivity was generally positive and significantly larger than zero across all species. Residents showed the highest levels of migratory connectivity, partial migrants intermediate levels, and full migrants the lowest values. This is consistent with previous studies which have shown that migratory connectivity decreases with migration distance. Most likely, our full migrant species were those experiencing longer migration distances, which may explain their weaker connectivity. We also found that species with a larger body mass tended to show stronger migratory connectivity, but passerines and non-passerines showed similar levels of migratory connectivity. Generally, phylogenetically close species showed substantial differences in the degree of migratory connectivity as shown by the absence of a phylogenetic signal in the analyses. Larger species tend to live longer, and a longer lifespan, in turn, promotes the social transmission of migratory routes and helps maintain their knowledge giving rise to strong connectivity. In contrast smaller species have fewer opportunities for social transmission which may result in higher population mixing and lower connectivity.

In conclusion, our analyses offered a critical tool that can be used to inform conservation and management strategies of European birds by describing migratory connectivity patterns accurately on a species specific basis. In addition, these results were summarized across species with a sufficiently robust dataset to shed light on the ecological drivers of avian migratory connectivity. Indeed, the results of our comparative meta-analysis suggested that geographical predictors or social life-history traits are more likely to affect how birds redistribute between breeding and non-breeding periods and grounds, while the phylogenetic relatedness between species plays a key role in shaping migratory connectivity. In quantifying and describing the strength and patterns of migratory connectivity across European bird species, we hope that our analysis will improve understanding of avian migration and, more generally, of the geographical links between individuals during different periods of their annual life-cycle and will thus facilitate conservation and management at the population level.

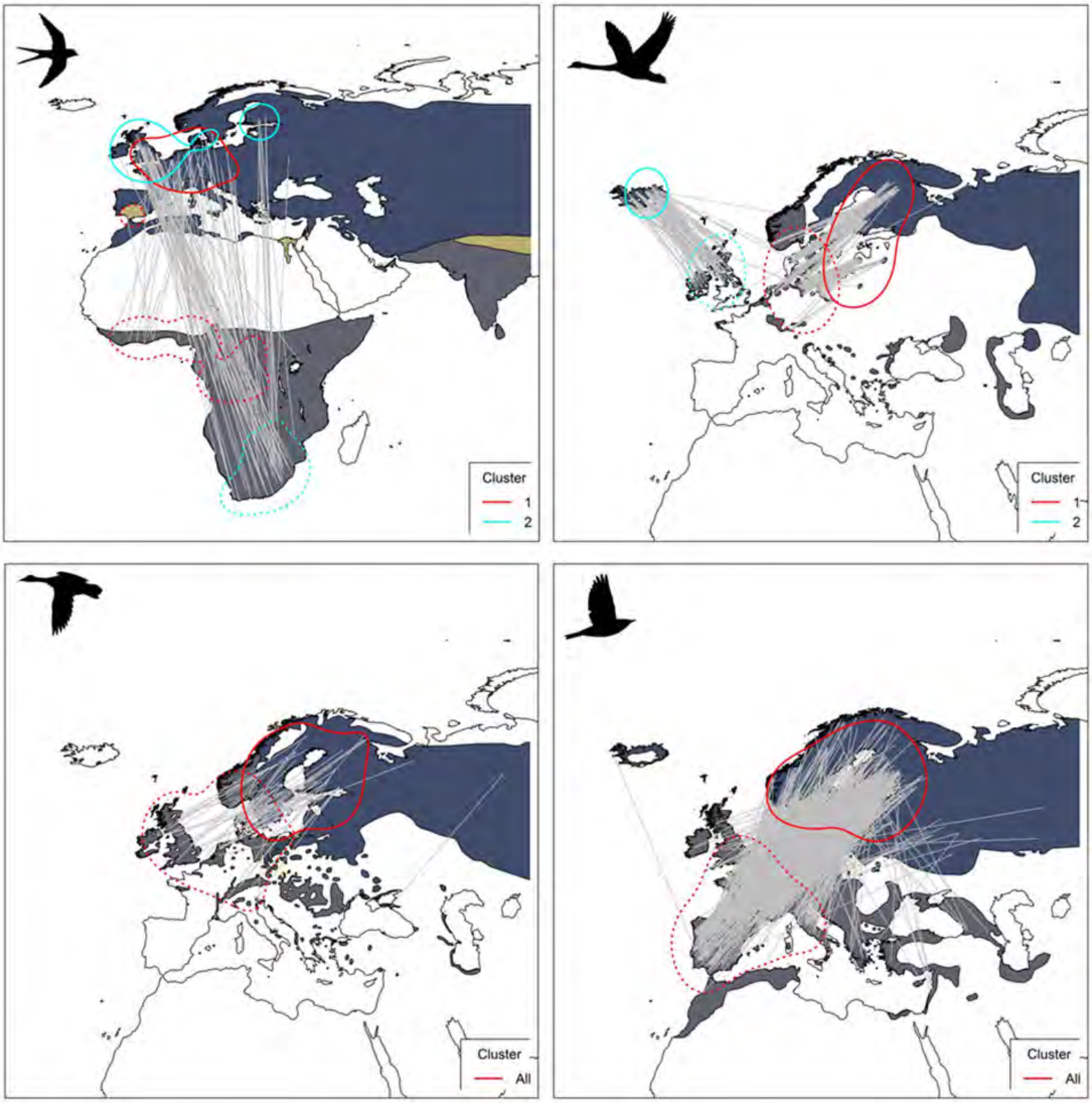

Figure 3.1. Migratory connectivity maps of illustrative bird species showing (a) weak connectivity and strong clustering (e.g. Hirundo rustica); (b) strong connectivity and strong clustering (e.g. Cygnus cygnus); (c) moderate connectivity and weak clustering (e.g. Bucephala clangula); (d) no connectivity (e.g. Turdus iliacus). The grey lines connect individual breeding sites and non-breeding locations, while different coloured kernel contours depict geographical populations identified by the cluster analysis (solid contour: breeding, dotted contour: non-breeding). Species breeding, non-breeding and resident ranges are also shown according to BirdLife International (2019).

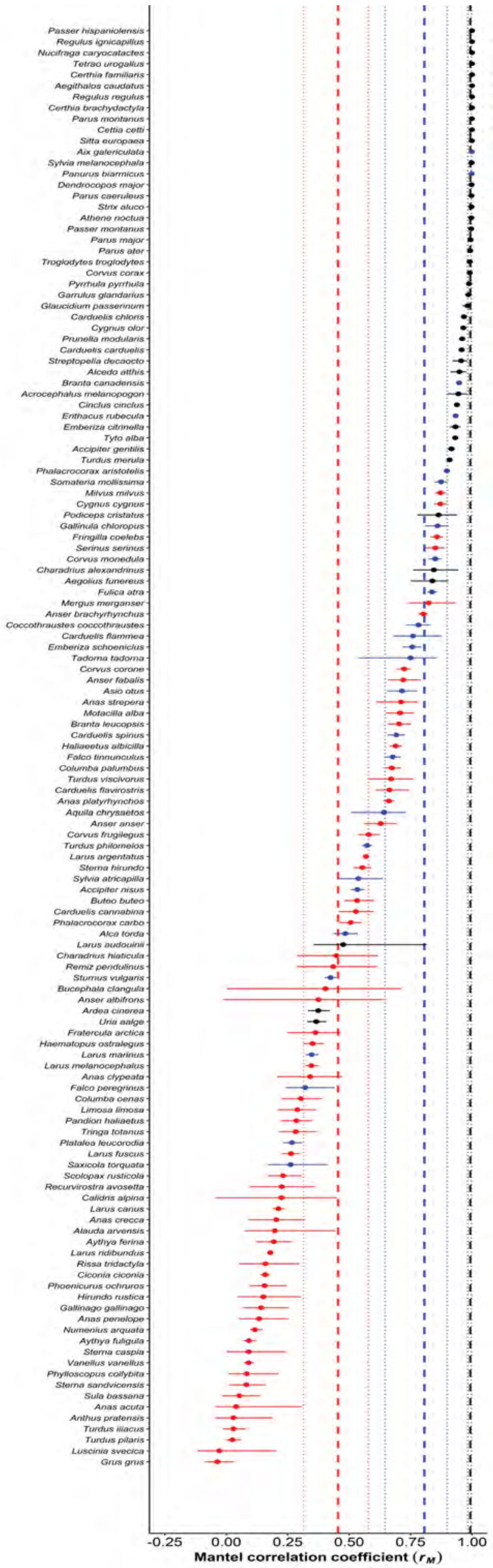

Figure 3.2: Forest plot showing the strength of migratory connectivity (r_M values and their 95% CIs) across the 129 species included in the comparative meta-analysis (black: residents; blue: partial migrants; red: full migrants). Dashed lines depict marginal means estimated by the phylogenetic model, dotted lines their 95% confidence intervals.

4. Historical changes in migration patterns

4.1 Background and objectives

Our world is changing and forecasting biodiversity changes is therefore important for society. Understanding past changes is a tool to predict those that will happen in the future. Thus, investigating such changes in movement patterns is important for the conservation and management of bird populations. Changes could involve the seasonal distributions of populations and might lead to increases or decreases in population sizes. For example, warming climate could lead to more migrants wintering further north or moving shorter distances; land use change could cause populations to respond to large-scale changes in feeding opportunities such as open dumps or other newly available resources arising from anthropogenic activities, or to habitat loss. Past changes in movement patterns provide an essential source for investigating and understanding the underlying causes and thus forecasting future changes. Ringing data provide a unique source of such information with the standardised method of bird ringing having been undertaken, mostly by amateurs, for more than a century.

4.2 Material and methods

To assess historical changes in bird movements, we analysed data available from the EURING Databank (EDB; du Feu *et al.* 2016). Two data sets were used – one of all recoveries and one of birds ringed during breeding and recovered during winter (breeding period defined as June-July and wintering period as December-February for all species).

