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Research Article

Movement ecology of the Sacred ibis (*Threskiornis aethiopicus*) outside of its natural range

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Abstract

Understanding the movements of alien species in newly colonized territories is crucial for addressing the challenges posed by global transformations and threats to biodiversity conservation. In this study, we used mark-resight data to investigate the dispersal movements of the sacred ibis (*Threskiornis aethiopicus*; class: Aves) in Italy, which were virtually unknown until now. We analyzed data from 357 color-ringed ibises, the majority of which were marked as nestlings, including six hybrids with the African spoonbill (*Platalea alba*). Resightings revealed a tendency towards philopatry, with most observations occurring within 10 km of the original colony. However, few individuals travelled much farther, with maximum recorded distances exceeding 300 km from the ringing site. The average long-distance travel speed was 15.4 km per day. Movement directions showed clustering along both the North-South and East-West axes, influenced by colony location. Landfills emerged as significant feeding sites, particularly in winter. Age class had a significant negative effect on dispersal distance, whereas timing of hatching showed a positive effect. Although philopatry was predominant, our results indicate that the species retains the potential for longer-range dispersal under certain conditions. While based on a limited number of individuals, such movements could nonetheless facilitate expansion into distant areas, particularly given the availability of suitable habitats. These findings provide the first evidence of the dispersal capability of the sacred ibis outside its native range and should be used to inform management actions aimed at mitigating the potential effects of this invasive species.

Key words: Alien, banding, dispersal, IAS, invasive, ringing

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Introduction

The increasing spread of invasive alien species (IAS) is considered one of the major drivers of biodiversity loss in the Anthropocene (Park 2004). This spread can vary considerably depending on species ecology and environmental conditions, ranging from a slow and localized process to the rapid colonization of extensive areas (Liu et al. 2014; Cameron and Bayne 2015). The rate, mode, and circumstances of this process depend on several factors, including species-specific dispersal strategies. In IAS, these strategies may differ from those observed in their native range and may also shift during the invasion process. Furthermore, when tracking invasion

patterns, it is crucial to consider the potential increase in activity levels or exploratory behavior of the alien species (Burstal et al. 2020).

The sacred ibis (*Threskiornis aethiopicus*; class: Aves), native to sub-Saharan Africa and Iraq, has been present in Europe as an alien species since the 1970s, following repeated escapes from aviaries and wildlife parks (Yésou and Clergeau 2005). The presence of these escaped individuals complicates efforts to determine whether other birds could have arrived spontaneously from their native range (Cocchi et al. 2023). While the likelihood of isolated immigrants appears low, it is not implausible, as observed in other highly dispersive avian species and hypothesized by Marion (2013). In Europe, breeding in the wild has been confirmed in France, Germany, Italy, Portugal, Spain, Switzerland, and the Netherlands (Robert et al. 2013; Yésou et al. 2017). In Italy, the species has been recorded since the 19th century (Arrigoni degli Oddi 1929), but until the early 2000s, it was not yet considered naturalized (Brichetti and Fracasso 2003). The exact origin of the Italian population remains uncertain. However, since the 1990s, the population has been reinforced by numerous accidental releases and escapes from zoos in Italy and neighboring countries (Cocchi et al. 2023) and possibly by individuals dispersing from the expanding French population (Cucco et al. 2021).

This exotic and relatively easy-to-maintain bird is commonly kept in zoological gardens, wildlife centres, and private parks. The risk of escapes and subsequent population growth remains a concern, particularly in non-EU countries where the keeping of alien species is not regulated. In recent years, more than 10,000 individuals have been counted in captivity across Europe. Currently, 142 facilities in EU countries and 34 in non-EU European countries house sacred ibises (Zootierliste, n.d.).

Until the early 2000s, the few recorded sacred ibises were concentrated in northwestern Italy. However, since 2006, their expansion has been continuous and exponential, initially across a large area of the Po Valley and later, with increasing frequency, into at least 14 regions of central and southern Italy, including the major islands of Sicily and Sardinia (Cucco et al. 2021; Ercole et al. 2021). Beyond the core population in northwestern Italy, in the past five years, the species has established thriving colonies in central and northern regions (Scarton and Valle 2020; Cucco et al. 2021). This geographical expansion has been accompanied by an exponential increase in numbers, from around 70 individuals with sporadic nesting until 2010, to 1,249 breeding pairs and more than 11,000 wintering individuals in northwestern Italy by 2019 (Cocchi et al. 2023).

Regulation 1143/2014 of the European Parliament requires Member States to implement measures for managing IAS, including provisions to prevent their introduction and control their spread (European Parliament and Council 2014). Since 2016, the sacred ibis has been listed as an IAS of Union Concern, meaning it is subject to management measures and restrictions on keeping, importing, selling, breeding, and releasing into the environment. This classification is primarily due to its predation on amphibians and the eggs of native bird species, as well as its potential competition for breeding sites with native species such as the Eurasian spoonbill (*Platalea leucorodia*), colonial herons, and egrets. In response, Italy approved a national management plan for the species in 2023 (Cocchi et al. 2023), aiming to eradicate, reduce, and control the population in the Po Plain while preventing its expansion into currently unoccupied areas.

