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Review

Lessons from GPS-tagged Eurasian Curlews: synthesising movement ecology to inform conservation

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ABSTRACT

Remote tracking of animals complements traditional marking and recapture methods across ecological studies, improving estimates of demographic rates, migration connectivity, habitat selection, and social interactions. Its insights into how individual behaviour scales up to population dynamics are especially critical for effective transnational conservation, particularly for threatened migratory species. Here, we synthesise over two decades of GPS tracking data from 626 Eurasian curlews (*Numenius arquata*) to assess how movement ecology informs conservation and policy for this species of high conservation concern across Europe. We show how tracking has refined our understanding of migration connectivity, demography, and habitat selection, and how it can be translated into actionable insights for conservation. Tracking data provided unprecedented information confirming strong site fidelity among adult curlews and evidence of local recruitment. It highlights the importance of young birds' survival until they become reproductively mature and recruit for the population dynamics, and therefore the need for appropriate conservation measures. At the same time, this review shows how movement data contributes to or can contribute to characterize most of the threats to curlews, such as human disturbance or the development of human infrastructure. These findings translate into policy recommendations, including habitat protection, network-based conservation of migratory nodes, mitigation of anthropogenic threats, and the strategic use of population reinforcement. Overall, this synthesis highlights the critical role of individual-based tracking in bridging ecological knowledge and conservation action and provides guidance for the future use of tracking data to improve the conservation status of the Eurasian Curlew along its flyway.

Animal conservation is a mission-oriented science that focuses on how to protect and restore animal populations and their habitats. It especially aims at improving the conservation status of threatened species. Within such a research-action framework, understanding how population-level dynamics emerge from the behaviour and fate of individual animals (Lomnicki, 2018) – how they occupy habitats, select resources, survive, reproduce, move, disperse, and migrate – is key for identifying and proposing effective management and restoration actions that are most valuable for long-term species conservation. In field ecology, research programmes are based on natural or experimental observations of animals in the wild to document their occurrences, behaviours, numbers, and trends. Field ecologists often use individual marking to study vertebrate populations and understand the mechanisms that govern their functioning. The monitoring of marked individuals allows documenting demographic rates (McCrea et al., 2012; Arnold, 2018), short- to long-distance movements (Franks et al., 2022; Gregory et al., 2023), habitat selection (Tellería et al., 2012), and social interactions (Loretto et al., 2017). Traditional marking and recapture methods, such as fitting coded bands or rings on birds and tags on mammals, can generate large sample sizes at low cost, but recapture/resighting probabilities depend strongly on observation effort and are therefore spatially and temporally heterogeneous, especially away from the main capture-recapture sites. This can introduce substantial uncertainty into estimates of demographic and movement parameters. The remote tracking of animals with GPS or other systems is more costly per individual, and therefore usually involves smaller sample sizes, but it overcomes heterogeneity in resighting probability or at least provides data to estimate it precisely (Jetz et al., 2022). Multiple sensors now also allow consideration of behavioural activities, such as foraging, resting, or flying, up to estimations of energy expenditure (Qasem et al., 2012; Shepard et al., 2008; Wilson et al., 2008).

Among birds, the *Numeniini* (curlews and godwits) are of particular conservation concern. Within the 8 species of curlews, two have recently gone extinct (Pearce-Higgins et al., 2017; Buchanan et al., 2024). Two more are considered endangered (Jiguet, 2023), three are declining but considered of Least Concern, while the Eurasian Curlew is listed as Near Threatened (BirdLife International, 2026). To overcome the global threats to *Numeniini*, Pearce-Higgins et al. (2017) listed three priority actions associated with monitoring and research, including the need to deploy tracking technologies to identify migratory connectivity. *Numenius* species have been tracked with GPS devices for more than 25 years, initially to unravel the migration strategy of endangered species (Ueta et al., 2002). Conservation and policy responses prioritised two actions: identifying and protecting key non-breeding sites along flyways, and implementing successful conservation interventions at a sufficient scale across human-dominated landscapes to support sustainable population development.

In this review, we document how individual tracking can contribute to research, conservation and policy decision-making for the threatened Eurasian Curlew (*Numenius arquata*). After two decades of GPS tracking and an unprecedented accumulation of individual-based data, a review is timely to synthesise lessons from tagged Eurasian curlews, understand drivers of decline and inform conservation. Remote tracking data from this species have been used to examine movement patterns and orientation, habitat selection and avoidance, use of remote areas, breeding status and performance, migratory connectivity, carry-over effects, and causes of mortality. Here, we propose a summary of the main findings and achievements and provide some future prospects for the conservation of Eurasian curlews, derived from data collected from 626 curlews fitted with GPS tags by research teams across Europe (Fig. 1), with data archived on the Movebank platform (Wikelski et al., 2026). These birds have been tagged as breeders or fledglings (approximately one-third of the sample) in France, Belgium, Germany, the Netherlands, the United Kingdom, Poland, Estonia, Finland and Russia, while non-breeders have been tagged in France, the United Kingdom and Germany at important wintering sites (Fig. 2). This sample does not cover the full range of the species, but it provides a large sample within a European context, able to inform European Union policies. Unless otherwise stated, "curlew" refers to the Eurasian Curlew throughout this review. The maps presented here were produced with R version 4.5.2 (R Core Team, 2025).

1. Tagging effects

Before presenting in detail the scientific insights provided by the tags, it is important to review the potential or observed impacts of this monitoring method on the birds. Tag impacts on the biology of any species of interest must be considered and transparently reported to be confident in obtaining unbiased parameters of interest (Douglas et al.,

2010; Bodey et al., 2017). In curlews, there are few studies reporting on tagging effects. Grant (2002) found no effects of radio tagging on the weight gain and survival of curlew chicks tagged at hatching with small back-glued or ring-mounted small tags representing up to 4.6% of the hatching body mass. Small radio tags are short-lived but can be invaluable in determining the survival and causes of mortality of the chicks of waders and other precocial birds. Ewing et al. (2018) reported short-term adverse responses to tagging in the period immediately after release, although the severity of the response was variable, suggesting individuals may be differentially sensitive to capture and handling. Two of the three tracked curlews showed no detectable effects of tagging post-release, with one of these seemingly resuming normal activity patterns almost immediately. Captures at the nest in Finland also revealed sex differences in behaviour, with males returning first to the nest (M. Piha, pers. comm.). Breeding curlews trapped on the nest during incubation have also been observed to show delayed resumption of incubation duties, potentially increasing the risk of predation (S. Franks, pers. comm.). Whether this is a tagging effect, a handling effect or a trapping effect is impossible to distinguish. Among curlew taggers, it is well known that the species can be sensitive to restraint and prone to developing cramps and myopathy, but mostly in winter and according to some weather conditions. Curlews have also been observed to be more sensitive to adverse effects when tagged during their annual remigial moult (S. Franks, pers. comm.). Taking these risks into account is of paramount importance when organizing winter captures of curlews at nocturnal high-tide multiple-species roosts.

Any bird tagging must consider the reduction of short-and long-term impacts to be of paramount importance. Capture method, duration, and conditions of bird handling, as well as release methods, should all aim to minimise the bird's perception of a deadly predator act. Electronic equipment and harnesses must also minimise discomfort and overload for birds (Douglas et al., 2010; Jirinec et al., 2021). The use of elastic harnesses allows for adaptation to the body reserves of curlews, but their durability is lower than that of Teflon rubber. Equally, however, different silicone materials may have different durability and therefore longevity. The decision on harness material must be a compromise between the scientific needs in relation to desired deployment duration and the welfare of the bird. Curlews have been tagged using leg-loop or wing-loop, silicone or Teflon harnesses, while their large size and recent tag miniaturization generally allow the equipment to remain below 3% of a bird's body mass. A complete analysis of the impacts of wearing a GPS tag is still needed to fully understand the advantages and disadvantages of the design and material of the harness, and of the mass, shape, and profile (aerodynamics) of the tag.

2. Migration

Understanding the migration strategy of threatened species is often crucial to their conservation (Newton, 2024). Monitoring numbers and colour-marked individuals are classical approaches to document phenological schedules and links between breeding and stopover and wintering sites (Thorup et al., 2014). Remote tracking of individuals provides further information on individual strategies, such as stopover locations and durations, and can also document individual decisions (conditions of departure, routes, flight altitude, orientation). Tracking data can also complement knowledge obtained from other data sources, especially concerning flyways, connectivity and phenology. Tracking data further allows the study of individual navigational decisions, while the tracking of tagged juveniles has begun to reveal the ontogeny of migration in the species.