All the analyses are based on recoveries of birds found dead to avoid the substantial biases caused by variation in recapture and resighting probabilities. For 128 species, there were a sufficient number of recoveries (more than 50) to investigate changes over time. Our focus is on estimating changes in migration distance rather than phenology. Complex changes might occur over the long time-span and large geographical area considered here. Whether calculated trends were likely to reflect true changes was evaluated by reviewing changes in latitudes and longitude during ringing and recovery both from trends and visually from maps, to judge whether the observed changes could be a result of changes in spatial patterns of ringing effort or recovery probabilities.

Picture 4. The new population of Red Kites (Milvus milvus) established in Britain migrates only short distances, while longer distance movements of other Red Kite populations are unchanged (Figure 4.5). © Canva.com

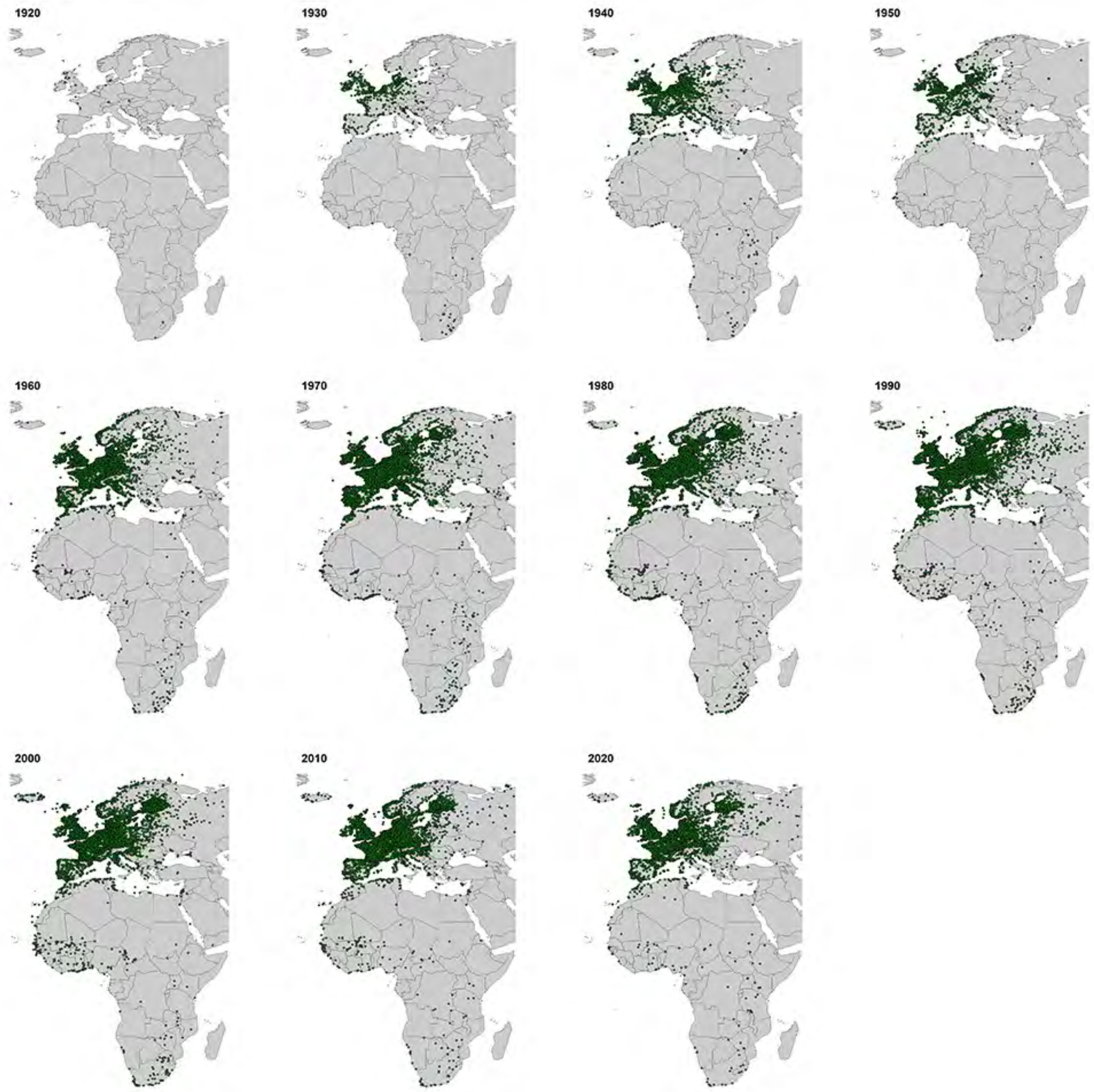

Figure 4.1 Distribution of recoveries of birds ringed during breeding and recovered during winter by decade. A few recoveries outside of the map range are not shown.

Furthermore, changes in recovery causes were checked to judge whether a change in recovery cause explained the apparent change in movement patterns. In some species, the breeding distribution has expanded over time and the resulting increase or decrease in movement distance was interpreted as a true change. The trends in distance moved were checked for whether the average distances showed changes or whether the trend is caused by increasing sedentariness.

Descriptive statistics are provided for recovery distributions per decade and species: Decadal geographical maps and changes over time in movement parameters, such as latitude/longitude of ringing and recovery, movement distance (distance between ringing and recovery locations) and sedentariness (proportion found within 100 kilometres).

At the European scale, population level changes might easily be masked by the merging of data from populations with opposing patterns of change. Furthermore, identifying true changes in movement patterns from ring recovery distributions is complicated by variation in ringing effort across populations and countries as well as by spatiotemporal variation in recovery probabilities. We assess some of these potential biases by developing two measures that correct for biases in spatiotemporal variation in recovery probability.

4.3 Results

Across the 128 species, migration distance became shorter (3.7 km per year), individuals wintered further north (0.02° per year) and sedentariness increased (0.2% per year). For 25 species, the ringing data documented changes in migration patterns over time. The migration distance changed in 13 species; in 7 species the wintering location changed and in 19 species individuals have become more sedentary.

Examples of consistent changes in White Storks *Ciconia ciconia* , Barnacle Geese *Branta leucopsis* and Red Kites *Milvus milvus* are shown in Figures 4.2-4.4. The migration distance of White Storks decreased steadily (74 km per year) and the spatial pattern changed from South and East Africa to a larger proportion wintering in the Iberian Peninsula and West Africa. Barnacle Geese and many other waterfowl decreased migration distance but winter distributions did not change accordingly. In Red Kites, the migration distance was much shorter in the new population in the United Kingdom.

The bias-corrected estimate of the proportion of individuals wintering north of the Sahara in long-distance migratory species increased overall, indicating that fewer individuals of these species now cross the Sahara.

The results provide a basis for future research on relating changes in migration patterns to climate and land use changes. Corroborating the findings here, requires studies at the species- and population-specific levels where more detailed analyses are possible and more factors can be taken into account. The approaches for dealing with recovery bias presented here provide promising avenues for studying changes at a smaller scale. The analyses and results provide a foundation for research on past changes and lay out a framework for relating changes in migration patterns to climate and land use changes, as is necessary for projections of migration patterns.

Figure 4.2 On average, species migrated shorter distances over time. Change in movement distance (km per year) across species. In the majority of species movement distances have become shorter over time.

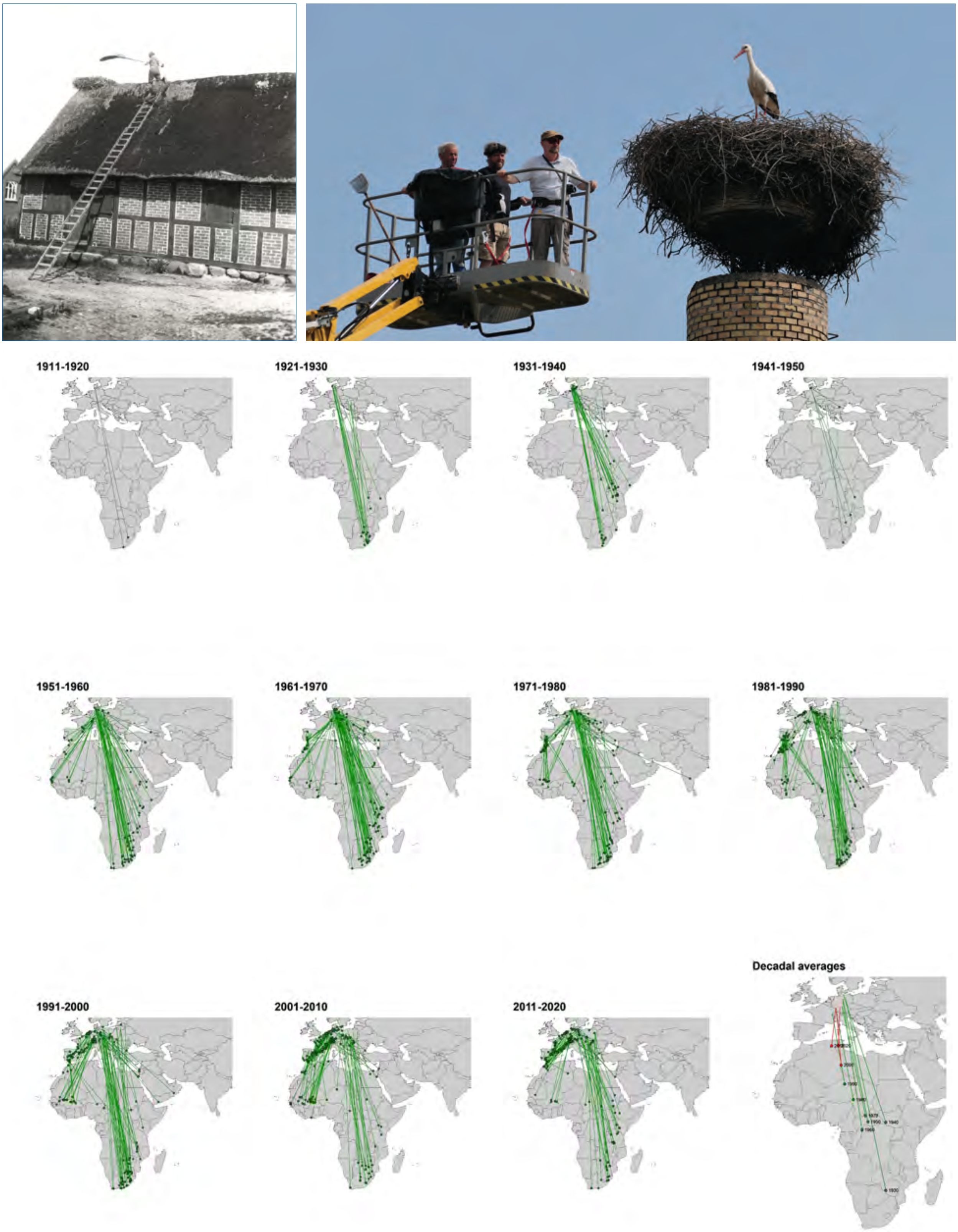

Figure 4.3 Ringing recoveries of White Storks from 1914 to 2020. White Storks are migrating shorter distances and more individuals winter close to where they breed. The wintering grounds have changed from southern and eastern Africa to West Africa and Iberia. Maps show the ringing and recovery locations for birds ringed during breeding and recovered during winter for each decade. The last panel shows decadal averages with the three latest decades in red.