However, the effectiveness of a species management plan—both in terms of economic cost and technical feasibility—relies on a comprehensive understanding

of the target species' ecology, population dynamics, and distribution. One critical factor in this context is dispersal, which significantly influences the extent and pace of invasion. Without robust quantitative ecological data clarifying the mechanisms driving species demography, developing a targeted control strategy and evaluating its effectiveness may be challenging, if not impossible.

In this study, we analyze a 19-year capture-mark-resight dataset to assess the dispersal capacity of the sacred ibis outside its native range within Italy. We also evaluate the role of dispersal in the context of the management strategies applied to this IAS of Union Concern.

Methods

Mark-resight data

From 2004 to 2023, a total of 357 nestlings and fledged ibises were marked with metal rings provided by the Italian Ringing Scheme and a yellow plastic ring with a unique 2- or 3-digit alphanumeric code. These color-rings can be read from a distance of up to 100 meters using a telescope or digital images taken with a telephoto lens. Nestlings (n = 321) were marked in five colonies located either in inland locations (Desana and Valbrembo) or coastal wetlands (Comacchio and Ravenna) (Suppl. material 1, Fig. 1). Most of the fledged birds were accidentally caught in cages originally intended for anatids and herons at the Casalbeltrame ringing station (province of Novara), and occasionally in colonies during nest monitoring.

The first nestlings were ringed in the southern Po Delta, where the sacred ibis settled in a large mixed heronry, breeding in close association with Eurasian spoonbills and other colonial waterbirds (Cocchi et al. 2023). In fact, the very first ringed nestlings were hybrids from a mixed pair formed by a male sacred ibis and a female African spoonbill (*Platalea alba*) nesting in a flooded *Salix* bush (Volponi et al. 2008). In 2016-2018, nestlings were ringed at the colony situated within the Valbrembo zoological park (province of Bergamo), where free sacred ibises bred on tall coniferous trees (Castiglioni 2017). There, ringing was only possible by approaching the nests from a mobile aerial platform during tree maintenance work. More regular and intensive ringing started in 2017 in the colony inside the large coastal lagoon of Comacchio (province of Ferrara) where ibis nests were built on the ground, again close to the spoonbills' nests. In addition, a small number of nestlings were ringed from ground nests in the Desana colony, located near the city of Vercelli in an area of intensive rice cultivation. Hybrids were easily recognizable, as they share a similar body morphology with the ibis but display different bill shape and plumage characteristics — for instance, they lack the typical black coloring on the head and neck and show a much more limited extent of black on the tail region (see pictures in Volponi and Emiliani 2008; Volponi et al 2008). Moreover, all hybrids were ringed while still in the nest, under parental care.

Most of the resighting data came from the observation of color-ringed birds and to a lesser extent (less than 2% of the total number of records) from the recovery of dead birds. Birdwatchers, wildlife photographers and amateur ornithologists provided most of the observations outside the ringing sites. Such observations were often reported via social media or, secondarily, directly to the Italian ringing scheme or to the ringers themselves. For each resighting event, the coordinates of the observation site were recorded and information on the specific habitat type where the resighting was