2.1. *Delineating flyways and identifying connectivity*

The management of migratory species needs to properly identify the functional units of a species and understand potential distinct flyways. A contribution of tracking studies is to confirm and complement our

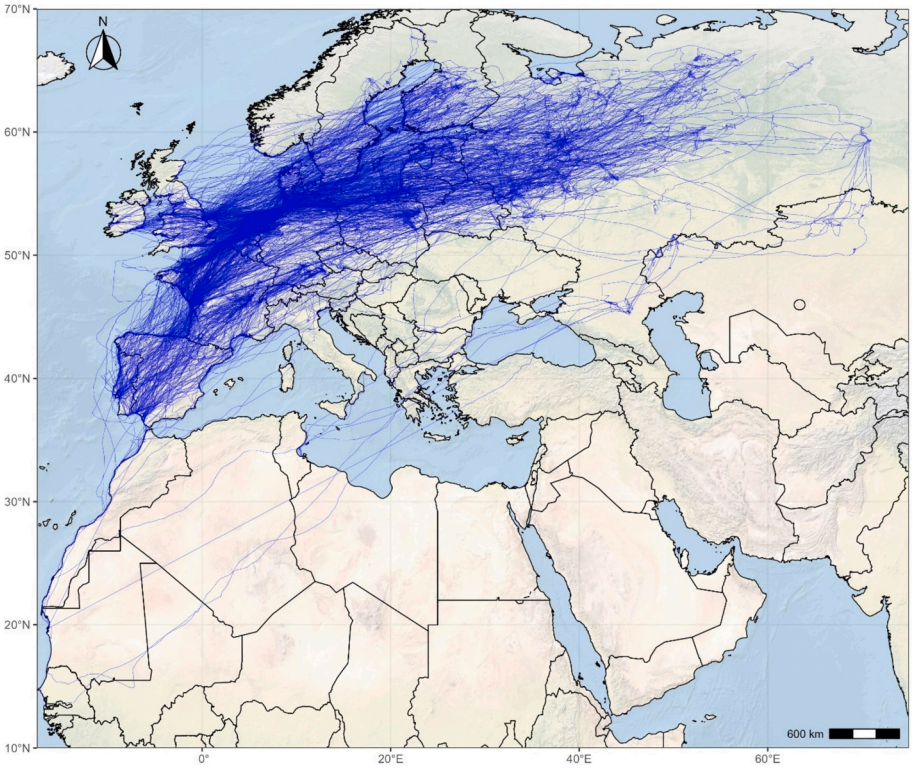

Fig. 1. Map with tracks of all 626 individuals from studies shared with the HABITRACK consortium by Movebank ID studies: 1077731101, 325569416, 2157073446, 1514295375, 1515581326, 2072863294, 1519345208, 1471582747, 1126572166, 2770756216, 4015912608, 229624463, 1532326679, 1773089088, 4244675565, 7481022, 1392178681, 2719795271.

understanding of flyways, even if already documented by ring recoveries or geolocators (Summers et al., 2023). For the curlew, the recent EURING Migration Atlas mentioned that migration movements of birds throughout the species' wide breeding range occur mainly along a strict NE-SW axis, though with unclear destinations of Eastern European populations, as few individuals are ringed there (Franks et al., 2022). Tracking data confirm this NE-SW axis (Schwemmer et al., 2016; Pederson et al., 2022) for eastern populations too, including the first documentation of the flyway used by curlews breeding in the steppes of southern Russia and northern Kazakhstan, belonging to the subspecies *suschkini*. They migrate along a similarly oriented axis and winter in Africa, with records in Tunisia, Gambia, Mauritania, but also Djibouti. There was only one ring recovery in West Africa (Franks et al., 2022) of a bird ringed in Finland (ssp. *arquata*) and found in the Inner Niger delta in Mali, though this record is now considered unconfirmed by the Finnish ringing Centre (Jari Valkama, pers. com.). A headstarted colour-ringed curlew released in Poland in 2021 (yellow flag S17) was observed in Senegal in October 2022. A few birds tagged in French breeding populations wintered in West Africa. Finally, it is interesting to report that some individuals tagged in winter in western Europe (France and Germany) breed east of the Ural Mountains, in Asia, within the breeding range of the *orientalis* subspecies.

Tracking the birds in a given breeding population can document their non-breeding grounds and help identify the potential threats they encounter when away from their breeding grounds. As an example, 86 adult curlews breeding in NW Germany wintered along the coastlines of Great Britain/Ireland, western France and the Netherlands, in particular the Rhine-Meuse-Delta and the Wadden Sea (Kämpfer et al., 2023). Tracking individual birds further provides additional data for connectivity modelling tools, integrating multiple heterogeneous datasets, such as ring recoveries, colour-ring reports, and any probabilistic assignments to origins as deduced from feather stable isotopes (Hobson and Wassenaar, 2019) or genomic structure (Manioulloux, 2025). The contribution of individuals fitted with transmitters can be twofold: to document how birds breeding in a given population disperse across the wintering range, and where birds from a functional wintering site migrate to breed. Tagging can be very effective in identifying connections over a short period of time, reducing uncertainties and at a low economic cost, particularly in terms of fieldwork expenses (Gregory et al., 2023). This is especially true for waterbirds like curlews, as classical stable isotope approaches based on deuterium concentrations in feathers (Hobson et al., 2012) can be flawed, as the isotopic signatures found in locally grown feathers are not necessarily linked to those in local rainwaters, depending on the complex hydrographic system feeding wetlands and coastal estuaries (Franks et al., 2012). Further developments considered integrating demographics and connectivity into spatially structured models (Gregory et al., 2025). The application of this new modelling approach on both ring and GPS data allows estimating that curlews breeding in the North-East area (Scandinavia, Baltics, Russia) show a diffuse migration strategy. 13% stayed in the breeding region, 42% migrated to the North-West area (UK, Ireland) and 45% to the South-West (mainly France and Iberic peninsula). On the contrary, breeders from both the North-West area and South area show a strong tendency to stay in the same area during the non-breeding season (Gregory et al., 2025). The next methodological challenge would be to develop such models in a continuous space, but ongoing work is promising. For instance, O. Rumianowski and colleagues are developing a new method to identify migratory strategies without any a priori of their spatial definition. Applied to the GPS data of the curlew, this model identifies a dominant strategy representing approximately 57% of individuals whose breeding location is centred in Finland (breeding centroid: 61.95 N, 21.84 E), with its 95% spatial ellipse encompassing most of northern Europe. Its wintering centroid was located in France (wintering centroid: 48.9 N, 0.06 E), and its 95% spatial ellipse extended across northern France, southern England, and the Benelux region. The second and third strategies accounted for 22.8% (CI 13.0–30.5%) and 18.9% (CI 10.3–53.4%), respectively. The second strategy was characterized by relatively restricted breeding grounds located in the United Kingdom (breeding centroid: 55.51 N, −2.73 E). Its wintering centroid was situated in approximately the same region (wintering centroid: 55.36 N, −2.87 E), confirming the limited seasonal movements shown in Gregory et al. (2025). The third strategy exhibited a breeding centroid located in south-eastern Europe (breeding centroid: 44.91 N, 28.90 E), with a comparatively broad 95% spatial ellipse encompassing much of the southern portion of the species breeding distribution, where overall abundance is much lower. Its wintering grounds were more spatially restricted and located along the western coast of the Iberian Peninsula (wintering centroid: 37.51 N, −7.84 E).

Fig. 2. Example of an adult male Eurasian Curlew, colour-ringed and tagged at Butjadingen, Lower Saxony, Germany, on 25 March 2025 (Credit: Andreas Bange).

These new models are very promising tools to develop concrete adaptive management scenarios for threatened migratory species, linking breeding and non-breeding grounds, to model the impacts of any pressure occurring on population dynamics. Applications of this approach could consider pressures such as the widespread development of offshore wind farms, hunting and possible associated quotas/bags. Finally, tagging can also contribute to connectivity resolution by giving the opportunity to sample genetic material on individuals wintering in easily accessible areas and later track them to their remote and inaccessible breeding grounds (e.g. Siberia). This approach substantially improved the spatial sampling to resolve the curlew genomic structure and identify clusters within the European flyway (Manioulloux, 2025), including a Spanish group (contra Rodrigues et al., 2019).