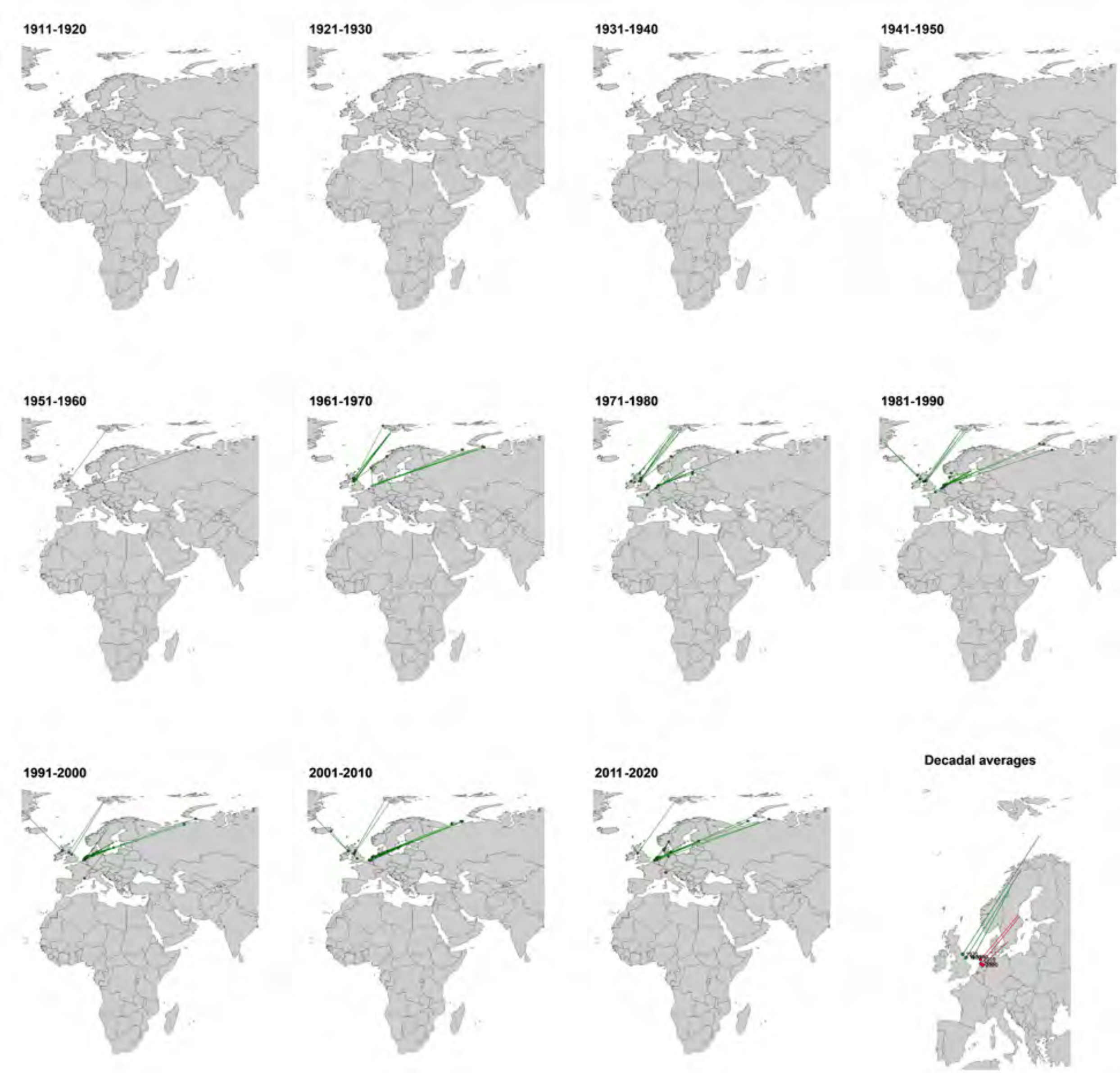

Figure 4.4 Barnacle Geese migrate shorter distances and more individuals winter close to where they were ringed. The species has colonised breeding areas closer to their wintering grounds resulting in distances becoming shorter. Maps show the ringing and recovery locations for birds ringed during breeding and recovered during winter for each decade. The last panel shows decadal averages with the three latest decades in red.

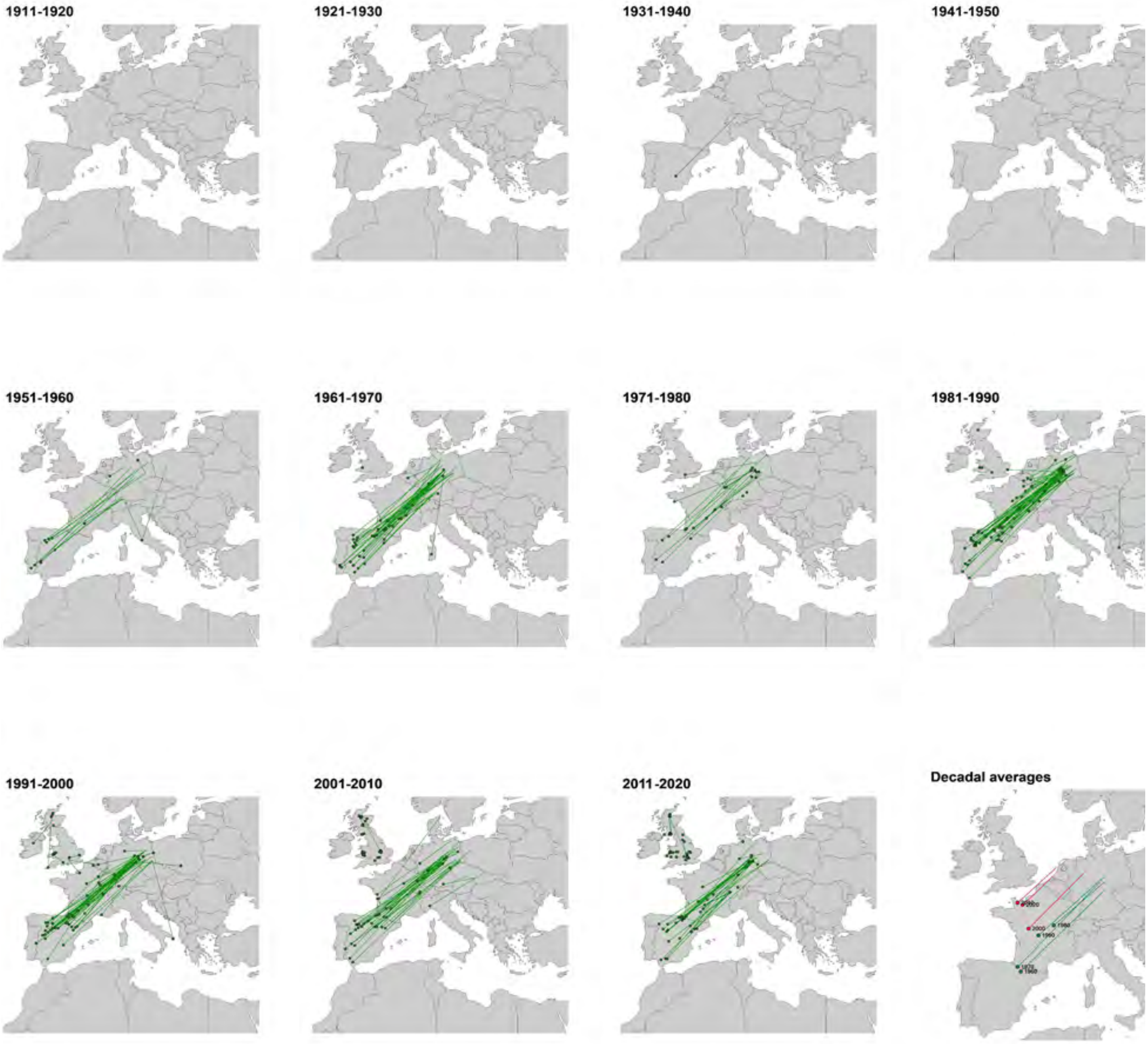

Figure 4.5 The new population of Red Kites in United Kingdom migrates short distances only. For other populations, there is no evidence that migration has changed. Maps show the ringing and recovery locations for birds ringed during breeding and recovered during winter for each decade. The last panel shows decadal averages with the three latest decades in red.

5. Migration season of hunted species

5.1 Background and objectives

The Key Concept of Article 7(4) of the Birds Directive 79/409/EEC is to "present information on the timing of the reproduction period and of prenuptial migration (return to the breeding areas) for bird species listed on Annex II of the Directive on the conservation of wild birds (79/409/EEC) occurring in EU28." Annex II species may be hunted under national legislation but not during their period of reproduction and, in migratory species, during their return migration to their rearing grounds. Therefore, reliable estimates of the timing of prenuptial migration are essential and data on individually marked birds can provide this information.

5.2 Material and methods

To analyse the timing of prenuptial migration we made use of the large numbers of recoveries of ringed birds available from the European Union for Bird Ringing (EURING) databank (EDB; du Feu *et al.* 2016).