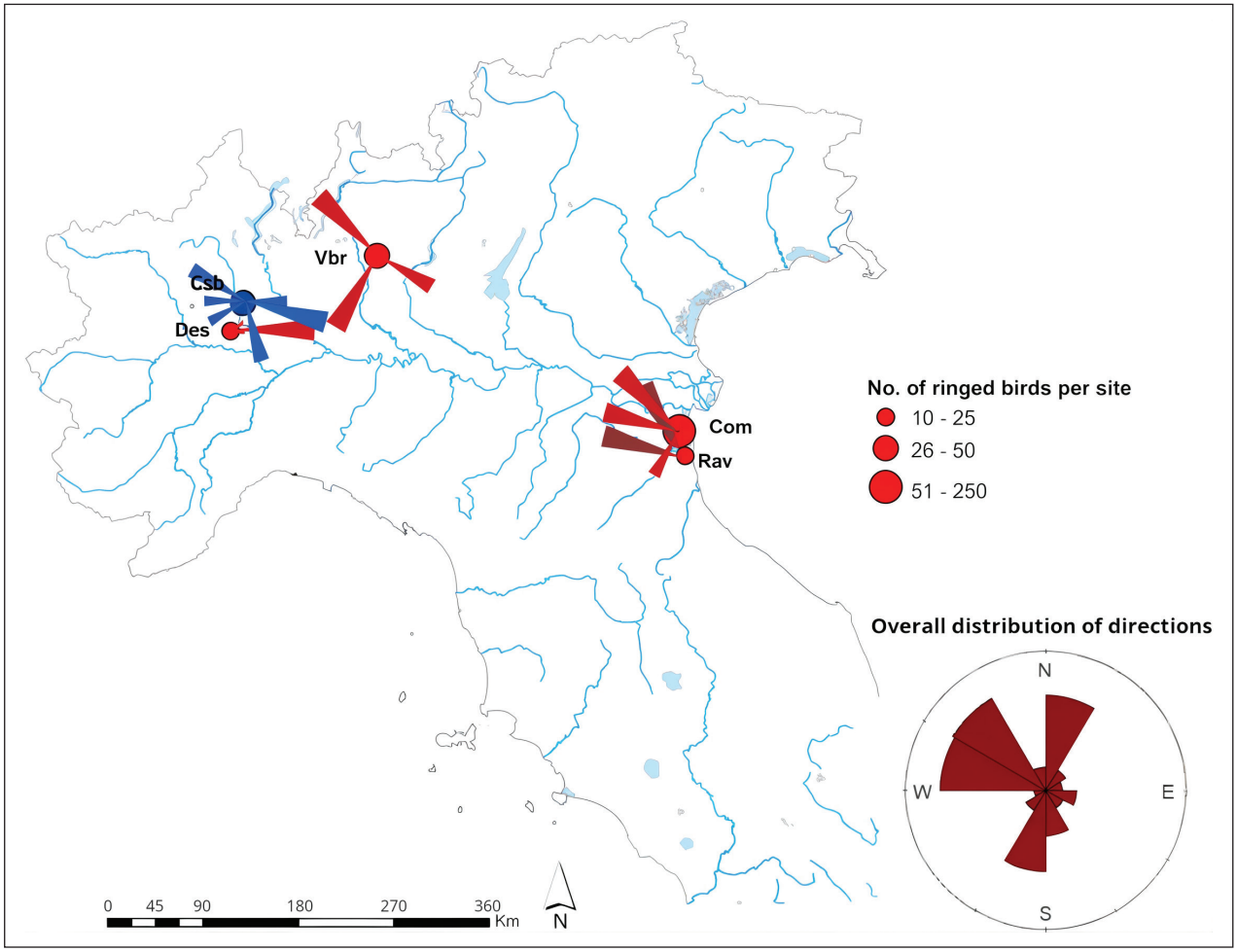

Figure 1. Map of ringing sites in Northern Italy and the corresponding movement directions observed. The size of each dot is directly proportional to the number of individuals ringed. Red dots represent breeding colonies, while the blue dot marks the location of the Casalbeltrame ringing station. Abbreviations: Com: Comacchio; Vbr: Valbrembo; Csb: Casalbeltrame; Des: Desana; Rav: Ravenna. The circular plot in the bottom-right corner illustrates the overall distribution of movement directions for resighted birds.

performed was derived from both images provided by the observers and from satellite maps. Searches for ringed birds were regularly carried out during visits to known ibis colonies, heronries and their surroundings. Other resightings were obtained from images taken by camera traps used to monitor nests in the Comacchio colony.

Resightings of individuals marked as nestlings and seen in or near the ringing site were only included in the analysis if they occurred after 40 days of marking, in order to exclude records before fledgling. Data collection for resightings ended on 30 September 2024.

Movement analysis

Data from resightings were analyzed to derive quantitative metrics of ibis movement and dispersal. To perform the analysis, when more than one resighting of the same individual occurred within the same month, only the one furthest from the ringing site was retained. Specifically, we (i) calculated both the orthodromic distance and direction between an individual marking site and each resighting location; (ii) calculated the average travel speed using the method of Smith and Munro (2011), which involves dividing the distance

travelled by individuals covering significant distances (>150 km in our case) in a short period of time (<4 months) by the number of days elapsed; these thresholds were chosen in analogy to the > 500 km cut-off applied by Smith and Munro, adjusted to reflect the smaller geographic extent of our study area (Italy, as opposed to the much larger spatial scale of Australia) —the goal of this approach is to obtain a rough estimate of how fast ibis can travel on a regional scale, without capturing local movements, which would underestimate the species' potential for rapid range expansion; (iii) calculated the percentage of resightings per habitat to highlight any differences in occurrence among habitat types; (iv) checked whether, if an individual was resighted in a breeding colony, the latter was its hatching colony or not, to explore the possible tendency for philopatry or reproductive exchange among different colonies; (v) estimated how age class and hatching time of resighted individuals affected their travel distance, using a Generalized Linear Mixed Model (GLMM) fitted using restricted maximum likelihood (REML). We used age groups and hatching time (or "brood class") as predictive variables and ring code (i.e. individual) as random factor to avoid pseudoreplication. This analysis was performed using the R (R Core Team 2022) package lme4 (Bates et al. 2015). All classes were determined only for non-hybrid birds marked as nestlings. Age classes 1-, 2-, 3-, and 4-year old or older were categorized as follows: 1) birds resighted the same year they hatched, 2) birds resighted the year following their hatching, 3) birds resighted two years after hatching, and 4) birds resighted three or more years after hatching. We considered three brood classes: early broods (nestlings marked before 15 May), intermediate broods (nestlings marked between 16 May and 30 June), and late broods (nestlings marked from 1 July).

We used the Rao's spacing test (R package circular; Agostinelli and Lund 2024) to test whether the calculated directions were randomly distributed or clustered. This analysis was performed by first considering the total movements and then separately examining the movements of birds ringed in coastal (provinces of Ravenna and Ferrara) and inland sites (provinces of Bergamo, Novara and Vercelli).

Results

Mark-resight

In total, 491 resightings were achieved during the study period, representing 138 different individuals (38.7% of the total number of individuals ringed). The year with the highest number of resightings (234) was 2024, with 64 different individuals. There were no resightings before 2006 and none in 2015. The vast majority of resightings involved live birds, but six concerned birds that were found dead. Of these, three died of natural causes, two were shot, and one died as a result of a severe weather event. One of the shot birds was killed by a poacher in 2009, and the other by a wildlife ranger during a culling in Friuli-Venezia Giulia in 2023. Apart from the authors and ringers, 71 observers reported 215 resightings from 68 localities, spread across eight administrative regions and 19 provinces. Ringed birds were resighted at ibis and heron colonies, daytime aggregations, night roosts, and feeding sites in various habitats, including natural wetlands, ditches and canals, agricultural fields, and artificial environments (e.g. landfills, dung heaps). Most resightings were made at landfill sites (41.2%) and breeding colonies (38.8%) (Fig. 2).