2.2. Phenology

By tracking curlews in space and time, the complete phenology of the annual cycle can be derived from the collected data and reveal general patterns of breeding and migration schedules. By analysing data from 85 adults tagged in Germany, Poland, France and Estonia, Pederson et al. (2022) found that southern curlews have a longer nesting period due to their earlier arrivals on breeding grounds. As expected, spring arrival at breeding sites did not differ between the sexes. Females left their breeding sites earlier than males, which is in line with previous studies on curlews in some local breeding populations (Currie et al., 2001; Kämpfer et al., 2023). Migration duration and distance, as well as stopover number and duration, showed a significant increase with breeding site latitude but did not differ between the sexes or between spring and autumn migrations, suggesting that curlews took a comparable amount of time migrating during both seasons. Active migration lasts on average 10 days, including stopover times, in spring as in autumn (Pederson et al., 2022), which represents a short period during the annual cycle. Curlews breeding further away in areas with late snowmelt departed later, while departure dates varied by only < 4 days in 12 tagged curlews over consecutive years (Schwemmer et al., 2021). There is a clear bimodal pattern in spring migration departures for southern vs. northern breeders (Amélineau et al., 2021; Thaxter et al. in review). Overall, adult curlews leave their breeding grounds in Europe mostly in June (Pederson et al., 2022), between the end of May (for failed breeders, which do not lay a replacement clutch) and the end of July (for successful males) (Kämpfer et al., 2023). This schedule has almost no overlap with the onset of migration in juveniles, also because males leave their chicks before or just after they learn to fly (van Gils et al., 2020). As a consequence, juveniles migrate on their own, generally in August, sometimes in groups, but composed of juveniles only. As they are inexperienced migrants, they are potentially more exposed to natural and anthropogenic pressures, having not yet learnt any landscape of fear (Bleicher, 2017). On the other hand, the early independence of juvenile curlews makes it possible to confidently release chicks raised in captivity into the wild (headstarting; Colwell et al., 2020). Finally, the analysis of spring migration phenology of 26 curlews mostly tagged in winter in France and Germany (Amélineau et al., 2021) concluded that the departure date from wintering grounds was positively related to green-up date of the previous year at the breeding site, while arrival date at the breeding site was better explained by latitude and longitude of the breeding site, suggesting that other factors, e.g. local weather conditions, impacted migration timing en route. This suggests that curlews may be able to adjust their migration timing to advancing spring dates in the context of climate change. Such flexibility in migration timing may partly buffer the species against climate-driven shifts in phenology, although the limits of this plasticity remain unknown (Vähätalo et al., 2004).

2.3. Ontogeny and navigation

Tagging large yet unfledged juvenile curlews proved informative to document future recruitment and migration ontogeny. As reported from comparison of post-breeding migration onset for sex and age classes, juveniles migrate later than adults, and on their own or in groups, including siblings' groups (Jiguet et al., 2021a). The first migration by juveniles is oriented SW, and is often by trial and error, comprising overseas flights into the Atlantic before tracing back eastwards to land, then generally moving northwards along the coasts to find suitable habitats/sites, probably linked to the presence of older congeners (Fig. 3a, b). Associations might concern individuals that are ready to leave at the same time, but may not necessarily share a final destination. Migratory groups are temporary associations, reminiscent of fusion-fission dynamics (Jiguet et al., 2021a, Fig. 3c).

By providing precise information on individual onset of migration, tracking data allows the study of flight initiation and of the influence of wind assistance on departure timing of curlews tagged in France in winter (ongoing work by P. Bocher). During migration, it is traditionally believed that birds navigate using compass orientation and map-based navigation (Wiltschko and Wiltschko, 1996). One cue birds can use for orientation and navigation is the geomagnetic field (Kishkinev et al., 2015). Geomagnetic navigation during long-distance migration is widely debated, and it remains unclear which properties of the geomagnetic field birds use and how information might be used. Using curlew tracks recorded by GPS tags, Zein et al. (2026) revealed how curlews orient according to geomagnetism, providing the first empirical evidence for the effect of night-time and the effect of the angle between two navigational cues involved (intensity and inclination) on geomagnetic navigation.

2.4. Future prospects

The strong directional orientation of the flyway and the wide breeding range mean that the different European populations are exposed to different pressures and threats along their migration routes. For example, Finnish, Estonian and northern Russian birds must fly over the Baltic and North Seas and their offshore wind farms (Schwemmer et al., 2022, 2023; Thaxter et al. in review). Birds from central Europe, including those breeding in eastern France, do not generally visit the French Atlantic coast on migration and hence were not exposed to hunting pressure there (before a moratorium starting in 2019), but northern German breeders are exposed to human activities in the North Sea (Schwemmer et al., 2022, Thaxter et al. in review) and along French Atlantic coasts (Kämpfer et al., 2023). While many British birds undertake short-distance migrations within the UK and Ireland, some migrate to coastal France, Spain and Portugal. The differences in migration phenology between sexes and ages help understanding which individuals are exposed to which pressures at a given time and place (Box 1). As an example, the hunting season along the French coast used to start in early August, at the time juveniles actively migrate, when experienced adults have already arrived at their wintering grounds. The difference in experience and timing might explain the fact that 88% of the individuals in a sample of 120 curlews hunted in France were juveniles, before the hunting moratorium in France was introduced in summer 2019 (Manioulloux, 2025). Such a value is 4 times the proportion of juveniles in natural populations, as the current estimated productivity at the flyway scale is 0.57 fledglings per pair per year (Viana et al., 2023), so approximately 1 juvenile for 4 adults (20%). Such age-biased pressures could translate into very different survival rates and have demographic and even evolutionary consequences (Grzegorczyk et al., 2024), which remain to be investigated in curlews. The future tracking of juvenile individuals throughout their immature years will certainly provide information on the complete ontogeny of migration in the species, what is innate and what is learned through experience.

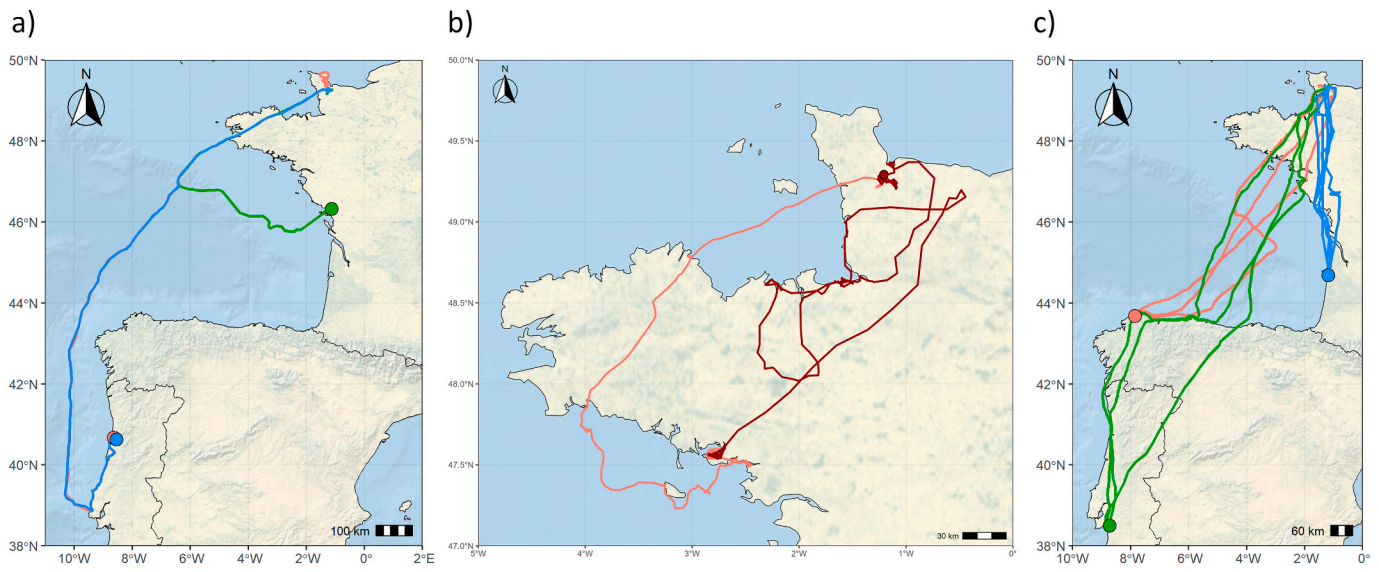

Fig. 3. Examples of (a) first post-breeding migration of three siblings in August 2022 (tags 215342, 215343, 215344), (b) first autumn (when juvenile, left track in light red) and first spring (when two-year-old; right terrestrial track in dark red) migrations of a young curlew (tag 210997) (from 12 June 2023 to 27 April 2025), and (c) post- and pre-breeding migration tracks of three adult curlews (tags 211000, 211001, 221155) from the same breeding population in Normandy (Movebank study 1077731101) (starting years 2021 and 2022). Dots show their final destinations. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3. Demography

Understanding population demographics and metapopulation dynamics is crucial in conservation biology. Population modelling and associated scenario-testing can inform management decisions and public policies to improve conservation status. Some parameters, such as clutch size, generation time, or survival rates, are generally estimated by direct field observations or the analyses of ring-recovery data. In the curlew, low breeding success has been identified as a key demographic parameter explaining population declines (see synthesis in Viana et al., 2023). Other parameters are necessary to fully capture population dynamics, including immigration and emigration, and the proportion of breeders, which are difficult to quantify using capture-recapture data because of high spatial heterogeneity in marking and resighting efforts. GPS tracking is then a useful method for estimating such parameters, but also for documenting breeding status and performance without disturbing birds (Bowgen et al., 2022), as well as causes of mortality.