The analysis used two different methodological approaches: (1) the analysis of the movements in space and time of each individual bird that was ringed and later recovered, dead or alive. (2) modelling the spatial and temporal course of return migration by taking any encounter of a ringed and/or recovered bird in a given geographical area into account. For details of both methodologies see the full report.

For assessing the timing of pre-nuptial migration by the use of recoveries we used only recoveries of birds moving north in a direction between 315-135°, because in Europe return migration movements are mostly directed north, northeast or northwest. Furthermore, of these recoveries only those that moved at least 100 km northbound were included in the analysis. To evaluate the seasonal course of northbound pre-nuptial (return) migration we considered only those recoveries which occured within the first 16 10-days periods (decades) of a year, which cover the period between 1 January and 31 May. Moreover, for geographical subdivision of the data we grouped countries into regional units.

For modelling the progression of bird migration we used conditional autoregressive models as described in Ambrosini *et al.* (2014) modified as described in

Picture 5. Eurasian Teal (Anas crecca) is a quarry species for which ringing recoveries provide good measures of the migration timing of different populations (Figure 5.1). © By Hobbyfotowiki - Own work, CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=87619423

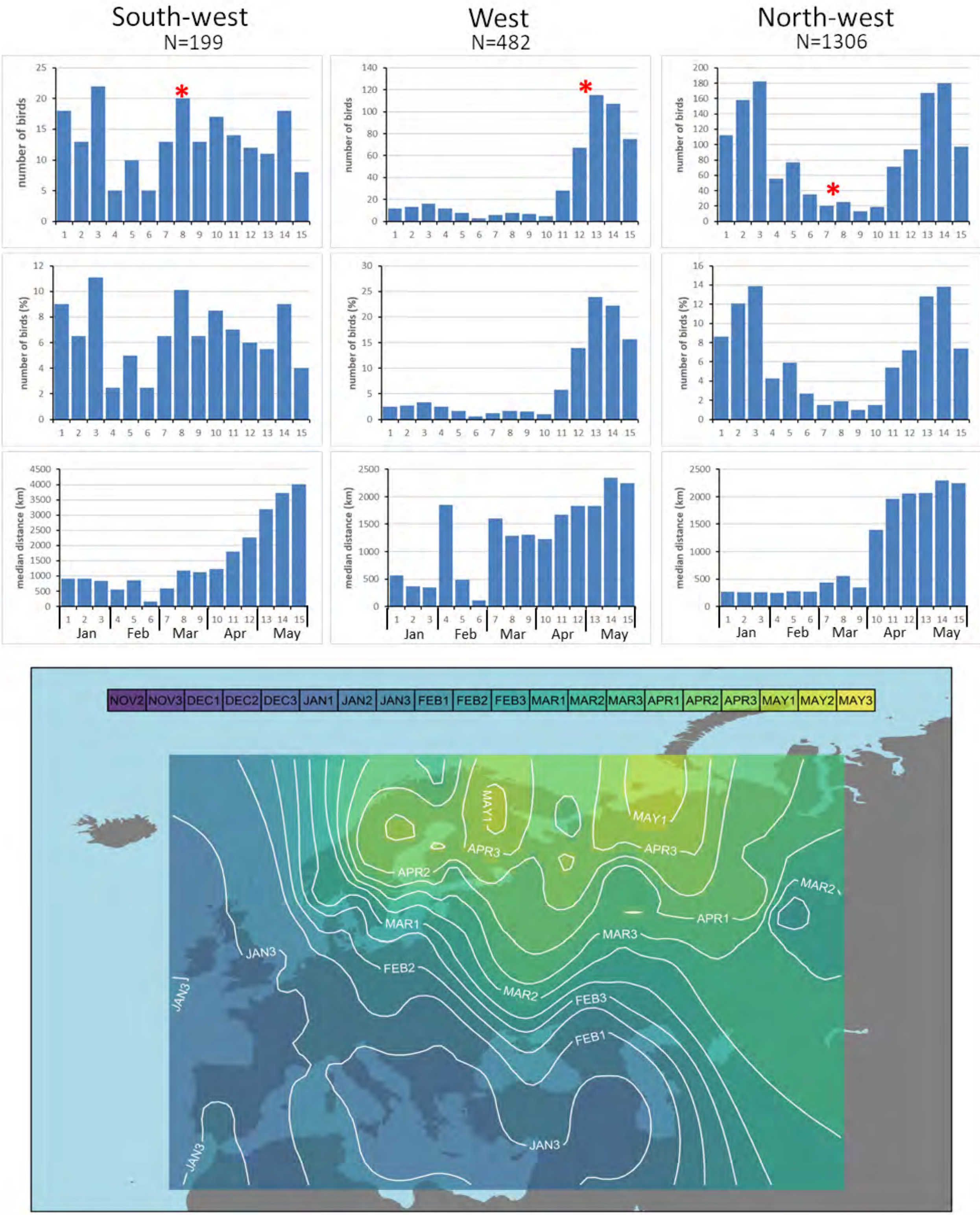

Figure 5.1 Top: Onset of prenuptial (return) migration of Eurasian Teal in the SW of Europe (southern France and the Iberian Peninsula), in the W (Central and northern France and Benelux countries) and in the NW (British Isles and Iceland) by decade and month based on individual ring recoveries. The upper graph in each panel shows the number of recoveries of birds that moved at least 100 km in northbound directions between the place of ringing and the place of recovery in each 10-day period between 1 January and 31 May (decades 1-15). The asterisk denotes the median date of onset of return migration. The middle graph shows the proportion of recoveries of birds that moved at least 100 km in northbound directions for each decade, and the lower panel depicts the median distance of these birds travelled in each decade. Bottom: Modelled onset of pre-nuptial migration of Eurasian Teal. The map shows the date when 5% of individuals are on migration (total number of ring encounters used: 30,454). Colours represent the decades; lines show the isochrones.

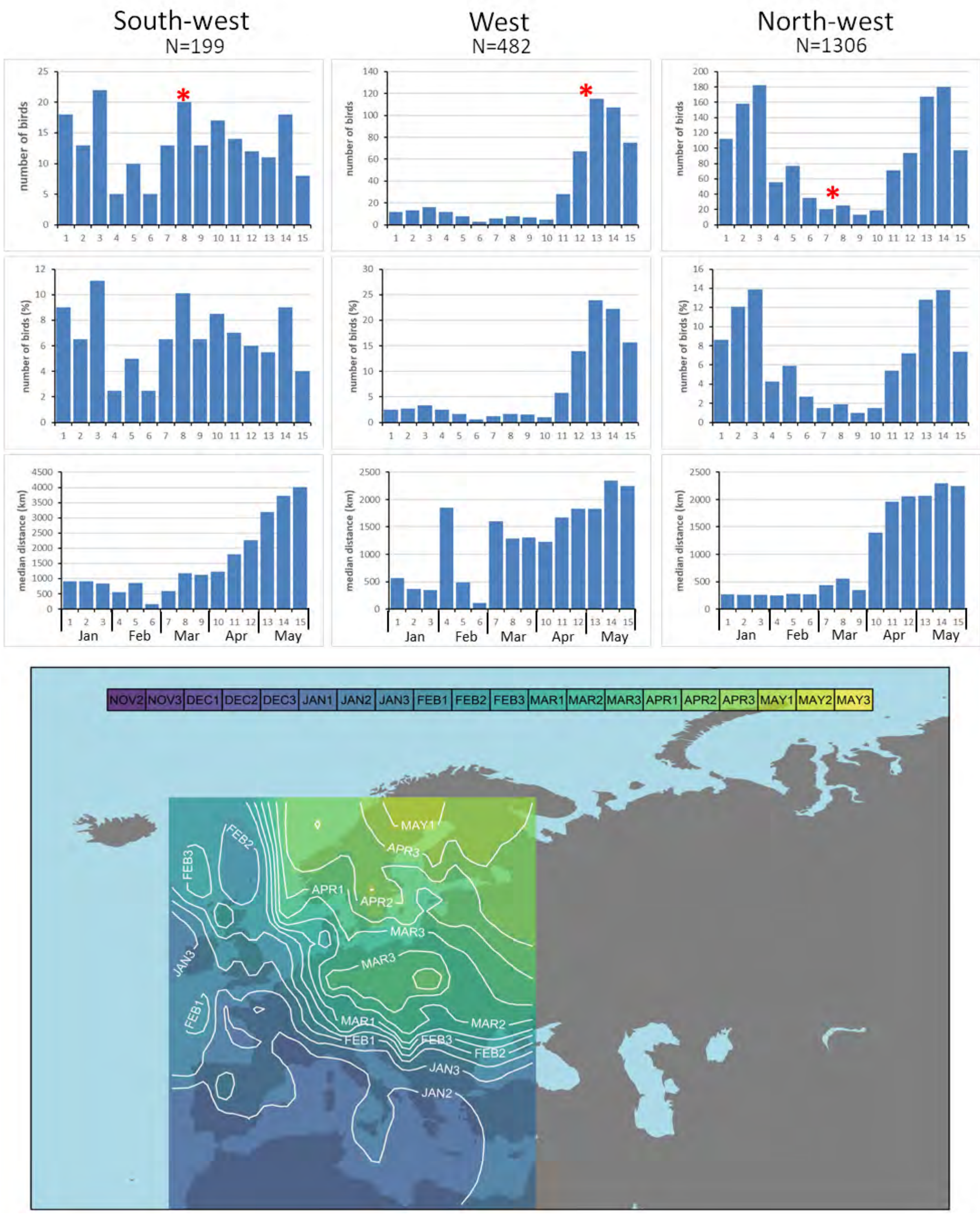

Figure 5.2 Onset of prenuptial migration of Song Thrush. Conventions as Figure 5.1 (number of ring encounters used for mapping: 54,448).