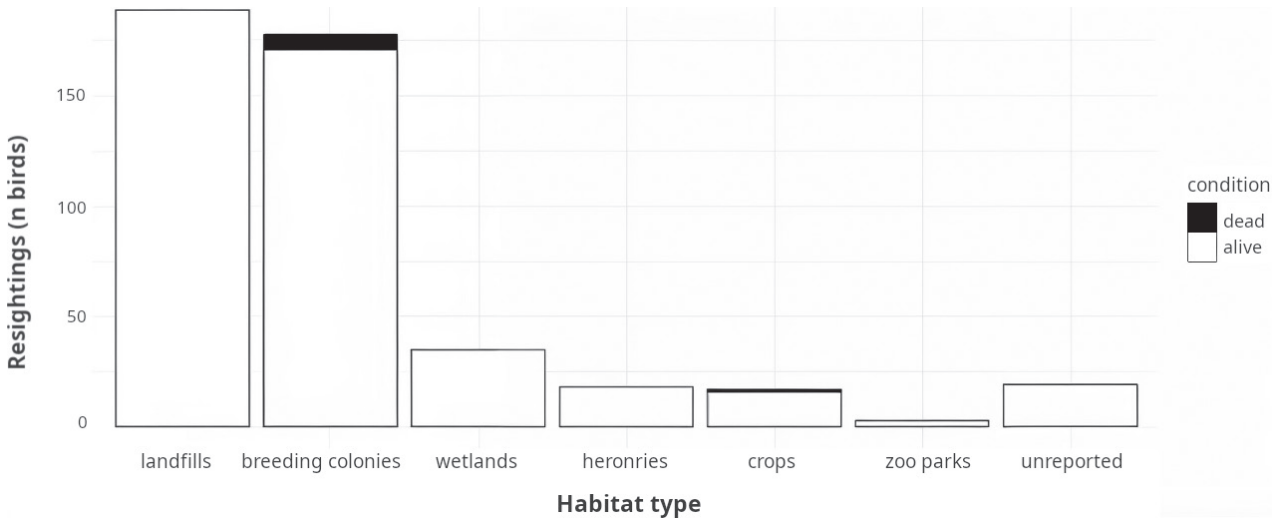

Figure 2. Number of resightings per habitat type. Recovery of dead individuals are shown in black. Observations at ibis breeding colonies and heronries were considered separately, as they occurred across a variety of wetland and terrestrial habitats and because these sites are used by ibises primarily as aggregation areas rather than for foraging.

The majority (97.8%) of the resightings occurred at a breeding colony referred to the natal colony where individuals were ringed as nestlings. Of the six hybrid individuals ringed, only four were resighted, resulting in a total of 16 resightings. However, only five of these resightings occurred more than a year after ringing.

Movement analysis

Dispersal distances

Local movement after fledging, calculated as the mean orthodromic distance, was 40.97 km (SD = 58.33 km). However, the longest orthodromic distance travelled by an individual was 358.48 km, and five birds (about 3.6% of the resighted individuals) travelled distances of over 250 km. The movements of hybrid individuals were much more restricted, with an average dispersal of 3.5 km and a maximum orthodromic distance covered of approximately 13 km. Around 42.9% of resightings (excluding hybrids and birds ringed as adults, i.e. 197 resightings, 63 different individuals) occurred within 10 km of the ringing location (Fig. 3). The average travel speed calculated for birds covering long distances (i.e. > 150 km) in a short (<4 months) time (corresponding to six birds) was found to be 15.4 km per day, with the highest speed achieved by an individual covering 316.7 km in just over 3.5 months (26.6 km per day).

Results from the GLMM revealed significant associations between distance travelled and both age and brood class factors (Fig. 3, Suppl. material 2). In particular, age group had a significant negative effect on distance travelled (mean effect and 95% CI = -29.28, [-50.99, -7.57], t value = -2.645 for age class 3 and -33.17, [-59.16, -7.18], t value = -2.502 for age class 4), suggesting that older individuals tended to travel shorter distances. Conversely, brood class 3 had a significant positive effect on distance travelled (mean effect and 95% CI = 51.49, [17.53, 85.45], t value = 2.968 for brood class 3), while brood class 2 effect was positive but not significant (mean effect and 95% CI = 17.15, [–6.66,40.96], t value = 1.412) indicating that only birds from the latest broods tended to travel longer distances.