3.1. Demographic parameters

Identifying the breeding status of cryptic bird species has proved problematic without intensive or inherently expensive field monitoring. Most intensive bird monitoring comes with high economic costs and disturbance risks. Hence, many projects now rely on tagging of individuals to provide remote information on movements. Given the importance of breeding status when targeting conservation interventions, novel methods are needed. Breeding status can be identified from GPS tag movement patterns using available statistical tools, such as computing revisitation metrics for trajectory data (Picardi et al., 2020, 2022; Bracis, 2022). Such approaches have been developed for curlew tracking data to distinguish breeding, wintering and stopover locations (Hanzelka, 2024), and to infer breeding status from revisitation rates (Bowgen et al., 2022). These methods typically require training data sets from individuals of known breeding status to assess the frequency of revisits to particular locations for identification of pre-breeding, incubation, chick guarding, and post-breeding stages from movement data.

Using the same statistical tools based on revisitation rates, Bowgen et al. (2022) further estimated key demographic parameters that were not readily available from other data sources, and are very useful for population modelling: the proportion of breeders in the population (0.74), daily nest survival rate during incubation (0.935), leading to an incubation success of 15.1%. Once the training of the method has been completed, using tracking data means there are no systematic visits to the nest or brood-rearing locations, hence reducing disturbance by humans. Such breeding parameters can feed population models relying on more traditional capture-mark-recapture methods used to obtain survival rates of both adults (0.90 in Taylor and Dodd, 2013; 0.92 in Robinson et al., 2020; 0.89 for males and 0.92 for females in Pakanen and Kylmänen, 2023) and immatures (in a Dutch population, 0.60 for year 1, 0.74 for year 2, 0.81 for year 3 in Gerritsen, 2021).

While being tagged might in itself impact survival (Setash et al., 2024, see below), estimating apparent survival from GPS tracking data presents both benefits and challenges when compared to more conventional survival estimation from ringing or colour-marking capture-mark-recapture data. Multi-sensor tag data (e.g. temperature and accelerometer) can often be used in conjunction with GPS data to distinguish mortality from tag loss (e.g. due to harness failure; see Jiguet et al., 2023). When a tag simply ceases data transmission, it is impossible to distinguish mortality from tag loss, malfunction, or the tag being out of communication range. In general, however, GPS tag data used in survival analyses can often produce better estimates compared to equivalent conventional CMR data due to higher re-encounter probabilities and, hence, reduced boundary estimate issues (Viollat et al., 2025).

3.2. Remote mortality causes

Tracking also allows documenting mortality causes that would be difficult to observe in unmarked or ringed individuals. As an example, tags enabled Obłoza et al. (2025) to examine the early post-release survival of 62 tagged headstarted curlews in Poland. Headstarting is a translocation technique that involves hatching or rearing wild eggs or young in captivity and releasing them back to the wild at or before independence. Obłoza et al. (2025) documented their survival probability until the start of migration (0.42), with the highest mortality occurring within the first week, and in the landscape features that seem to favour natural predation. In Bavaria, Germany, Rupprecht et al. (2026) reported that, among 33 tagged non-fledged juvenile curlews, data transmission ended on the breeding grounds before first migration in 18

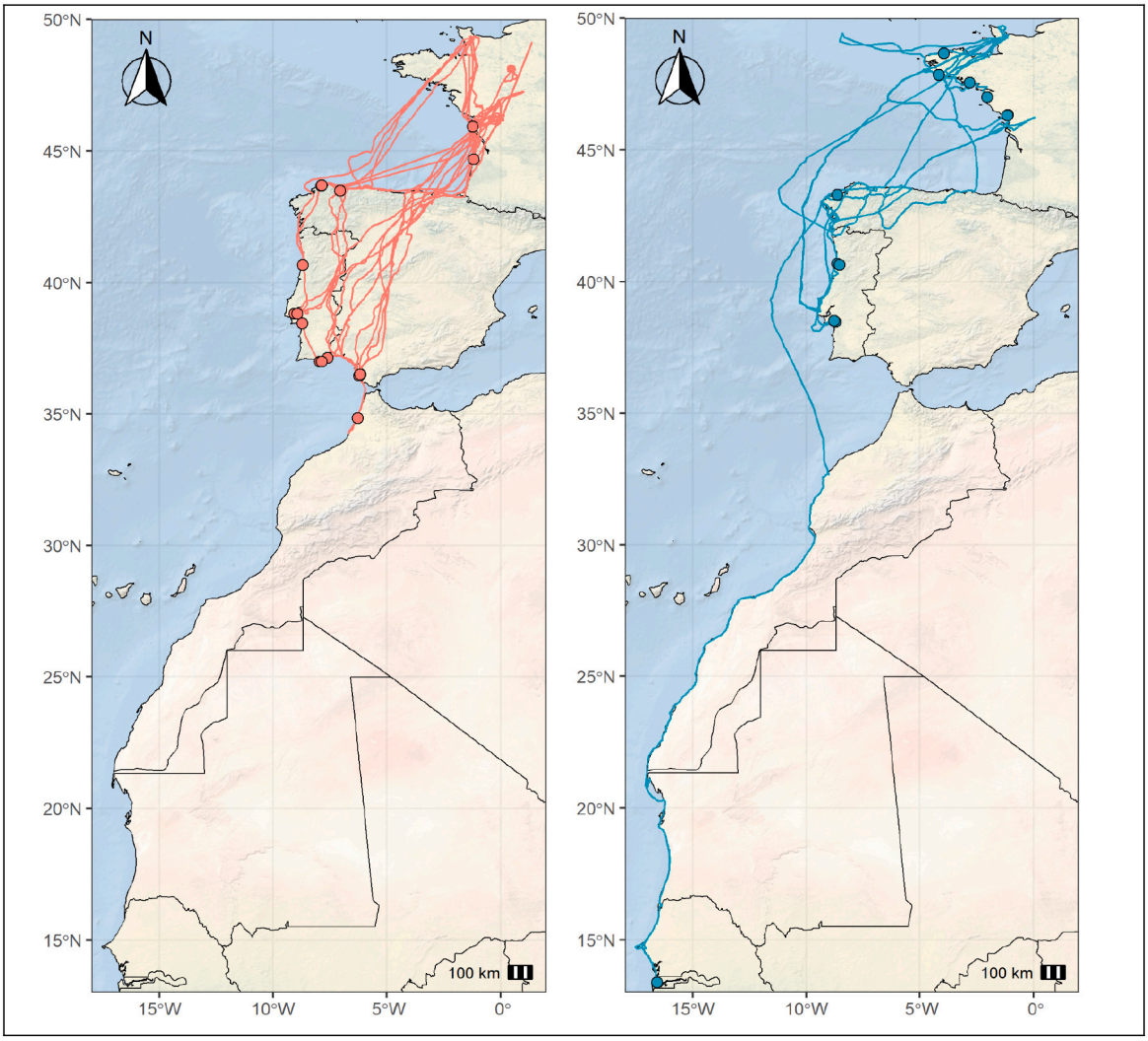

Fig. 4. First tracking years of 18 adults (left panel, in red) and 12 juvenile curlews (right panel, in blue) breeding in France (tags deployed from 2021 to 2024). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Box 1
Deducing the benefits of a hunting moratorium from tracking data.