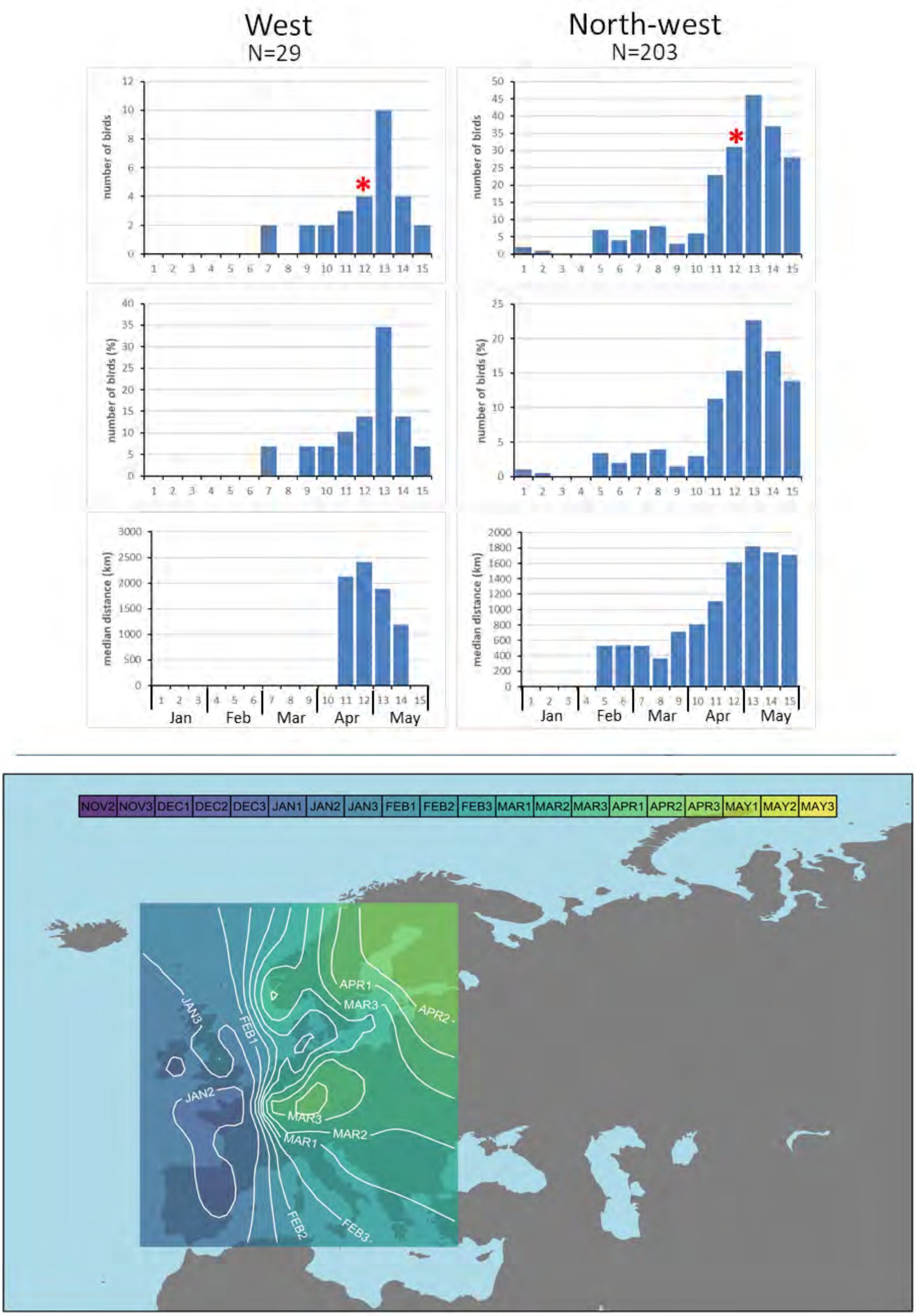

Figure 5.3 Onset of pre-nuptial migration of Eurasian Curlew. Conventions as Fig. 1. (number of ring encounters used for mapping: 6300).

details in the full report (https://migrationatlas.org/research-modules/migratory-connectivity). This approach calculates the proportion of encounters that occur in a location at different times of the year, and uses any encounter of a ringed and/or recovered bird.

Comparing these different methods revealed very similar results underpinning the validity of both. While the results of the recovery-approach are often limited by sample size the modelling enables a more robust assessment of migration movements with higher spatial resolution.

5.3 Results

Of the total of 80 species listed in Annex II of the Bird Directive as huntable in Member States 57 provided sufficient data for either recovery analysis and/or mapping of the onset of pre-nuptial migration. For the remaining 23 species neither recovery analyses nor mapping could be conducted because of a lack of sufficient data.

For each species with sufficient recovery data in at least one geographical region or with sufficient data for mapping we provide standardized figures and maps. Four cases are presented here to illustrate our approach: Eurasian Teal *Anas crecca*, Eurasian Curlew *Numenius arquata*, Turtle Dove *Streptopelia turtur* and Song Thrush *Turdus philomelos*.

Eurasian Teal (Figure 5.1): The analysis of recoveries of ringed birds in the SW of Europe (Iberian Peninsula and S-France) shows that Teal start their northbound migration as early as the beginning of the year (Figure 5.1 top) with median distances moved of more than 1000 km. This is confirmed by the modelling and mapping analysis which also shows that Teal start their prenuptial migration in the SW of Europe in early January (Figure 5.1 bottom). In western Europe prenuptial migration also starts at the beginning of the year but the numbers of Teal moving northbound remain rather low until the middle of April. However, those individuals that do move cover median distances of more than 500 km until early March and more than 1000 km thereafter, before main migration commences. In the British Isles, a first pronounced movement, though with median distances below 500 km, occurs early in the year, but most long-distance northbound movements are from early April onwards.

As with Teal Song Thrushes start their prenuptial northbound migration at the beginning of the year (Figure 5.2), particularly in the SW, although median distances

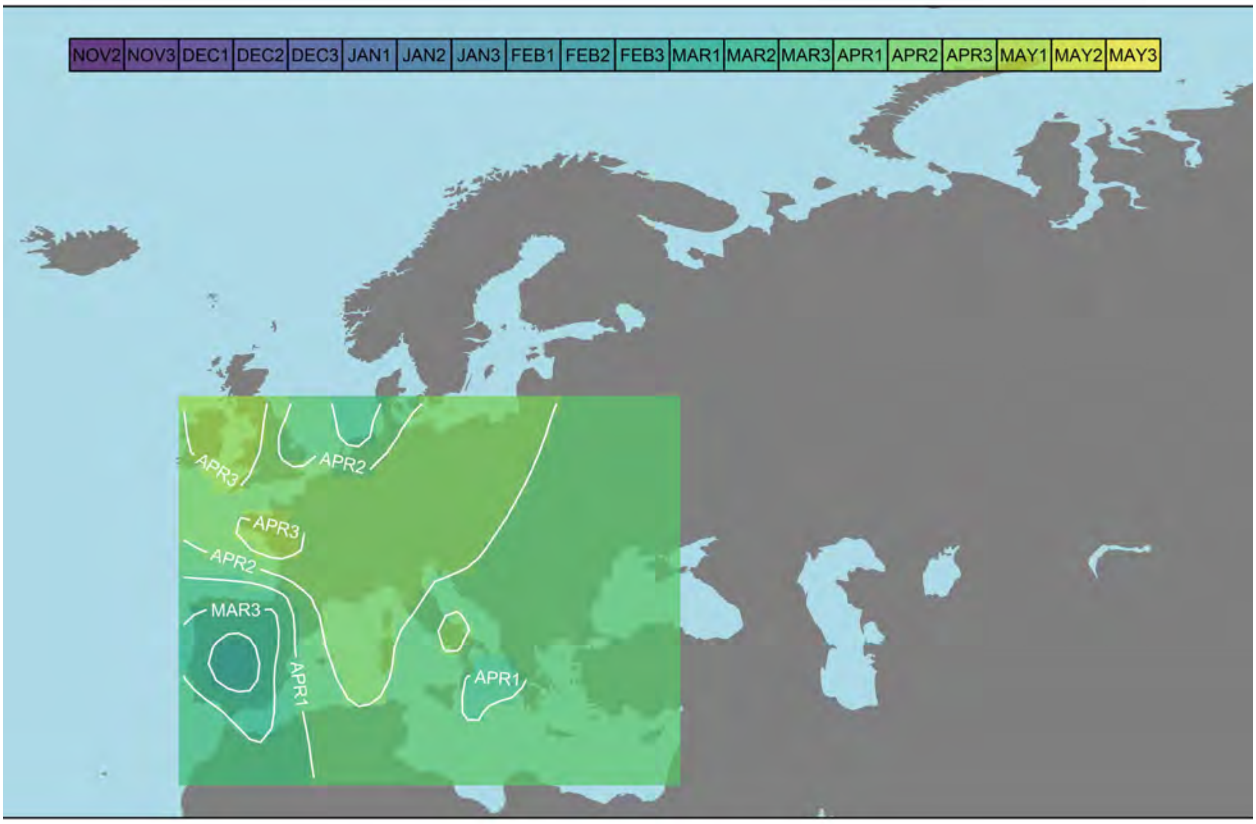

Figure 5.4. Onset of pre-nuptial migration of European Turtle Dove. The map shows the date when 5% of individuals are on migration (number of ring encounters used for mapping: 1125).

moved are relatively short. Longer movements commence from the middle of March onwards in the SW, and from the end of April onwards in the W. Song Thrushes in the NW (British Isles) move northbound mainly from early March onwards but in general rather short distances.

Many Eurasian Curlews spend the winter in western parts of Europe. Individual ring recoveries show that the start of their prenuptial northbound migration is not before the middle of February (Figure 5. 3), but mapping shows the onset of prenuptial migration already from mid-January onwards. Early distances moved are rather short; long-distance movements commence in mid-April.

While Eurasian Teal, Eurasian Curlew and Song Thrush spend the northern winter mainly in SW and western Europe, the Turtle Dove is a trans-Saharan migrant spending winter in the Sahel and savanna zone of western sub-Saharan Africa. The number of individual recoveries with northbound movements are insufficient for a robust analysis but the modelled mapping (Fig. 5.4) reveals that the first northbound passage in SW Europe occurrs as early as mid-March.