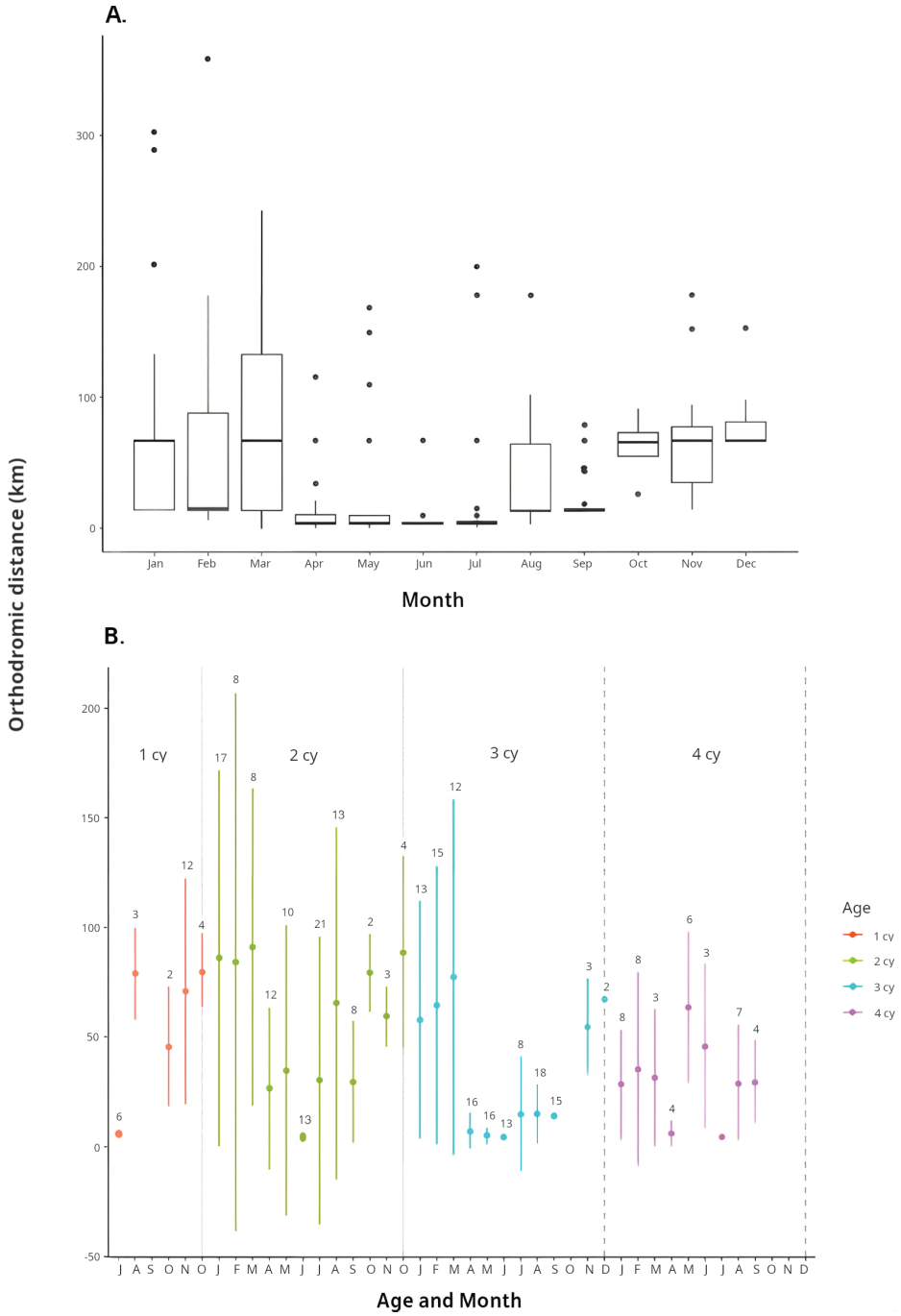

Figure 3. A. Mean orthodromic distance travelled by resighted birds, divided by month of resighting, without distinction by age class; **B.** Mean orthodromic distance (± standard deviation; in kilometers). Resightings are grouped by month and age class (calculated in calendar years, see methods). The numbers on each bar indicate sample size.

Directions

Rao's spacing test on the directions (in degrees) taken by resighted individuals significantly ($t = 292.2$, $p < 0.001$) indicated that angular directions were not uniformly distributed in space. When considered all together, the dispersal paths of the ibises were not randomly directed; instead, they exhibited a clear clustering, predominantly directed towards the northwest and roughly along the north-south axis (Fig. 1). Two individuals showed interesting commuting movements along the east-west axis between the Adriatic coast and the western Po valley.

