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ORIGINAL ARTICLE

Are Western European ospreys (*Pandion haliaetus*) shortening their migration distances? Evidence from trends of the wintering population in the Iberian Peninsula

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Abstract

Here, we provide evidence that the number of Western European ospreys wintering in the Iberian Peninsula has been increasing over nearly two decades due to a reduction of the migration distances. We compared trends in wintering and breeding populations of ospreys in the Iberian Peninsula and western Europe, respectively, and we provide a detailed description of the present distribution and the numbers of ospreys wintering in the Iberian Peninsula. Observations of the species were collected as a citizen science project in January 2017. Based on the long-term data series from the Andalusian region (2004–2016) and from the Bay of Cadiz site (2000–2016), we estimated temporal trends in the population size of the ospreys wintering in these areas. Trends in the western European breeding population were derived from counts of ospreys migrating over the Strait of Gibraltar conducted by volunteers (1999–2016). All the trends were estimated by fitting a linear regression to the logarithm of the annual counts. For quantifying the origin of ospreys wintering in the Iberian Peninsula, we collected 204 confirmed field sightings of wintering ospreys in Spain and 155 in Portugal. We showed that the number of wintering ospreys has been increasing in southern Spain over the last 16 years. The magnitude of this increase is similar to the rate of change observed in the ospreys breeding across Western Europe. Recoveries of ringed birds in the Iberian Peninsula during winter indicate a reduction in the migration distances of Central and Northern European ospreys, making these birds winter at higher latitudes more than before. According to our results, this reduction in the migration distance was fairly uniform among different breeding populations in western Europe, but it did not affect all age classes equally, with juvenile birds more prone to winter at higher latitudes compared to adult birds. Our results showed that the overall number of ospreys which are shortening their migration distance, now over 3% of the total breeding population estimated for western Europe, is on an upward trend.

Keywords Citizen science · Long-distance migrant · Mediterranean Basin · Monitoring · Raptor · Osprey · *Pandion haliaetus*

Introduction

Monitoring animal populations is required to define the conservation status of species and to inform management decisions. Among other needs, continuing monitoring is critical for identifying long-term trends in populations related to environmental changes (Martin et al. 2007). In this context, active public involvement in scientific research (i.e., citizen science) can become a key source of high-quality data for scientists and policymakers (Irwin 2018). Particularly when a sustained investment in long-term monitoring over wide areas is not possible, the use of volunteers becomes a powerful tool to maintain cost-effective monitoring programmes of species of conservation concern (e.g., Gouraguine et al. 2019). Long-term monitoring is of crucial importance to understand population changes and to develop plans for the adoption of proper conservation and management measures in long-lived species, such as raptors.

Osprey (*Pandion haliaetus*) is a long-lived, long-distance migratory raptor widely distributed across the northern hemisphere (Cramp and Simmons 1980) and Australasia. It was a common breeding species throughout Europe before the

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nineteenth century (Poole et al. 2017). During the mid-twentieth century, however, the European breeding population of the osprey suffered a considerable decrease, leading to its extirpation in several countries, and it almost completely disappeared from the Mediterranean Basin, except for the Balearic Islands, Corsica and northern African coasts of Morocco and Algeria. Human-induced factors, such as hunting (Poole et al. 2017), the use of poisons and pesticides (Lensink 1997), and the adverse consequences of habitat destruction and tourism (Schmidt 1998) caused the extirpation of the species in many parts of its range (Schmidt-Rothmund et al. 2014). The banning of organochlorine pesticides (i.e., DDT) in the first half of the twentieth century (Lensink 1997), together with the legal protection of the osprey in Europe between the 1920s and 1950s, as well as other conservation measures, such as those implemented to mitigate electrocution fatalities on power lines (Janss and Ferrer 1999), have gradually led to an ongoing recovery of the species' range and increase in population size (Poole 1989; Schmidt-Rothmund et al. 2014).

Currently, osprey populations are large and show stable or even positive trends in central and northern Europe (BirdLife International 2017). In contrast, the species is still absent or only present in small isolated populations in much of southern Europe. The Iberian Peninsula is, however, an important passage and stopover area for migratory ospreys from western Europe (Bernis 1980; Sanz 1997). These birds mainly winter in West Africa, in contrast to easternmost European individuals, which winter in eastern sub-Saharan Africa (Zwarts et al. 2009), occasionally as far south as South Africa (Österlöf 1977; Saurola 2002).

Migratory ospreys spend over half of the year on migration and at wintering sites in Africa (Hake et al. 2001; Alerstam et al. 2006; Dennis 2008; Bai and Schmidt 2012) and more recently in southern Europe (Gil and Valenzuela 1997; Sanz 1997; Casado and Ferrer 2005; Dennis 2008; Sayago 2011). Events during these stages through the life history annual cycle affect individual survival and therefore may modulate the breeding population trend (Klaassen et al. 2014; Monti et al. 2018). Since adult ospreys usually return to the same wintering location year after year (Poole 1989), the identification of sites used by ospreys during winter should direct us to reduce threats that represent a potential mortality risk for ospreys in those areas.