6. Intentional killing of birds

6.1 Background and objectives

The demographic effect of taking of individuals from a population through hunting or trapping varies in relation to the numbers, sex- and age-classes of the individuals taken, as well as the phenological phase when the killing or trapping takes place (e.g. during breeding, or on post-nuptial vs pre-nuptial migration or wintering). European legislation governing harvesting of bird populations has taken these issues into account, implementing measures guided by sustainable harvesting models.

For millennia man has killed or trapped birds for food and, in more recent times, for leisure activities (sport hunting, caging). Attitudes towards harvesting of bird populations, along with national and international laws, have evolved over time, with a growing awareness of the decline in the conservation status of various bird populations. The opportunity to investigate long-term changes in the intentional taking of wild bird populations is of special interest, as the illegal or unsustainable killing of birds has been identified as a significant conservation issue.

Although most countries have adapted their national legislation to implement international environmental treaties, illegal taking continues in many countries. Initiatives under CMS (and in Europe, the Berne Convention) address the illegal killing, trapping and trade in wild birds (IKB) in the Mediteranean and elsewhere.

With respect to legal taking through, for example, sport hunting, there is still a lack of sound, detailed and regularly updated information on which permitted hunting levels can be based. The overall size of the annual harvest of different species, as well as its geographical and seasonal distribution across the EU is still poorly documented.

Thus the long historical coverage offered by the contents of the EURING Data Bank (EDB) represents a unique opportunity to improve existing knowledge of the causes, circumstances, changes and trends of intentional taking of birds in the region. Here we investigate this on a geographical, historical, and seasonal basis, as well as with reference to the different methods adopted and the taxonomic groups affected.The analysis also considers and describes changes in historical patterns of intentional taking with the entry into force of the European Birds Directive, with signs of positive effects of species listing and of increasing compliance with this important environmental legislation.

Picture 6. A Red-backed Shrike (Lanius collurio) caught on lime stick in Egypt. © Mindy El Bashir/Nature Conservation Egypt

6.2 Material and Methods

Although the EDB dataset provides a large volume of relevant data, it is well known that recoveries of ringed birds can be affected by variability, in time and space, in the willingness of finders to report a ringed bird. This is particularly so when recoveries originate from intentional killing or trapping, especially in the case of protected species. However, there is no other dataset, either from ringing or any other type of information, which is free from such possible biases. Every recovery of a ringed bird within the EDB includes standard codes for the conditions and circumstances of recovery, based on which we could filter only those cases of birds reported as intentionally killed or trapped by man. In this way, we obtained a dataset composed by the following cases:

1,553,872 individuals
391 species
73 families
23 orders
147 countries
119 years, from 1900 to 2019

For details on methods used in each of the different analyses, see the full report (https://migrationatlas.org/research-modules/intentional-killing).

6.3 Results

In dealing with this complex subject, we started with a general data exploration. Our overview of historical, geographical (Figure 6.1), and taxonomic patterns confirmed a general declining trend in the reporting of deliberate killing of wild birds by man (Figure 6.2). We considered several possible reasons for this reduction and tested the role of the entry into force of the EU Wild Birds Directive, as the first European environmental legislation. In our analyses we considered multiple spatial and temporal scales. At a large scale we analysed how the intentional killing and taking of birds varied with the entry into force of the Birds Directive, both for the original EU members and for those that joined more recently. When focusing on species listed in Annex I (strictly protected) and Annex IIA (huntable across the EU) of the EU Directive, it was possible to demonstrate a marked decreasing historical trend in reporting of the former group of species. In terms of seasonal patterns, we describe different temporal dynamics across countries in reporting intentional killing of birds listed in Annex IIA.

At a finer scale, we analysed the geographical distribution of "black-spots" (i.e., sites/areas of particularly intense deliberate killing of birds by man). Detecting these areas, where the likelihood of deliberate killing of birds is high, can be beneficial in

Figure 6.1 Map of overall data. For each country (centroids of coordinates/country) a pie-chart shows the frequency of intentional (dark blue) and not intentional (green) killing of birds. Not intentional includes other specified causes such as road casualties or predated, but not records simply recorded as "found dead".

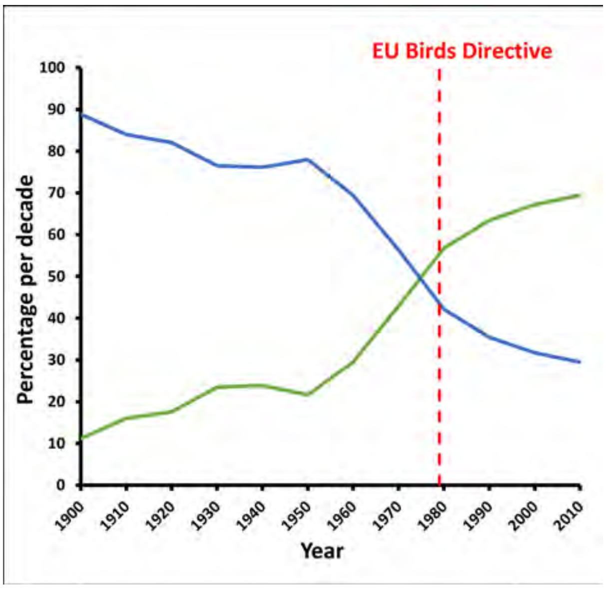

Figure 6.2 Overview of the historical distribution of the intentional killing (blue) and not intentional killing (green) as a percentage of cases per decade. The red dotted line and arrow highlight the entry into force of the EU Birds Directive. Data are from all EU countries.

dealing with this important conservation issue. The black-spot identification was performed at different spatial resolutions, starting with the whole Eurasian-African flyway and narrowing down from the European region to single EU countries. The results of each analysis are relative to the geographical scope and period considered, allowing both the global and local exploration of this issue, and identifying which regions within a country show the highest estimated probabilities of deliberate killing. Furthermore, this is one of the first attempts to date to identify critical areas of deliberate killing of birds in Africa based on ring recoveries, so as to inform conservation actions on the ground.

When considering protected species, the map obtained by spatial interpolation of the data covering the period after the EU Birds Directive showed a considerable change in the Mediterranean region, including the Balkans and Tunisia, while the black-spot locations in the cells covering the Middle East remained similar. In Europe, these results suggest a positive effect of the entry into force of the EU Directive. In Italy the presence of black-spots persisted locally, in areas in the north and south, while a wide black-spot remains in areas of the Balkans and in Greece (Fig.6.3). Across Africa the black-spot location moved with time from North-Western countries towards more South-Eastern ones (for details see main report).

When considering huntable species, the data covering the period after the EU Directive indicate areas where estimated black spots caused by deliberate killing remained. In North Africa, black-spots are distributed particularly along the Mediterranean coasts and in Mauritania, with an improving situation in the Middle East, but remaining critical across Turkey, Syria and Lebanon. Within the seasonal limits of possible hunting seasons, the frequency of deliberate killing reports changed only in some areas such as the UK and Norway, which became "cold-spots", while the other black-spot areas identified before the EU Directive remained and, in some cases, became larger and showed increased intensity (i.e. Portugal, Pyrenees, Italy, Greece and Albania, Finland; Fig.6.4).

Finally, we exploited the unique features of the EDB to estimate the frequency of the "look-alike problem" (i.e., intentional killing of non-huntable species which are wrongly identified as legally huntable ones). Despite the limited sample size of cases available, across the EU15 countries we identified such events affecting over 90% of the protected species listed in Annex I of the EU Directive. Such events occurred both before and after the entry into force of the Birds Directive. Deliberately killed birds of protected species are generally identified as belonging to huntable species, while a high frequency of cases of wrong identification refers to mismatches between species belonging to pairs of huntable ones.

The results of this research module contribute to a better knowledge of historical changes, categories of species affected and methods used, and provide unique spatio-temporal and cultural perspectives on the deliberate killing and trapping of birds by man across the whole Eurasian-African flyway. This general overview also provides a useful reference to inform the intense

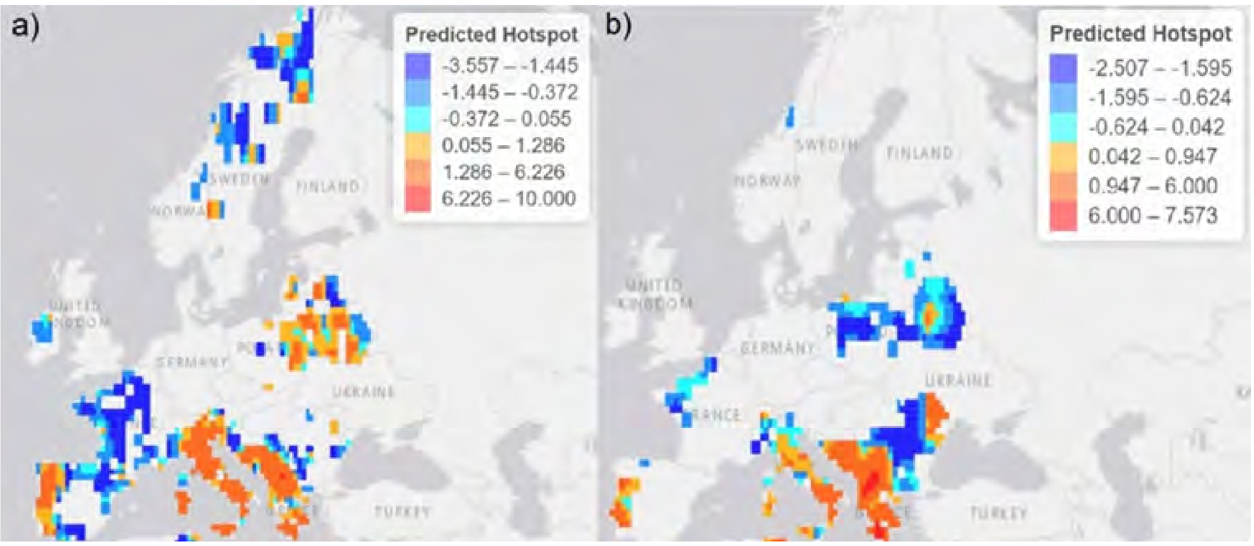

Figure 6.3: Local black-spots of deliberate killing of species listed in Annex I of the EU Birds Directive, focusing on the European region. Only the locations with high values (above the third interquartile of the average distribution of probability) are shown, using a 0.5 x 0.5 pixel grid and combining all data before (a) or after (b) the entry into force of the EU Birds Directive.