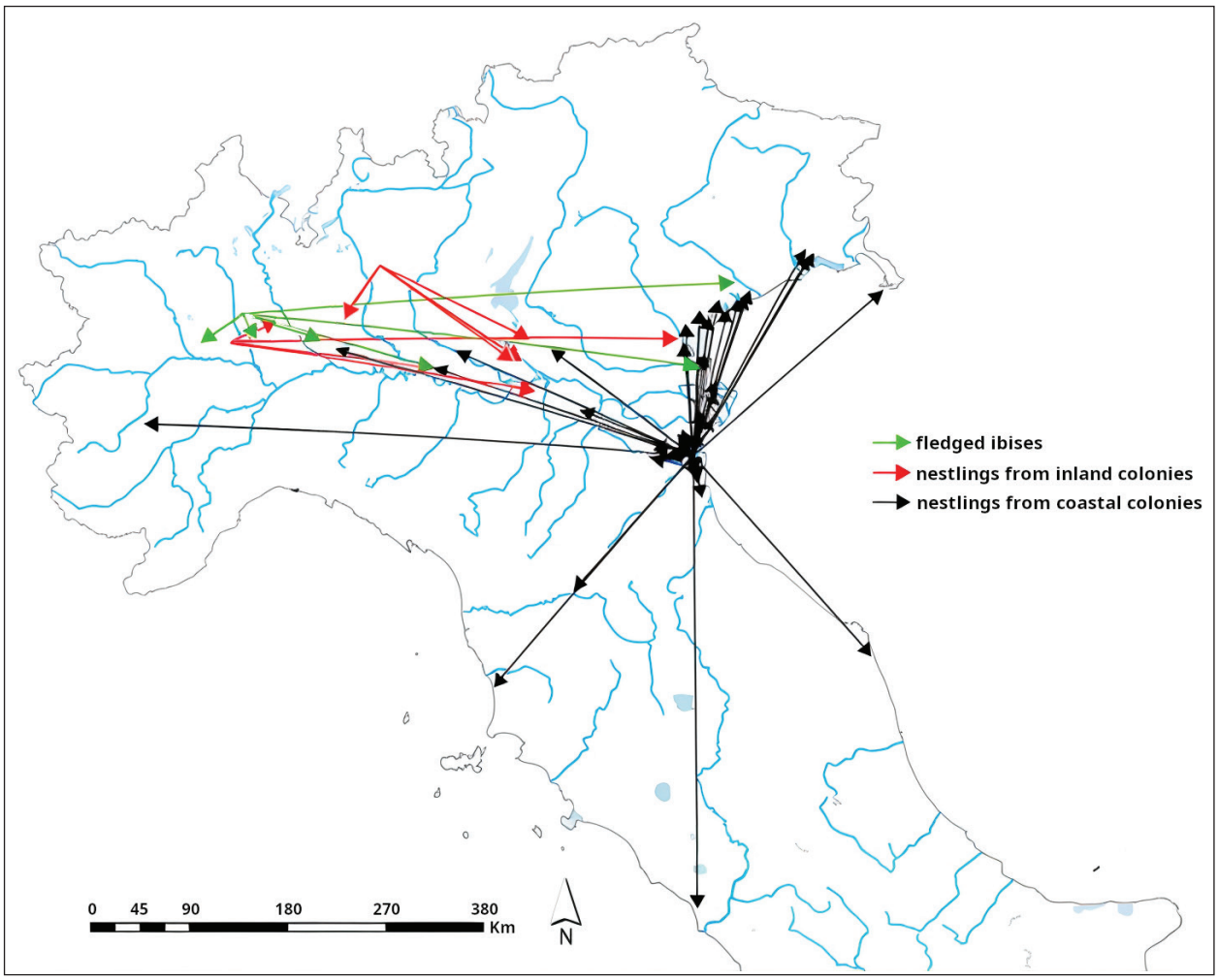

Figure 4. Movements of the sacred ibises ringed in Italy. The color of the arrows corresponds to individuals ringed as fledged birds (green) or as nestlings from inland (red) and coastal (black) colonies. The arrowheads indicate the recapture sites.

For both birds ringed in coastal and inland colonies, the directionality of movement was found to be non-random and highly clustered (assessed by Rao's spacing test, t = 237.6 for inland and 301.0 for coastal, both $p < 0.001$). The Watson's two-sample test of homogeneity yielded a test statistic of 1.261 and a p-value of less than 0.001, indicating a significant difference between the directional movement angles of individuals ringed in coastal colonies compared to those ringed in inland colonies. This suggests distinct directional patterns between the sampled populations. While birds from inland colonies — as can be observed from Fig. 4— showed a prevalence of movement along the east-west axis, those ringed in coastal colonies showed a distinct directional trend along the north-south axis, accompanied by a secondary dispersal cluster towards the west-northwest direction. (Figs 2, 4).

Discussion

Understanding the dispersal of alien species beyond their native range is crucial for addressing the challenges of managing them in a constantly changing environment (Webber and Scott 2012). Although ringing has inherent limitations—such as potential sampling biases (e.g., certain age groups of birds being more likely to be resighted; Giuntini et al. 2023) and its inability to track entire migration routes,

capturing only segments through resightings (Smith and Munro 2011) — the exploration of movement ecology through ringing has consistently proven its worth (Baillie et al. 1999; Thorup et al. 2014; Dalui and Mondal 2023). In this study, we used this technique to unravel previously unknown dispersal movements of this alien species during a period of population expansion outside its native range.

The analysis of resightings showed a pronounced tendency for adults and juveniles (probably during prospecting movements) to be philopatric towards the colony where they had been marked as nestlings. Specifically, whenever a bird was resighted in a breeding colony—the most common resighting habitat after landfills—was consistently the same breeding colony where the individual had been ringed. On the other hand, nest site fidelity is indeed characteristic of the species (Maillard et al. 2020) and has also been observed in the closely related Australian white ibis (*Threskiornis molucca*, Smith and Munro 2011). In fact, as already mentioned in the results, a substantial number of resightings (approximately 38%; see Results) were recorded within the natal colonies, and nearly half of the total number occurred within 10 km of the ringing site. This pattern may in part reflect the fact that many observations were collected during nest monitoring activities. Nevertheless, although the distribution of observers and the resighting effort were not uniform across the study area, the overall pattern of observations still highlights individual variation in dispersal behavior within the sacred ibis population.