Recent tracking efforts confirmed extreme natal philopatry in Eurasian Curlew, as well as extreme fidelity to wintering grounds, with first-breeders returning to their initial wintering sites. In Normandy and Poitou, France, curlew tagging started in 2021, alongside the implementation of a national hunting moratorium in 2020. 18 adults and 12 fledglings have been tagged there from 2021 to 2024 and successfully tracked to their wintering sites (Fig. 4). Among them, only two adults used a French wintering site (12%), while all others had a non-breeding site in Iberia ($n = 15$), and one in Morocco. As curlews are faithful to their wintering sites, from their first winter onwards, we would expect to find a similar proportion of juveniles settling in France to winter. However, 6 of the juveniles settled their wintering site in France (50%), the others in Iberia ($n = 5$), and 1 in Gambia. Although the sample sizes are not large, the difference in proportions is statistically significant (chi-square test = 5.57, $P < 0.02$). We deduce from this discrepancy that the survival of juvenile curlews until maturity is or was very different between France and Iberia. Among the 12 tagged juveniles, 6 survived until recruitment – 4 wintered in France, 2 in Iberia. All 6 were recruited in the local population where they hatched. These are, of course, small samples, but they point towards a strong increase in survival of immatures in France since 2021, coinciding with the implementation of the moratorium. Simultaneously, breeding numbers have increased in Normandy (from 88 to 92 pairs in 2019 to 167–182 pairs in 2025), with the recolonisation of sites that were abandoned for decades (Chartier et al., 2023). The hunting ban on curlews started in 1990 in Spain and in 1999 in Portugal. One alternative (though unlikely) explanation would be that the migratory strategy of French curlews drastically changed around the 2020s. Modelling population dynamics using demographic parameter scenarios to simulate observed population trends should confirm if an increase in immature survival in France is sufficient to explain the ongoing population recovery.

individuals, and fatal predation was confirmed in 11 of them. Most predation events ($n = 8$) occurred during the evening or night. In contrast, in Polish headstarted curlews, most mortality events occurred during the daytime. Tracking is also informative to document anthropogenic mortality, such as poisoning or poaching. Katzner et al. (2020) argued that an abnormally high mortality rate among tagged long-billed

curlews (*Numenius americanus*) is evidence of poaching. The tags also make it possible to suspect injury and rescue injured individuals (see a case of a windfarm casualty in the Netherlands in Jiguet et al., 2021b), to recover the bodies of dead individuals and, in some cases, to document the causes of death (poaching in Jiguet et al., 2021c), or even assist in criminal investigations to convict poachers (Jiguet et al., 2023). In the latter publication, the authors report three poaching cases of tagged juvenile curlews on the opening day of the hunting season in northern France, while the curlew was under a national hunting moratorium. At that time, these three were the only tagged juvenile curlews present in that region, suggesting a very high poaching pressure on the species in 2022, which would have been just as great or greater in the years before the moratorium.

3.3. Nest predation

Tracking data allow to detect and identify predation events by analysing data provided by multiple sensors (Jiguet et al., 2023). In incubating curlews, it also allows early detection of nest abandonment and potential predation events that impact hatching success (Bowgen et al., 2022). The tags allow to estimate the date and time of the loss of eggs or chicks and inform managers about the laying phenology and the precise nest locations, allowing the prompt installation of nest protections. GPS data can also potentially be used to identify nesting attempts which go undetected by conventional nest monitoring, usually because predation occurs during laying, as demonstrated by Verhoeven et al. (2020) in black-tailed godwits (but using geolocator data).

Numerous scientific publications promote lethal predator control to enhance shorebird breeding success (Dowding and Murphy, 2001; Fletcher et al., 2010; McMahon et al., 2024). Concerning curlews, Zielonka et al. (2019) identified Red Fox *Vulpes vulpes* as the main predator of eggs in a UK population with a very low breeding productivity of 0.16 chick per nest. Across Europe, curlew nest predation has increased from 16% before the 1980s to 65% in the period 1996–2006 (Roodbergen et al., 2012). Baines et al. (2023) also reported that fledging success was four times higher on moors managed for red grouse *Lagopus lagopus scotica* with lethal predator control by gamekeepers. Predator control is indeed often implemented as the solution to improve breeding success of threatened ground-nesting shorebirds. Franks et al. (2017) recommended reducing generalist predator abundance together with improving habitat quality to counter the decline of the species in Britain. At a local experimental scale, Fletcher et al. (2010) reported that lethal control reduced the abundance of foxes (−43%) and crows (−78%) and led to an average threefold increase in breeding success of curlews. They did not quantify control effort and the number of culled predators, although two full-time gamekeepers were hired year-round. Obviously, a new predator-prey equilibrium can be efficient to increase curlew breeding success, yet the relative contribution of lowered predator abundance and of higher availability of alternative prey (notably grouses) has to be investigated. Also, the possibilities for lowering predator abundance are not limited to lethal methods; reducing access to thrash for scavengers can reduce the survival and abundance of the predators (Lequitte-Charransol et al., 2024); habitat can be managed to reduce predation risk (Obłoza et al., 2025), for example by removing forest plantations in suitable breeding habitats (Kaasiku et al., 2022) and electric fences can be effective (Maslo and Lockwood, 2009; Ewing et al., 2023), while research on effective olfactory solutions to deter or repel mammalian predators are to be investigated.

Although lethal control might appear as a simple and effective solution, it represents high economic costs and does not reduce predation (Madden et al., 2015) or predator numbers durably (Comte et al., 2017; Pépin et al., 2025; Jiguet, 2020; Jiguet et al., 2026). Economic investment should be preferentially directed to habitat restoration, while control of native predators should be used only as a temporary measure to prevent local or global extinction (Dowding and Murphy, 2001). To paraphrase Woinarski (2019), "killing Peter to save Paul" has complex social implications that need ethical and philosophical considerations that bird conservationists can't solve on their own (Young et al., 2020). Indeed, predator control can be contentious if predators and prey are valued differently by different stakeholders (Redpath et al., 2004). Tracking predators within curlew breeding areas should reveal how they operate and visualize the curlew landscape of fear.

3.4. Natal philopatry and site fidelity

Natal dispersal can be documented by intense ringing (Paradis et al., 1998), which can be efficient for colonial species where most colonies have high monitoring effort to record marked recruited individuals at a large spatial scale. For other species, ringing is not necessarily appropriate because of the bias arising from heterogeneity in sampling effort, with a higher probability of detecting local recruitments. For such species, tagging can provide insights into the main drivers of natal dispersal, prospecting behaviour, and breeding-site selection and settlement, though tags must remain functional until the birds reach breeding age. Eurasian curlews exhibit delayed breeding maturation. While in rare cases, individuals may exhibit breeding behaviour in their first summer, most individuals do not exhibit breding behaviour until their second summer or later. In northern Ostrobothnia, recoveries of curlews colour-ringed as chicks showed that individuals usually returned to Finland for the first time in their third calendar year, although the interval ranged from one to ten years after ringing (Kylmänen and Ojanen, 2023). The data suggest that juveniles spend at least one summer, and most often two or three summers, on non-breeding areas before recruiting into the breeding population. Tagging large but still non-flying juveniles, as well as tagging headstarted curlew before release, can provide the opportunity to record prospecting and breeding settlement behaviour. Among 12 non-flying wild juveniles tagged in France (Normandy and Poitou) that survived their first migration, six (50%) survived until recruitment at 2 years old, and they all recruited into the population where they had fledged. In line, Gerritsen (2021) reported that 29 out of 36 wild juveniles colour-ringed between 2000 and 2019 were found breeding within 12 km of their hatching site. However, some of his colour-ringed birds dispersed over large distances of up to 600 km. We can therefore hypothesise that the recruitment is highly probably local, even when birds cover long distances between the wintering and the breeding grounds (Fig. 5). This result is in line with Bainbridge and Minton (1978) reporting a high natal philopatry in juveniles ringed in Britain and Ireland, and with ring recoveries from Finland, where seven birds ringed as chicks and later found as breeders were all located within 10 km of the initial ringing site (Saurola et al., 2013).