Many migratory birds have shortened their migration distances (e.g., Visser et al. 2009) as climate change and other human activities have increased food availability at higher latitudes in their wintering range. As a consequence, the wintering areas of many bird species are moving north (La Sorte and Thompson 2007). This also appears to be the case of ospreys as more and more ospreys are spending the winter in the Iberian Peninsula (Gil and Valenzuela 1997; Sanz 1997; Dennis 2008).

However, individuals of long-lived species, such as ospreys, could be affected differently, since behavioural responses of migrants to climate and other human-induced changes may vary among different fractions of the overall population, such as age classes (e.g., Martín et al. 2014; Martín et al. 2016a; Scholer et al. 2016). In this respect, identifying changes in the migration patterns of different age classes within the population is crucial for the proper understanding of how birds, and particularly ospreys, may or may not persist under the current scenario of climate change (Martín et al. 2016a).

The osprey is a clear example of a flagship species in the framework of conservation management projects as well as in projects for environmental protection (Muriel et al. 2010). Ospreys frequently select conspicuous nest and perch sites, it is easily identified and observed in the field, and it tolerates well the presence of humans (Bierregaard et al. 2014), since the potential disturbances of birds arising from human presence seem to be low in human-modified environments (e.g., Bird et al. 1996). For all these reasons, the osprey is a species well suited to monitoring by citizen science projects.

In this study, we determined the present distribution and the numbers of the ospreys wintering in the Iberian Peninsula by means of the public participation of different organizations devoted to bird conservation from Portugal and Spain. Long-term data counts available from southern Spain allowed us to quantify the trend in the wintering osprey population over the last 16 years. Additionally, trends in migration counts are a broadly accepted, cost-effective indicator of the breeding population trend of a migratory species (Martín et al. 2016b). Long-term data counts of migrating ospreys over the Strait of Gibraltar from 1999 to 2016 conducted by volunteers were used to determine the trends in the western European breeding population of the osprey and to compare these trends with the observed changes in the number of ospreys wintering in Iberia.

Our main aim was to provide evidence that the number of wintering ospreys has been increasing in the Iberian Peninsula over the years due to a shortening of migration distances and to assess if these changes have been age- and population-specific. Specifically, we compared trends in wintering and breeding populations of ospreys in Iberia and western Europe, respectively, and we identified the age and origin of the ospreys wintering in the Iberian Peninsula from recoveries of the ringed ospreys. In addition, we provide a detailed description of the present distribution and the numbers of ospreys wintering in the Iberian Peninsula, which can be helpful for the conservation and management of the species in Europe.

Methods

Study species

The osprey is a large, specialized fish-eating raptor inhabiting freshwater lakes, reservoirs and rivers, as well as sea coasts, estuaries and brackish water ecosystems. Ospreys breeding in

the Western Palearctic region (*P. h. haliaetus*; Linnaeus, 1758) occur from the North African coast to the Arctic Circle (Poole 1989) but, due to more severe human disturbance south of the northern populations, nowadays, most of the breeding population is in the northern half of Europe. The Western Palearctic osprey was extirpated in Portugal, mainland Spain and Turkey in the 1980s and 1990s (Schmidt-Rothmund et al. 2014), although a wild pair was recorded breeding in Portugal in 2015 (own unpublished data). In the Mediterranean region, only a few small breeding populations (about 100 breeding pairs) remain in Corsica, the Balearic and Chafarinas Islands, as well as on the North African coast (i.e., Algeria and Morocco; Monti 2015). This subspecies is also present in the Canary and Cape Verde Islands and the Red Sea (Poole et al. 2017). Because osprey populations are very large, and hence do not approach the thresholds for "Vulnerable" based on population size, the species is globally classified as "Least Concern" (BirdLife International 2017). In Spain and Portugal, however, ospreys are considered as "Critically Endangered" (Triay and Siverio 2008; Cabral et al. 2005; Equipa Atlas 2008).

After a reintroduction project started in 2003, almost 20 pairs now breed in southern Spain (Muriel et al. 2010). A few more pairs are found in Tuscany, Italy, as a result of the translocation of juveniles from Corsica (Monti et al. 2014). A reintroduction project is also ongoing in Portugal at the Alqueva reservoir (Alentejo region). The project was started in 2011, and successful breeding took place in the area for the first time in 2016, after the translocation of 56 juveniles from Sweden and Finland (Palma et al. 2019). Similarly, up to 70 juveniles were translocated from Scotland to the Urdaibai Biosphere Reserve (northern Spain) between 2013 and 2017 (Galarza 2019). In our study, new established breeding individuals from the different reintroduction projects have been considered to be an integral part of the ospreys breeding in Western Europe.

Although ospreys breeding in Europe mainly winter in sub-Saharan Africa (Poole et al. 2017), ospreys breeding in the Mediterranean islands and North Africa are frequently resident or short-distance migrants (Monti 2015; Monti et al. 2018) mostly traveling to wintering grounds in Spain and Portugal (Monti et al. 2018). Ospreys wintering in the Iberian Peninsula are the subject of the present study.