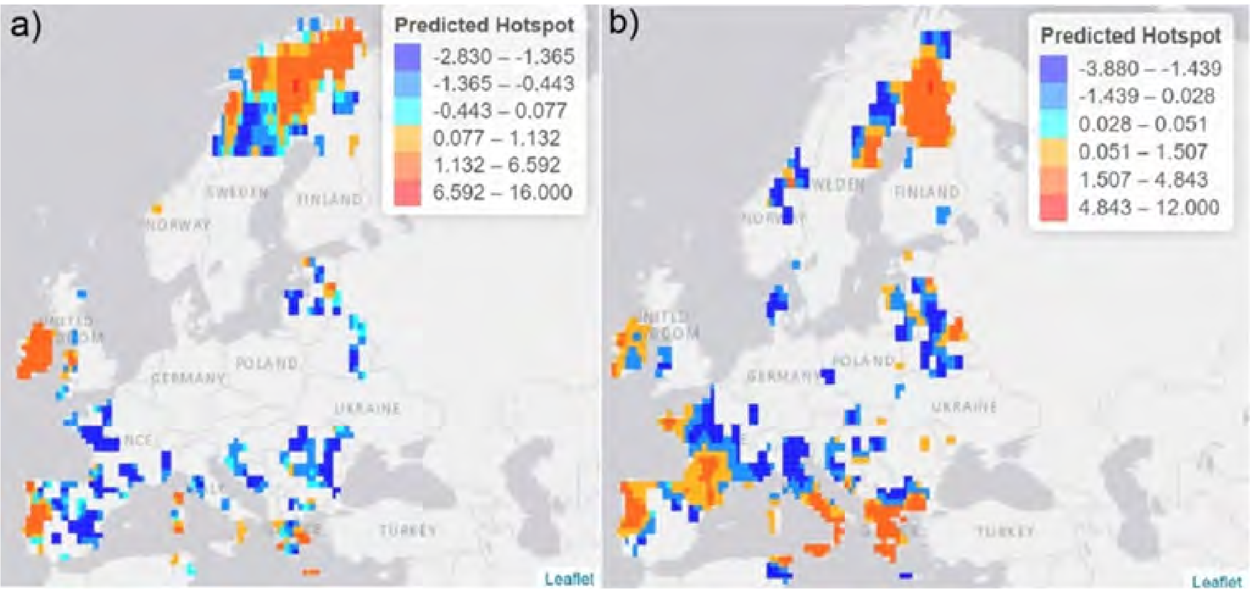

Figure 6.4: Local black-spots of deliberate killing of species listed in Annex IIA of the EU Birds Directive during the period Sept-Mar, focusing on the European region and considering only the worst locations (above the third interquartile of the average distribution of probability), visualizing them over a 0.5 x 0.5 degree grid before (a) and after (b) the entry into force of the EU Birds Directive.

A reduction of black-spots was recorded across the EU during those months which fall outside legal hunting seasons (Figure 6.5).

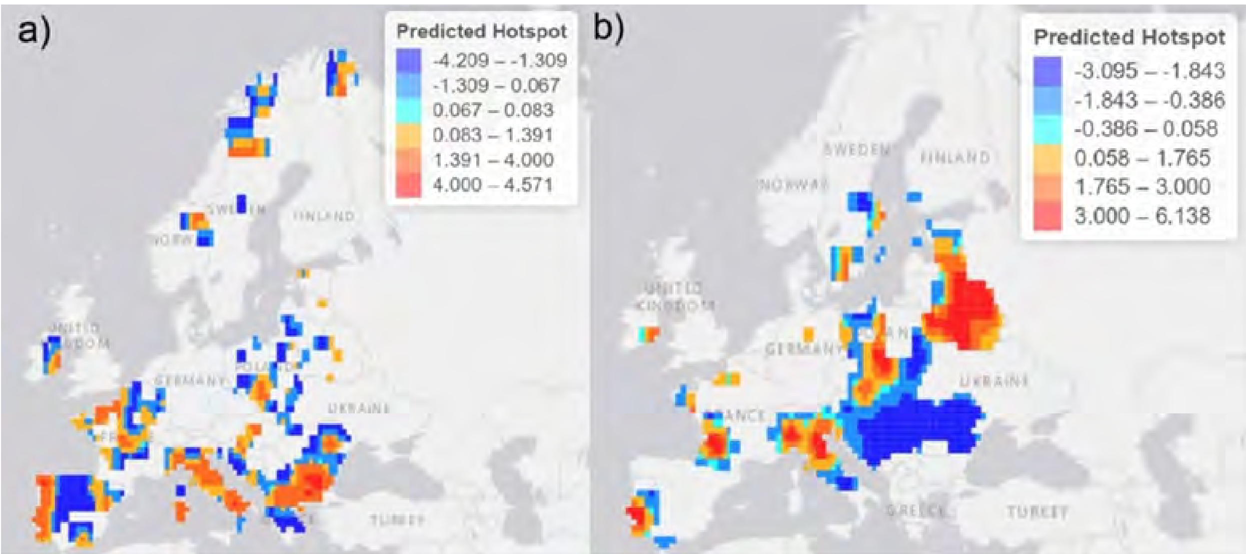

Figure 6.5: Local black-spots of deliberate killing of species listed in Annex IIA during the period May-Aug, focusing on the European region and considering only the worst locations (above the third interquartile of the average distribution of probability), visualizing them over a 0.5 x 0.5 degree grid before (a) and after (b) the entry into force of the EU Birds Directive.

activities carried out by CMS and the Berne Convention. This is important for addressing illegal killing, especially within the Mediterranean region, through conservation actions and priorities firstly outlined in the Larnaca Declaration, which was adopted at the 1st European Conference on illegal killing, trapping and trade of birds (IKB). Subsequent actions include the Tunis Action Plan, the setting up of the CMS Intergovernmental Task Force on Illegal Killing, Taking and Trade of Migratory Birds in the Mediterranean (MIKT) with the Cairo Declaration and a detailed PoW, and more recently the Rome Strategic Plan.

Our findings from analyses of the long time series of data on intentional taking of birds by man along a whole flyway are also useful for understanding changes in bird harvesting activities across different geographical areas and cultures. The opportunity of looking at these data, gathered over more than a century, helps us to understand the drivers which lead to continued illegal killing and trapping of birds. A very general pattern in frequency of recoveries due to intentional killing and trapping across most European countries during the last ca 120 yrs. shows peak values in the 1960s and 1970s, despite ringing activities (i.e. numbers of ringed birds) not peaking in the same years. Hence, we may infer that those years have seen a real maximum in killing intensity within our study period.

In terms of legal aspects of harvest, this module offers new insights into the role played by international environmental legislation, as exemplified by the EU Wild Birds Directive, in setting principles of sustainable harvesting and in improving bird conservation across the European Union. The historical patterns of relative frequencies in different circumstances and methods of intentional killing within the EU, in particular when considering the shooting of birds, provide support for a positive effect of the entry into force of the Directive. This is particularly true when considering species which are listed in Appendix I and the situation recorded before and after the implementation of the Directive. Also when considering areas of particularly intense intentional killing of birds, be it legal or illegal, here defined as “black spots”, the geographical distribution and intensity of harvesting show positive changes after the onset of the Birds Directive, although intensive killing still continues over large areas. Although there is a negative trend in the hunting of species listed in Appendix IIA, which are legally huntable across the EU, the rate of decline is markedly less pronounced compared to protected species. The large geographical area considered in the analyses, and the similarity of historical patterns across many different countries, suggest the differences between species with different legal status show a real effect of the Birds Directive and are not a bias caused by not reporting the intentional taking of a legally protected species.

The time series and geographical scope of the dataset analysed here indicate significant differences across countries in intentional taking, together with methods used and categories of species affected. The geographical scope of initiatives carried out by Multilateral Environmental Agreements (Berne Convention, CMS with MIKT) to identify illegal activities in particular are confirmed by our analyses, with the Mediterranean including North Africa and the Balkans as critical areas. Also within Africa, the relative frequencies of intentional killing have an uneven distribution, with areas of high intensity, as in West African countries, largely matching the wintering quarters of many species and populations breeding and moving across Europe.

Our description of general historical and geographical patterns of intentional killing in time and space should be useful for interpreting the maps provided by this atlas, together with information on spatio-temporal return movements of huntable species during a particularly critical phase of their annual cycle, as well as on connectivity which is covered by a separate module.

The patterns of temporal variation in deliberate killing recorded in our analyses suggest a positive trend towards decreasing harvesting and increasing compliance with international legislation, both across major components of the flyway and also within areas which still show critical levels of killing. From this perspective, several of our results demonstrate a significant and positive role of the EU Birds Directive, the first example of environmental legislation within the EU. This in turn has contributed positively to improving attitudes towards the intentional harvesting of wild bird populations.

7. Policy Relevance of the Atlas

7.1 The Atlas for international cooperation on bird conservation and management

This Atlas offers a tool for informing the implementation and development of conservation instruments and strategies and environmental legislation on birds. Under CMS, the results offered by the different components of the Atlas are expected to provide support for the implementation of several instruments developed in the framework of the Convention, such as the Agreement on the Conservation of African-Eurasian Migratory Waterbirds (AEWA), as well as the Memorandum of Understanding on the Conservation of Migratory Birds of Prey in Africa and Eurasia (Raptors MoU) and the African-Eurasian Migratory Landbirds Action Plan (AEMLAP). A large number of species of interest for all these conservation instruments and initiatives are covered by this Atlas, with new insights into migration patterns at the species and population levels and into human-related issues affecting species and populations. This is important, from a CMS perspective, and for general conservation strategies along the main flyways (see CMS resolution 12.11 on Flyways). In terms of contributing to the implementation of other existing international environmental legislation, the Atlas offers many different and relevant perspectives for the EU Council Directive 2009/147/EC on the conservation of wild birds (Birds Directive). Virtually all species covered by the Directive are included in the migration maps and associated species' accounts. In addition, two research modules, on migration seasons of hunted species and on intentional killing of birds by man, provide specific information of direct relevance to its implementation. Information in the migration maps and species accounts is also very relevant to the implementation of the Berne Convention on the Conservation of European Wildlife and Natural Habitats.