Being faithful to individual home ranges may help to promote knowledge about local features and site quality, though stereotyped behaviours may also create an ecological trap by preventing the flexibility required to adjust to environmental changes. Schwemmer et al. (2026) assessed 24 spatial and temporal parameters describing the repeatability of the entire annual cycle in 94 tracked curlews. Twenty-two parameters showed significant repeatability, with the highest repeatability for use of the same breeding and wintering sites, indicating consistent site faithfulness (Fig. 6). Indeed, repeatability values for longitude and latitude of breeding and wintering sites, within a 20-km buffer, ranged 0.995–1 (95% CI). Furthermore, all migration stopover temporal parameters during spring migration (dates and duration, rest lengths) were also significantly repeatable, with lower repeatability for autumn migration, likely related to variable breeding success (earlier departures for failed breeders). The location of migration routes varied between consecutive years, but intra-individual similarity was significantly greater than inter-individual similarity. Bocher et al. (ongoing work) further investigated the degree of fidelity of 62 tagged curlews to their breeding and wintering sites by calculating the distances between nests and roosts between years, as well as the degree of overlap between year-to-year wintering or breeding home ranges, concluding that fidelity

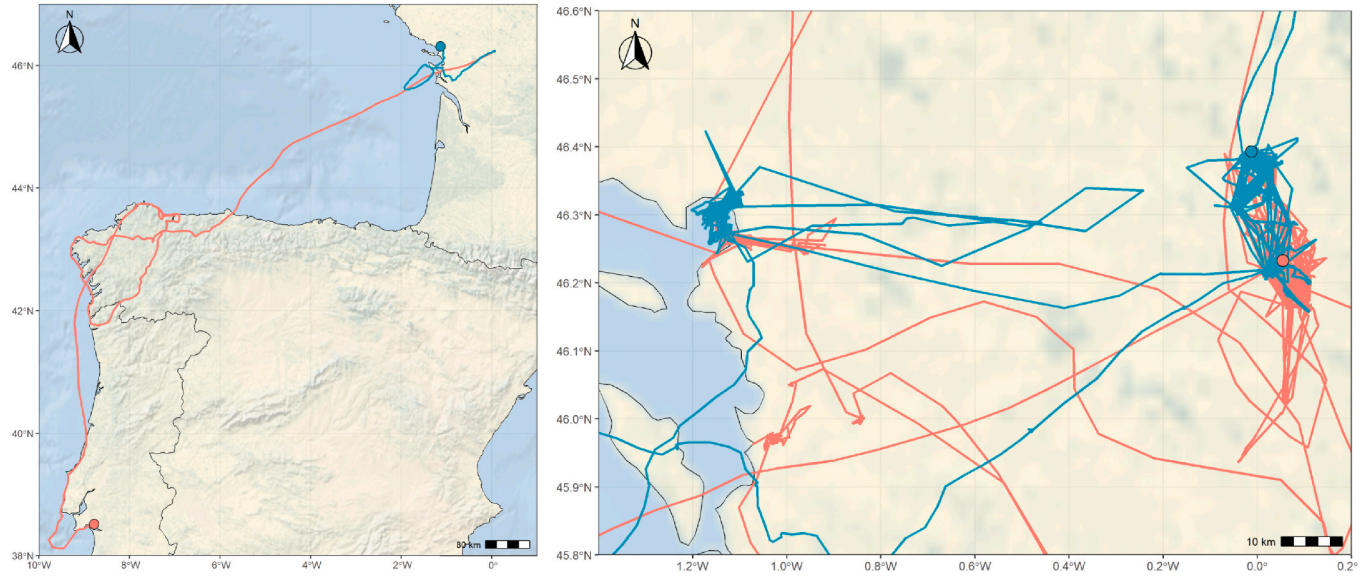

Fig. 5. Tracks of two curlews tagged in 2022 as juveniles on their hatching site (in 2022), then migrating to two different winter sites (left panel), then migrating back in spring 2024 to recruit at their hatching population in Poitou, western France (right panel) [tags 221367 221380, from Movebank study 325569416]

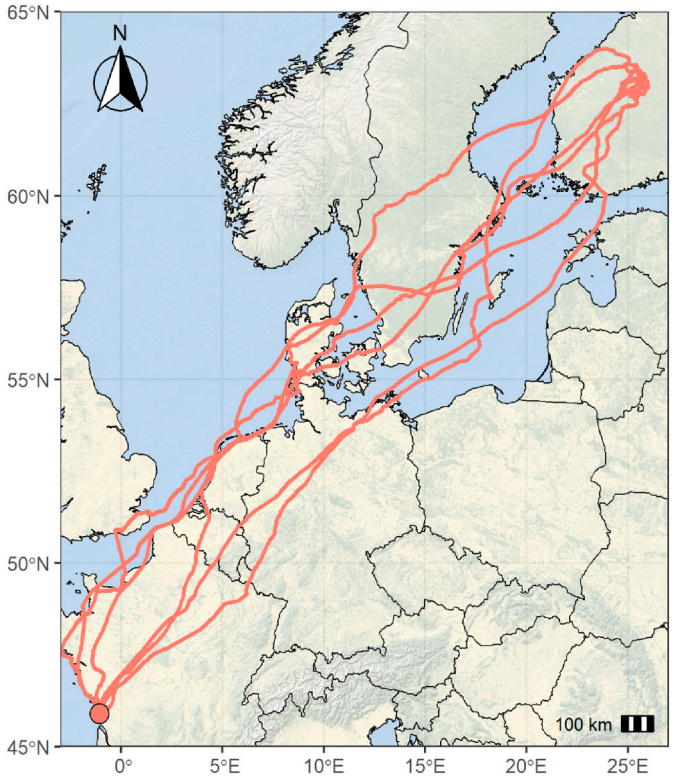

Fig. 6. Curlew breeding in Finland and wintering in western France, tracked since 2 December 2021 (still connecting in March 2026) [tag 215407, Movebank study 1077731101].

was very high, with only slight interannual variations in the extent of home ranges, in line with Schwemmer et al. (2026). Beyond this very high site fidelity, cold spells can provoke movements during the non-breeding season, as for other wetland birds (Masto et al., 2022), and this has been documented in tagged curlews (Düttmann et al., 2024).

3.5. Future prospects

Local population dynamics depend on the breeding success and survival rates in a given population. Previous studies on curlew dynamics have focused their arguments on low reproductive success to explain the decline in populations of this long-lived species (Viana et al., 2023). However, this should also account for the survival of young birds until breeding recruitment, so during their first two years or more of life. A population with low breeding success but high immature survival can have a similar trend to a population with high breeding success but low immature survival, for example, if juveniles are exposed to additional anthropogenic mortality. Future advances in tag miniaturization should offer the opportunity to tag more curlews at low costs (low economic cost for the researchers and low impact on the birds), and to document demographic rates of larger samples as well as previously difficult life stages to monitor, such as survival during the immature period between fledging and recruitment. The apparent annual survival estimates reported in the literature and cited above (0.89–0.92) appear slightly higher than those published for other *Numenius* species. For example, Ruthrauff et al. (2024) reported an apparent survival of 0.83 for whimbrels in Alaska, although they displayed a lower site fidelity compared to curlews (app. 0.8 compared to 0.995 in curlews across Europe). Natal dispersal and site fidelity should be further investigated across various contexts, including geographic location and population density, as well as habitat, as breeding success can vary between main habitats (Bocher et al., 2024). Finally, potential climate-driven range shifts are more likely to be driven by recruitment of young birds (Alves et al., 2019), highlighting the importance of successful breeding performance.

4. Habitat use and selection

Habitat use is the proportion of time animals spend in a particular habitat. Habitat selection is the process by which an animal chooses its habitat within available habitats (Fieberg et al., 2021; Northrup et al., 2022). By providing location data at a reasonable, and sometimes high, temporal frequency and with positional errors reduced to just a few meters, GPS tracking provides invaluable data for studying habitat use and selection in curlews. Various steps have been considered to study habitat requirements at the individual and population levels, starting with modelling individual home ranges during stationary

periods, then documenting how habitat use can influence breeding performance.