In our sample, local post-fledgling dispersal consistently averaged less than 50 km. However, substantial movements of more than 350 km were documented as early as the first autumn-winter of life. The much shorter distances observed for hybrids, which never exceeded 12 km and averaged less than 4 km, are not particularly surprising, as almost all observations of the few hybrids were restricted to the first few months after fledging. Except for hybrids, the observed dispersal distances align with findings from other invasion areas, such as France, where ibises have dispersed over hundreds of kilometers (Clergeau and Yésou 2006), and with patterns in their native range, where adult ibises travel significant distances during post-breeding dispersal, often accompanied by juveniles (Hancock and Kushlan 1992). In Africa, the extent and direction of movements vary with seasonal rainfall. Ringing records indicate that birds ringed in South Africa have been recovered across a wide territory, reaching as far as Zambia, Botswana, and Namibia, with the most distant recovery recorded 1,474 km from the ringing site (Clark and Clark 1979). Similarly, the Australian white ibis (*Threskiornis molucca*)—once considered a subspecies of *T. aethiopicus* (Hancock and Kushlan 1992; Christidis and Boles 2008) and now recognized as one of three species in the *Threskiornis aethiopicus* superspecies complex (Lowe and Richards 1991)—frequently travels distances exceeding 300 km, with occasional movements surpassing 1,000 km (Smith and Munro 2011).

The average dispersal speed we calculated appears relatively high, though it must be interpreted with caution due to the small sample size (n = 6) of individuals meeting the criteria for this estimate. Nonetheless, when considered alongside observations from other recently colonized areas and the known high mobility of ibises in their native range (Clark and Clark 1979), our findings suggest a notable potential for rapid movements to new areas and possible colonisation by single individuals. Theoretically, individuals could traverse the entire length of Italy in under three months, a pattern broadly consistent with dispersal speeds reported for the Australian white ibis by Smith and Munro (2011), where the fastest ringed individual travelled at an average of 14.5 km per day. It is worth noting that, unlike

Smith and Munro (2011), who considered only displacements over 500 km, our threshold was lower (>150 km), which could lead to lower average speeds—yet the values we found remain comparably high, further supporting the potential for rapid expansion. It is important to highlight, moreover, that our estimate likely represents a conservative value, as we cannot determine whether a bird arrived at the resighting location on the same day of the resighting or was already present. Considering all of the above, the potential for large-scale expansion remains relevant, particularly in light of the extensive availability of suitable yet uncolonized habitats throughout Italy (Cucco et al. 2021).

Indeed, while the species has primarily been recorded in northern Italy, recent years have seen an increasing number of regular sightings in central and southern regions (Nicoli et al. 2022; Pantalone et al. 2023; Fraticelli 2024; Maio et al. 2024). Given the species' potential to disperse to new areas, it is reasonable to assume that its range expansion could impact countries near Italy that are either not yet colonized or only partially so. Colonies in northwestern Italy (e.g., Piedmont) could expand into neighboring France, where an eradication program has been in place since 2007, leading to a significant reduction in the French ibis population (Yésou et al. 2017). Moreover, ibises dispersing from colonies in other Italian regions may have already contributed to the colonization of nearby countries. For instance, the six immature birds that spent a few weeks in the Magadino Plain (Canton Ticino, Switzerland) in early 2021 (Mordasini 2021) may have originated from colonies in Piedmont or Lombardy. Similarly, some of the at least 30 ibises observed in Corsica (France) in 2021 (CorseOrnitho 2021) could have arrived from Tuscany, possibly following migrating Eurasian spoonbills that were present in the same coastal wetland at the time. Finally, at least one of the 12 individuals recorded in Slovenia in February 2024 (Maks Sešlar, pers. comm.) was confirmed to have been born and ringed in the Comacchio colony in 2023.

The prevalence of movements along the east-west axis (and vice versa) in the Po Valley and northwards from the Emilia-Romagna colonies appears to be guided by the hydrographic network of the Po River and the sequence of wetlands characterizing the northern Adriatic coast (north-east axis); two individuals, notably, also showed interesting commuting movements along the east-west axis between the Adriatic coast and the western Po valley. Similar behaviour has been observed in spoonbills, herons, cormorants, and other colonial wading birds ringed in the Po Delta (Volponi S. unpublished data). Elsewhere, closely related species, such as the glossy ibis (*Plegadis falcinellus*), have been found to follow wetland flyways (Samraoui et al. 2023). Additionally, sacred ibises within the same roost and colony seem to consistently maintain an awareness of local foraging areas from one day to the next. This is supported by the relatively stable and directional flight paths of birds departing in the morning (Evans et al. 1981) or returning at dusk (Volponi S., unpublished data). This pattern may help to explain the tendency of some ringed individuals to exhibit east-west commuting movements from their original coastal colony towards the core area of initial settlements (i.e., the western Po Valley). Such behavior could be an extended form of the commuting movements between foraging areas and roosts characteristic of the species. However, it is important to note that typical commuting movements generally cover shorter distances (less than 1 km, Evans et al. 1981; Yésou et al. 2017) and are therefore likely distinct from the longer-range movements (several tens of kilometres) observed in this study. The most plausible hypothesis remains that these movements

involve individuals returning in spring to their marking colony following breeding or prospecting dispersal.