7.2 The Atlas as a contribution to the CMS Global Atlas of Animal Migration and to strategies for the conservation of migratory species of wild animals

The Atlas is a significant contribution to the Global Atlas of Animal Migration project (CMS GAAM). It is also expected to contribute to the development and implementation of a variety of strategies for the conservation of migratory species. Outlined below are some key aspects of what its different components can contribute.

Data typology and management, data mapping

This Atlas makes use of data on individually identifiable birds through the use of ring recoveries and tracking data. Both types of data are used for the interactive mapping tool, while the research modules are based entirely on ring recovery data as this provides a more complete geographical and temporal coverage. From a CMS GAAM perspective, analyses of any data allowing unique identification of individual animals (e.g., fin tags for sea turtles or fish, patagial rings for bats), including identification without tagging (e.g., as in the case of photo ID of cetaceans) can benefit from the tools and analytical models used for this Atlas. Large datasets based on individual identification exist for cetaceans, sea turtles, marine and freshwater fish and terrestrial mammals, including bats. Protocols used for this Atlas for data checking, selection and preparation, web tools for data visualization and analytical model developed for the different research modules can potentially be adapted to process datasets on other taxonomic groups in order to optimize mapping and analytical efforts. The web solutions used to map individual movements by overlaying different types of data from ringing and tracking can directly support analyses on other groups of taxa, such as terrestrial mammals, cetaceans or sharks. The bird Atlas has also solved many technical computing issues on how best to use geo-referenced data and how to manage excessive data richness at the individual level. Approaches have also been developed for optimal selection of symbols, colours, map structure and visualizations, enabling the Atlas to offer interactive user-friendly mapping tools with a wide range of options.

Movement maps produced for birds, and all those which can potentially be produced for other groups of taxa, document migratory movements in time and space, in particular from the perspective of the annual cycle of migrants. This is highly relevant to conservation when considered in relation to the distribution of protected areas and other area-based conservation measures (OECMs), both on land and at sea. One example involving birds is the Critical Sites Network which is very important for CMS instruments such as AEWA. Here the Migration Atlas maps complement the Critical Site Network Tool by providing key information on movement patterns and on links between protected areas. It can also, for example, provide sound indications of the distribution of areas used by high concentrations of migrants which may be important for the Raptors MoU. When considering the conservation needs of marine species, e.g. the distribution and boundaries of IMMAs for marine mammals, together with the lack of protected species for areas which may be identified through mapping of existing data, this geographical approach to documenting the movements of migratory species can support the evaluation of the functional role of protected area networks for large-scale international conservation strategies. Many of the maps produced by the Atlas can offer an important contribution to CMS initiatives on spatial planning, for example the complex perspective of possible interactions between renewable energy infrastructure and animal migration, with a special emphasis on the risks of collisions of migratory birds with wind farms. Detailed maps of the seasonality of movements of a large array of species across a huge geographical area can help to define strategies aimed at minimizing mortality risks caused by energy infrastructure.

Migratory Connectivity

Migratory connectivity is defined as the linkage among individuals between the periods and areas where they spend different phases of their annual life cycle. A specific research module has been devoted to this topic, with analyses for a group of 137 species providing quantifitative measures of migratory connectivity. A better understanding of how individuals are linked to others when they move in time and space is crucial for strengthening the approach towards shared and better "connected" environmental policies among different countries, across which the same individuals and populations move. In recent years, CMS has been leading on the need for conservation strategies for migratory species to be supported through awareness of the key importance of connectivity for migratory species. Thus the results of this Atlas module on migratory connectivity are of direct interest for all CMS instruments specifically targeted towards birds. This is also the case for legal instruments like the EU Birds Directive, given the importance of connectivity, for example, in relation to the sustainable hunting of migratory species. Furthermore, the modelling approach used in this Atlas can be transferred and adapted to similar data on different taxonomic groups that fall within the CMS GAAM.

Historical changes in migration patterns

Migration is a response to variations of ecological conditions in time and space and the distributions of migratory species are therefore strongly linked to environmental seasonality. Thus migratory species are particularly sensitive to climate change. CMS has been addressing the impact of climate change on migratory species for many years, focusing on the assessment of the vulnerability of migratory species to climatic variations and the development of strategies and approaches to help migratory species to adapt. As a contribution to these efforts, a module of this Atlas is devoted to studying changes in migration patterns over time. This work was only possible thanks to the long period covered by data held in the EURING Data Bank, with recoveries of ringed birds encompassing over one century across a huge geographical area. Previous analyses have already demonstrated how different species of migratory birds are trying to adapt to the new challenges posed by climate change, for example by timing their return migration to the breeding grounds in relation to conditions in stopover areas (as in the Pied Flycatcher *Ficedula hypoleuca*; Both *et al.*, 2005), or through a progressively earlier arrival at Mediterranean stopover areas from wintering grounds in Equatorial Africa (Jonzen *et al.*, 2006). There is also evidence of wintering in progressively more northern areas of sub-Saharan Africa (as in the Barn Swallow Hirundo rustica, Ambrosini *et al.*, 2011), and of wintering in areas which are progressively closer to their breeding grounds (as in the White Stork). Modelling these long-term trends in migration patterns is a challenging task. The EURING databank provided us with the largest existing set of data to address these issues across a substantial number of species. In the context of a growing concern for the negative effects of climate change on many aspects of wildlife ecology, the approach and results of this module of the Atlas can inform similar analyses on other taxonomic groups for which relevant time-series of movement data are available.

Migration seasons of hunted species

Hunting was a key element of human subsistence in the past. It continues to play an important role in the subsistence for indigenous peoples and local communities, while it is also widely undertaken as a leisure activity in many parts of the world. Sustainable harvesting of natural populations needs to follow patterns of natural mortality as much as possible, in order to minimize the risk of additive mortality arising from hunting. Thus hunting should concentrate on age classes which are most vulnerable to natural mortality (e.g., inexperienced juveniles in the post-breeding period), while avoiding harvesting potential breeders which have survived the phases of peak natural mortality and will soon reproduce. In the case of birds, relevant international environmental legislation like the EU Birds Directive recognizes these management principles and foresees complete protection of migrants after the onset of their return movements to the nesting grounds, given that these birds are regarded as being potential breeders that will ensure the resilience of populations (see Article 7.4 of the EU Birds Directive). Long-lasting efforts at the EU level have been devoted to collecting phenological data on the onset of return migration of each of the huntable species under the Birds Directive and from each of the EU Member States, and data have been reported in a specific "Key Concept Document" in 2014, which has subsequently been updated. While data have been collected and analyzed at the level of individual countries, this approach has shown limitations, with frequent inconsistencies between the migration seasons defined by different EU Member States. The Atlas provides a module based on an innovative modelling approach, applied to the huge amount of data available in the EURING databank. For the first time, at the scale of the territory of the EU, estimates are provided of the onset of return migration for many of the huntable species covered by this aspect of the Birds Directive. This module provides data of direct relevance for the implementation of one of the most debated articles of the Birds Directive, as well as for significant initiatives which are being developed under, for example, AEWA in terms of adaptive harvesting models of selected waterbird species (additional information available here). This approach may also be useful when considering sustainable harvesting models in other taxonomic groups.

Intentional killing of birds

The time series of data analysed provided an important opportunity to investigate patterns of historical and geographical variation in the intentional taking (both killing and trapping) of wild birds. When breaching the principles, as set also in international legislation, for sustainable harvesting of bird populations, the taking of birds becomes unsustainable for the populations concerned. In many cases it may also be illegal. The results of this module offer the first description of the frequency and distribution of intentional killing across the whole Eurasian-African flyway and identify areas of particularly intense harvesting (be it legal or illegal), both in Europe and Africa. A general overview of seasonal patterns confirms the uneven distribution of intentional killing, with peak monthly values falling within legal hunting seasons across most countries, while methods of taking other than shooting have higher values during what is the breeding period for most species. Historical trends show large-scale decreases in intentional killing. This pattern is at least partly explained by a positive increasing trend in compliance with the EU Birds Directive, the most relevant legal instrument on the taking of birds within the geographical scope of the analysis.

The results are of direct interest not only from a Birds Directive perspective, but also for CMS and the Berne Convention. The latter have been very active in seeking to reduce illegal killing, especially within the Mediterranean region, through conservation actions and priorities firstly outlined in the Larnaca Declaration, adopted at the 1st European Conference on illegal killing, trapping and trade of birds (IKB) in 2011, the Tunis Action Plan in 2013, the setting up in 2016 of the CMS Intergovernmental Task Force on Illegal Killing, Taking and Trade of Migratory Birds in the Mediterranean (MIKT), with the Cairo Declaration and a detailed PoW and, more recently, the Rome Strategic Plan. The analyses within this module indicate negative trends over time in terms of IKT. The module also includes analyses of the extent and distribution of the so called “black spots” of IKB, which identify areas in which intentional killing is particularly intense. In this case, despite large areas of particularly intense taking of birds, a positive general reduction over

Picture 7. Understanding of the movements of raptors that migrate between Europe and Africa is important for the implementation of the Raptors MOU- Osprey (Pandion haliaetus) © Canva.com

time was identified. For birds, these results are of direct interest for IKB activities by CMS-MIKT and the Berne Convention; still within CMS, intentional killing of birds is a relevant subject for instruments like AEWA, the Raptors MOU and the Landbirds Action Plan. Furthermore, this module offers insights which are useful in relation to the expanding geographical scope of IKB monitoring, for example along the East Asian-Australasian flyway. Finally, the historical and geographical perspective provided by these analyses can support similar efforts to address active taking of animals from other taxonomic groups, with special attention to the complexities involved in managing migratory populations.

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