4.1. Breeding habitats

Bocher et al. (2024) analysed the tracking data provided by 83 adult birds tagged across Europe to quantify their breeding home range sizes, habitat use and hatching success, focusing on the core area of the European population in North-East Europe. Birds nested predominantly in bogs at northern latitudes and in grassland at southern latitudes, while abandoned farmland was mainly used at intermediate latitudes. Home ranges were estimated at approx. 100 ha (non-breeders used ranges three times larger), with a core range of only 15 ha. The mean home range was largest for birds breeding predominantly in grassland, while birds in bogs had the highest hatching success rate. In a National Park, Bowgen et al. (2025) found far smaller foraging ranges for 19 tracked breeders, hardly ranging further than 500 m from their nest location during the chick-rearing period. Donnez et al. (2026a) quantified the effect of spatial heterogeneity on the spatio-temporal use of habitats by 64 breeding curlews tracked in contrasting agricultural landscapes, in five breeding populations with contrasting dynamics in France. Home ranges were similar at all five sites, and comparable to those in NE Europe (97 ± 44 ha). Curlews selected open habitats to feed. They used grasslands for nesting and feeding preferentially, except in a drastically declining population, where all birds nested in moorlands. Birds increasingly used crops after incubation, potentially to supplement their resources before departure. This study highlighted the importance of floodplain grasslands for maintaining curlew populations, although a landscape structure with sustainable agricultural land embedded in semi-natural lands should be the most beneficial to the populations. Rupprecht et al. (2026) investigated patterns of nocturnal roost selection in GPS-tagged curlews across age classes and breeding stages on breeding grounds in Bavaria, Germany. Nocturnal roost use varied with both age and breeding stage. Non-fledged juveniles roosted almost exclusively in meadows, where most predation events were recorded. After fledgling, juveniles markedly increased their use of swales and shallow water zones. Adult birds roosted predominantly in meadows during incubation and chick rearing, but increasingly used water bodies at later breeding stages. These findings indicate that, although meadows were predominant habitat, wetlands and shallow water features provide safer roost sites. The creation and protection of wetlands and shallow water zones should therefore form part of conservation strategies for this species in order to reduce predation risk. In Poland, the post-release tracking of 20 headstarted juveniles until their departure for migration identified the necessary range prospected during emancipation by such young individuals, with a core area of ca. 30 ha and a global range of ca. 190 ha (Obłoza et al., 2026).

4.2. Non-breeding habitats

The first comprehensive study on winter habitat use in Europe (Donnez et al., 2023) concerned 204 tagged curlews, which used winter ranges of relatively small but variable size (533 ± 449 ha). They used a high diversity of coastal and inland habitats, with a higher occurrence on mudflats and salt marshes. By studying winter home ranges and roost sites of 62 tagged curlews, Bocher et al. (unpublished results) reported that the main roosts used by individuals in successive winters were on average 2 km apart, while birds wintering in the Wadden Sea exhibited the longest distances between successive main roosts, with some birds moving by up to c. 20 or 25 km from one winter to the next. So there is some relative flexibility of roosting location, though at the local scale. On the contrary, foraging home ranges are small, and highly repeatable for 63 tracked individuals and 159 winter ranges (Schwemmer et al., 2026), with a repeatability >0.998. Looking at home-range sizes, birds with more than 3 years of data had a large mean overlap across years, ranging from 61 to 80% (P. Bocher et al. unpublished results). Comparing 62 tracked individuals wintering in the German Wadden Sea and in western France, Donnez et al. (2026b) found similar home range sizes, though with larger size from arrival to September, which corresponds to the complete post-breeding moult, when curlews preferred to feed on seagrass beds located in nature reserves. This period corresponds to high disturbance in coastal habitats during summer tourism, when the birds have reduced flight capacity.

4.3. Carry-over effects

For migratory birds, the influence of habitat use during the non-breeding period can carry over to body condition in subsequent stages of the annual cycle and affect individual breeding performance (Drent et al., 2003; Norris et al., 2004; Harrison et al., 2011). The translation of carry-over effects into population dynamics has the potential to explain population declines in migratory birds. J. Hanzelka et al. (ongoing work) are investigating whether the habitat types used on the non-breeding grounds, at stopover sites, and on the breeding grounds influenced breeding performance as carry-over effects in the curlew, using a range-wide dataset of 92 individually tracked curlews, comprising 128 full annual cycles. They found noteworthy indications of carry-over effects on breeding performance associated with the use of intertidal mudflats and salt marshes, the two dominant habitats on the non-breeding grounds, and with the use of grasslands, the most used habitat on the breeding grounds. The indication of positive effects of salt marshes might result from their great importance as winter roosts during high tides.

4.4. Onshore and offshore wind farms

There is evidence of impacts of onshore wind farms on breeding curlew populations, with breeding densities (from visual counts) decreasing on wind farms during and after construction (Pearce-Higgins et al., 2012). Individual tracking also allows documenting large-scale or local interactions between curlews and wind turbines.

4.4.1. Collision risk

Schwemmer et al. (2022) analysed data from 51 tagged curlews (118 flight tracks) to inform collision-risk models and assess potential conflicts with current and future offshore wind farms (OWFs) in the south-western Baltic Sea. Despite a broad-front migration, they identified core migration areas, largely overlapping with already operating OWFs. Flight altitudes across the sea and during autumn (median: 60 m) were significantly lower than those across land (median: 335 m) and during spring (median across sea: 150; median across land: 576 m). Across the sea, curlews spent 74.8% and 62.2% of their migration times below 300 m during autumn and spring, respectively, indicating a potentially high collision risk with OWFs. Migration intensity was highest at night over a 10-day period during April, suggesting that restricted turbine operation for several days might be a possible management measure. A similar work is conducted by C.B. Thaxter et al. for curlews navigating the North Sea. Seasonal directional patterns of flight activity corroborated the previous study. Flight height and ground speed patterns are in line with wind-assisted support and predict general altitude patterns. Such results should enable a more accurate assessment of collision vulnerability and the development of mitigation strategies. As an illustration of direct interaction of a tracked curlew and a wind turbine, Jiguet et al. (2021b) reported that the trajectory of a GPS-tracked adult curlew stopped at a wind turbine, while the outcome of the interaction was non-lethal, as the bird completed its migratory journey the next day. Tracked curlews also provided the necessary flight altitude data, within 168 bird species, for a web application developed by Fluhr et al. (2025) for estimating cautionary detection distance of birds to reduce collisions with wind turbines.

4.4.2. Avoidance behaviour

Schwemmer et al. (2023) then assessed behavioural reactions to OWFs during migration. They compiled an international dataset consisting of 260 tracks of 143 GPS-tagged curlews recorded over four years to assess the individual avoidance behaviour when approaching offshore wind farms in the North and Baltic Seas. Small-scale integrated Step Selection Models consistently detected horizontal avoidance responses in about 70% of approaching curlews, which were strongest at approximately 450 m distance to wind farms. An overall proportion of 28.8% of flight tracks crossed OWFs at least once during migration. Flight altitudes within the OWFs overlapped with rotor levels to a high degree in autumn (50%) and to a significantly lesser extent in spring (18.5%). An estimation showed that about 15.8% of the curlew population during autumn and 5.8% during spring migrated at elevated risks. These results show strong small-scale avoidance responses, which likely reduce collision risk but which, at the same time, represent a substantial barrier effect. There are ongoing studies on the avoidance response of territorial breeding curlews to terrestrial windfarms in Germany (H. Kruckenberg pers. comm.).

4.5. Future prospects

In Europe, six countries (Belgium, Germany, Ireland, Poland, Spain and the UK) have implemented population reinforcement by releasing captive-reared juveniles (headstarting), most of them used GPS tracking for post-release monitoring (Ewing et al., 2025). Tracking released headstarted chicks is not sufficient to fully understand how chicks born in the wild gain independence, so we encourage conservationists to tag large juveniles just before fledging (at age 30–35 days) and further identify their habitat needs, to define management actions that could improve their immediate post-fledging survival, but also survival until breeding recruitment. Tracking juveniles could, for example, document their behavioural reactions to wind farms, either onshore or offshore, which might differ from those of experienced older individuals.

High-resolution spatial and temporal tracking data now feed into habitat selection models, providing new insights into how individual curlews move within their home ranges. The methodological framework exists to identify which current statistical methods are most suitable and robust for the technical specifics of this data (Mercker et al., 2021). The challenge now is to apply these methods across different populations with tagged birds to evaluate how local patterns of resource selection inference scale up across larger spatial scales and conservation units (Winter et al., 2024).

Within such habitat selection investigations, the exploitation of accelerometer data, now collected by most modern GPS tags that include multiple sensors, will inform the behavioural activities of the bird in the selected habitat – and even the bird's energy expenditure across habitats of varying quality (Chimienti et al., 2022; Qasem et al., 2012). It is therefore possible to statistically separate foraging and resting sites in winter, to document the important functional habitats and their spatial distribution (e.g. distances from roost to feeding sites at inland or coastal marshes), as well as the function of the various habitats used in a breeding territory. Simultaneous analysis of tags' multiple sensors has already proved very useful in documenting the precise individual behaviour in curlews (Jiguet et al., 2023).