The location of resightings underscores the key role of landfills as feeding sites and, more specifically, as winter hotspots. Across three winters (2021–2023), a total of 35 distinct individuals, accounting for 81 observations, were resighted at five landfill sites in the provinces of Cremona, Ferrara, Ravenna, and Venice. These sites, which hosted anywhere from a few dozen to over 1,000 ibises, served as foraging grounds where the birds scavenged a mix of animal, plant, and human waste alongside other bird species. The majority of ibises observed at landfills were juveniles and immature, with adults present in smaller numbers. This suggests that feeding at landfills, or more generally food subsidies (Oro et al. 2013), may play a role in winter survival, particularly for younger individuals, which are generally more vulnerable to winter mortality.

The use of landfills as feeding sites by ibises has been documented in other populations. Clark and Clark (1979) noted that ibises tend to concentrate in areas where food is produced by human activities, such as animal farms and rubbish dumps. Clergeau and Yésou (2006) reported over 600 ibises feeding at a single landfill, while Marion (2013) identified landfills as the primary feeding grounds for the species in Brittany. Similarly, the Australian white ibis exhibits the same foraging behaviour in its native range. Smith and Munro (2011) found that landfills played a dominant role in the species' feeding habits, with more than 90% of resightings occurring at these sites. Despite their ecological significance, the role of landfills as key feeding areas has not been previously highlighted in the Italian context. This is particularly important for population management initiatives, as the easy access and constant availability of food in landfills—especially during winter—can promote aggregation and enhance survival rates in large numbers of birds (Oro et al. 2013).

The analysis revealed a significant effect of age class on dispersal distance, which decreased with increasing age. This may reflect natal dispersal —i.e., the movement from the birth site to the site of first (or potential) reproduction— of immature birds (Greenwood and Harvey 1982). Although this might seem to contradict the observed philopatric tendencies, a plausible hypothesis, at least in our case study, is that juvenile ibises engage in extensive prospecting movements before returning to their natal colonies to breed, having gathered information on potential breeding sites during their first two years of life (Morales et al. 2010). This would also align with the observed non-random directionality of movements, which, as mentioned above, appears to follow the distribution of wetlands. Even immature northern gannets (*Morus bassanus*), although highly faithful to their natal colony, tend to explore and assess the habitat quality of other colonies (Votier et al. 2011) — a behavior also documented in the glossy ibis (Santoro et al. 2013).

By contrast, the observed positive effect of hatching time on dispersal distance is less straightforward. While no comparable analyses exist for the sacred ibis or other Pelecaniformes, Oudman et al. (2017) found a positive relationship between chick condition and hatching date in stable Eurasian spoonbill colonies in the Netherlands. Moreover, in several bird species, better body condition is associated with greater dispersal distances (Barbraud et al. 2003; Liu and Zhang 2008). However, this aspect requires further investigation.

Our data show that sacred ibises born in a single colony exhibit different dispersal behaviors and may be nomadic, as recorded in their native range (Clark and Clark 1979) and in the closely related Australian white ibis (Carrick 1962; Smith and

Munro 2011). These results have implications for the spread of this alien bird into new territories and the establishment of new settlements, highlighting the importance of understanding the movement ecology of alien species in order to prevent or mitigate potential negative impacts. At the same time, the dispersal capacity of the sacred ibis recorded in our study area can affect the effectiveness of management measures for this invasive species. Taking into consideration these results, a regular and effective monitoring program should be implemented to enable adaptive resource management.

Conclusions

Our findings offer valuable preliminary insights into the dispersal patterns of the sacred ibis outside of its native range, highlighting its mobility and the potential for range expansion across parts of Italy and neighboring countries. This study represents the first attempt to analyse the dispersal dynamics of the species in Europe, providing novel data on its movements during a phase of population growth. Although some individuals exhibited medium- to long-distance dispersal comparable to those reported in both native and invasive contexts, these estimates are based on a limited number of cases and should be interpreted with caution. Moreover, the apparent potential for colonising new areas may be counterbalanced by the species' demonstrated philopatry, suggesting a complex interplay between site fidelity and dispersal capacity. Nonetheless, the presence of a network of suitable habitats and anthropogenic food sources, such as landfills, may facilitate the expansion of certain individuals. In light of these dynamics, conservation efforts — including habitat monitoring and potential population management— should remain adaptable and responsive to new data. Ultimately, our study reinforces the importance of ongoing, large-scale monitoring to support evidence-based management of this emerging alien species.

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Additional information

Conflict of interest

The authors have declared that no competing interests exist.

Ethical statement

No ethical statement was reported.

Use of AI

No use of AI was reported.

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Author contributions

Conceptualization: SV, AG. Data curation: SG, SV. Funding acquisition: AG, SV. Investigation: SV, AG, ST. Methodology: ST, SV, SG. Resources: SV, AG. Supervision: DGP. Visualization: SV, DGP, SG. Writing - original draft: SG, SV. Writing - review and editing: AG, ST, SV, SG.

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Data availability

All of the data that support the findings of this study are available in the main text or Supplementary Information.

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Supplementary material 1

Number of Sacred ibises (including hybrids) ringed during the study period 1 divided by year and ringing site, number of resightings and corresponding number of 2 resighted individuals

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Supplementary material 2

Results of the GLMM used to analyse the relationship between the orthodromic 1 distance covered by individuals and their age and brood class

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Supplementary material 3

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Authors: Stefano Volponi, Silvia Giuntini, Alessandra Gagliardi, Damiano G. Preatoni, Simone Tenan
Data type: pdf
Explanation note: Special thanks to all the operators who provided resighting data.
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