Curlews gather at stopover and wintering sites during the non-breeding season, then depend on a reduced localized number of functional sites to accomplish their annual cycle. Identifying the networks of such sites and their critical nodes is necessary to ensure an effective conservation (Yang et al., 2011, Beal et al., 2025). Access to food resources and quiet high-tide roosting is highly necessary and often relies on protected areas, especially coastal nature reserves. Human exploitation of curlew food resources (mechanized cockle harvesting; Taylor and Dodd, 2013) reduces their survival, and disturbance on high tide roosts has an energy cost that must be avoided in winter (Lilleyman et al., 2016). Species distribution models can be used to investigate how changes in the favourable climatic conditions and future land use may affect the breeding and non-breeding grounds in the future (Jiguet et al., 2013; Piirainen et al., 2023). Future conservation planning should consider the impacts of sea level rise due to climate change on the availability of tidal mudflats by conserving land that facilitates upshore shifts of tidal flats at the most important stopover and wintering sites (Iwamura et al., 2014). GPS tracking data, available for the species' wintering range across Europe, should make it possible to identify gaps in protected areas to ensure a functional network for the protection of curlews during stopovers and in winter (see Xiao et al., 2025 for an example in Asia, including curlews). Conservation planning at these key nodes will benefit a large set of waterbird species sharing similar ecology and food needs (Ens et al., 1990).

Whether on land or at sea, the development of renewable energy facilities must take into account the presence of the curlew and assess the potential consequences of any avoidance effect, to limit, mitigate or compensate for the impact on this vulnerable species. Tracking curlews with multiple-sensor GPS tags is an efficient solution to obtain on-site measures of local space use by the birds.

5. Synthesis on conservation issues and tagging

The Eurasian Curlew is a species of high conservation concern across Europe. In an International Single Species Action Plan (Brown, 2015), and in a synthesis on global threats to *Numeniini* published two years later (Pearce-Higgins et al., 2017), curlew experts listed the key threats to the species: human intrusion and disturbance (including agriculture works), developments of human infrastructures and associated changes in habitats and corridors, pollution (at coastal mudflats as well as intrants in farmed lands), terrestrial land use change and predation, climate change and mitigation, and harvesting. This review provides examples of how GPS-tagging contributes to or can contribute to characterize most of these threats.

Recent studies have highlighted that population declines are likely to be driven by low productivity (Viana et al.2023). Remote tracking provided unprecedented information confirming that recruitment is local, site fidelity among mature adults is very high, and that understanding population dynamics must take into account the survival of young birds up to two years of age or more, when they become reproductively mature and recruit. As a consequence, any effort in increasing reproductive success can be locally beneficial, as long as the survival of the fledged juveniles allows them to return to breeding sites. In that context, tracking is an appropriate tool to identify the wintering grounds of juvenile birds and pinpoint the possible threats they face there during their first years of life. The first attempts to track wild juveniles also provided a great opportunity to study migration ontogeny in a species with juveniles that are not accompanied by experienced mature birds and migrate on their own.

Because juveniles predominantly recruit where they fledged and rapidly become independent, reinforcing natural populations with captive-reared juveniles is a reasonable solution to increase local reproductive success where it is otherwise unsustainably low and resulting in local population declines. There are several headstarting programs currently running in Europe, and tracking released juveniles can provide information on the most beneficial conditions favouring the survival of the released individuals. Optimal release sites include natural habitats for foraging, but should avoid human infrastructure (buildings and roads) to limit mammalian predation (by feral cats, wild carnivores and scavengers) and avoid isolated trees to limit the availability of perches used by potential avian predators.

Tracking curlews on their breeding and wintering grounds has quantified their home ranges, which are quite similar across the range, and has provided guidance on the scale of habitat management or restoration, as well as identifying important sites outside existing protected area designations. The identification of critical nodes within the migratory network from hundreds of tracks reveals weaknesses and

proposes new protected areas to complete the existing network. The integration of demography and connectivity models should be used to develop adaptive management being able to consider anthropogenic impacts, especially in the context of wind farm developments and hunting. The next important step is to integrate habitat selection, demography and climate change projections to determine the priority regions for targeted management and restoration.

Finally, GPS tracking needs to be developed to cover both research and conservation issues in the Asian range of the species.

6. Policy recommendations

Finally, a key objective of this review was to propose policy recommendations benefiting from the insights gained from tracking studies. They are not exhaustive, but they provide guidelines for future acquisition and use of tracking data to improve the conservation status of the Eurasian Curlew along the flyway. They are presented as policy briefs, largely based on the original results discussed in the review. The briefs are intended to guide policymakers, conservation practitioners and stakeholders in implementing measures that maintain breeding success, juvenile survival, habitat integrity, and population connectivity throughout the species' range.

Policy brief 1. The strong fidelity of curlews to their breeding and wintering sites requires prioritizing the protection and improvement of habitat quality at currently occupied sites. Long-term protection of breeding areas and main wintering sites is necessary. This concerns the key breeding habitats and their land use as selected by breeding birds, such as peatbogs, moorlands and grasslands. Finland hosts a very large part of the EU breeding population, with 90% breeding in agricultural fields, where implementing correct Agri-Environment Scheme measures through the Common Agricultural Policy is crucial. On the key non-breeding foraging mudflats, human disturbance should be limited and mechanized shellfish harvesting should be prohibited, especially until the post-breeding moult is completed (October). Although carry-over effects from non-breeding habitat use appear subtle, ensuring high survival during the non-breeding period remains important for overall population maintenance.

Policy brief 2. Very high natural philopatry will only allow populations to recover from the recruitment of locally born young, hence the importance of improving breeding success, but also immature survival until breeding recruitment. Conservation measures should enhance breeding success and the post-fledging survival and movements of young birds, especially during their first post-breeding migration. Habitat restoration should occur within or close to occupied sites, as recruitment is local, so colonisation will hardly occur away from already occupied sites.

Policy brief 3. Enhancing breeding success is overall necessary and must be based on various actions, and requires a combination of habitat management and nest protection. Conservation efforts should focus on a network of units corresponding to the average size of a curlew pair's territory (100 ha), ensuring that the majority of the area comprises favourable habitats. Human infrastructure and isolated trees within this area should be minimized to reduce predation risk on chicks. Nest protection can be implemented using electric fencing and any other method to repel mammalian predators. Lethal regulation of native predators should be the last option implemented, always in combination with active habitat restoration, ensuring a short-term rebalancing of predator-prey relationships.

Policy brief 4. Headstarting – the captive chick rearing from eggs collected in the wild – should be implemented for populations with critically low fledging success, to boost future recruitments, also possibly to restore extinct local populations where habitat conditions are suitable. Ensuring post-release survival is central to the success of such interventionist measures, and release sites should be selected with care according to predation risk and the potential for future recruitment. Monitoring post-release survival, for example using GPS tags, is recommended to guide adaptive management that will be favourable for the survival of both headstarted juveniles, as well as any local, wild counterparts. Headstarting should be tightly linked to habitat conservation and restoration.

Policy brief 5. It is necessary to give a protection status to all critical nodes within the migratory network along the flyway, to efficiently regulate disturbance, infrastructure developments and the exploitation of curlew food resources, acknowledging that some birds arrive at their non-breeding grounds as early as June, and undergo the annual complete active moult, which is an energetically expensive and sensitive part of the annual cycle, indeed occurring during the summer peak in tourist activity. Stakeholders should ensure that there is no disturbance at roosts where birds gather at high tide and also inland, which is best achieved by providing strictly protected areas close by the major foraging mudflats.

Policy brief 6. Priorities for population restoration should consider the evolutionary distinctiveness of conservation units, as identified from genome level data, the local extinction risk in the context of global change, including climate change, and the the regional contexts for potential habitat restoration. The small Spanish breeding population occupies the hottest part of the species niche in Europe and therefore might not seem like a priority for conservation action in the context of rapid climate change. Quite the opposite, it forms a distinct evolutionary lineage, representing a genomic diversity that is worth protecting, as it may represent the best evolutionary potential for adaptation to hot climates in the species.

Policy brief 7. Stakeholders should avoid placing onshore wind farms where curlew populations occur, or where they existed in the past and population recovery is expected. Impact assessments should consider collision risk and barrier effects in any local wind farm project, as the species is sensitive to both impacts, both on land and at sea. It is also necessary to develop a global analysis of cumulated impacts along the flyway.

Policy brief 8. The information and education of hunters and the control of hunting activities must continue, as there have been numerous cases of illegal killing since the moratorium in Europe, as first migrants are particularly naïve, and because of a high confusion risk with the huntable Eurasian Whimbrel *Numenius phaeopus*.

CRediT authorship contribution statement

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Declaration of competing interest

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

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No data was used for the research described in the article.

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