Data collection

Wintering distribution and population size in the Iberian Peninsula

The censuses for data collection on the distribution and the size of the osprey wintering population in Iberia were initially promoted by the "Birds of Portugal" project ("Aves de Portugal"; http://www.avesdeportugal.info/). These started in January 2015 and provided a first estimate of the total number of wintering ospreys in Portugal. In 2016, the public participation network "Friends of the Osprey" ("Amigos del Águila Pescadora"), led by the Migres Foundation ("Fundación Migres"; http://www.fundacionmigres.org/amigos-del-aguila-pescadora/) in Spain, joined the Portuguese initiative, when wintering ospreys in Portugal and the Andalusian region (southern Spain) were censused. Within the framework of these two projects, 235 and 153 volunteers in Spain and Portugal, respectively (Fundación Migres et al. 2017), representing more than 30 bird conservation organizations, were involved in an osprey wintering census at the supranational scale on the Iberian Peninsula in the 2016–2017 winter. Volunteers were jointly coordinated by the Birds of Portugal Project in Portugal and the Migres Foundation in Spain.

Observations of wintering ospreys were carried out in January 2017 over a variable number of days, depending on the number of observers and the extent of the areas to be covered in different provinces. Censuses covered the central wintering period for the species (Casado 1999), which lasts from mid-November until mid-March (Casado and Ferrer 2005). Observations were conducted from dawn to 13:00 h GMT by professional ornithologists, bird watchers and bird photographers initially contacted primarily through electronic forums. Expert ornithologists coordinated the census at the provincial level. Surveys covered those areas with osprey presence previously reported as well as areas with suitable habitat (i.e., water bodies with fish) that could be potentially occupied by ospreys in Spain and Portugal (Casado and Ferrer 2005). Each coordinator was responsible to determine the areas (i.e., water bodies) to be surveyed, ensuring that all the water bodies where ospreys might potentially occur within a province/district were surveyed. Although observers were sometimes amateur ornithologists, all the survey teams were led by an expert ornithologist having a good knowledge on the study species.

Each water body was surveyed at least by 1–2 observers. The only areas which were not surveyed were Guadalajara and Albacete provinces, in Spain, due to the lack of volunteers. Ospreys usually use conspicuous perches (Ferguson-Lees 1963), such as dead trees and artificial poles, facilitating the sighting of the birds. Birds were recorded by direct observation from vantage points (Bibby et al. 1992) using binoculars (10×) and telescopes (20–60×). Both presence and absence data were recorded. To avoid double counting of birds, local teams were coordinated and observers were in contact. For each sighting, observers were required to provide location (e.g., locality, department or province), date, geographic coordinates (as precisely as possible) and the type of aquatic or water system where the birds were observed (e.g., reservoirs, rivers, lagoons, or marshes). Because osprey sex and age are difficult to differentiate under field conditions (Poole 1989; Blanco and Rodriguez-Estrella 1999) and even more difficult for observers without previous experience, birds were not

classified by sex or age class. Counts of birds were conservative, reporting a minimum of observed birds to avoid duplications. All data collected at the provincial level were centralised and reviewed by the research team applying a conservative approach to set a minimum reliable number for observed ospreys by preventing duplication of bird counts (i.e., birds observed in nearby sites on consecutive dates) among provincial/district censuses.

Wintering population trend in Andalusia (southern Spain)

Long-term data series of wintering ospreys for the whole of the Iberian Peninsula are not available (Moreno-Opo 2012). However, regional surveys of the wintering osprey population were annually conducted in the Andalusian region (southern Spain; Fig. 1) by professional ornithologists following a similar methodology as described previously. Surveys in the Andalusian region were carried out between 2004 and 2017 (CMAOT 2016; Fundación Migres et al. 2017). Additionally, one of the largest osprey wintering population within the Andalusian region (Bay of Cadiz, where around 28% of the ospreys wintering in Andalusia are found; Jiménez and de las Heras 2015; CMAOT 2016) has been monitored since 2000; so an even longer temporal data series is specifically available for this site. Based on the overall long-term data series from the Andalusian region and from the "Bay of Cadiz" site, we estimated temporal trends in the population size of the ospreys wintering in these areas accordingly.

Migratory population trends

Annual counts of ospreys migrating over the Strait of Gibraltar have been recorded using standardized protocols since 1999 (De la Cruz et al. 2011). From 1999 to 2016, counts were conducted during the postnuptial migration between mid-July and mid-October. Numbers of migrants were recorded on a daily basis at two different observatories (Algarrobo 36°5′25″N, 5°29′02″W and Cazalla 36°1′58″N, 5°34′36″W). All observers were equipped with binoculars.

Main origins and age of wintering ospreys in Iberia

For quantifying the origin of ospreys wintering in the Iberian Peninsula, we obtained information from 326 recoveries in Spain for 1930–2014 provided by the SEO (Spanish Ornithological Society) database and 11 recoveries in Portugal up to 1999 (Catry et al. 2010) from birds ringed as nestlings (i.e., known age at the time of the recovery). Using these databases, we could identify the principal origins and the age of wintering ospreys by selecting records of ospreys

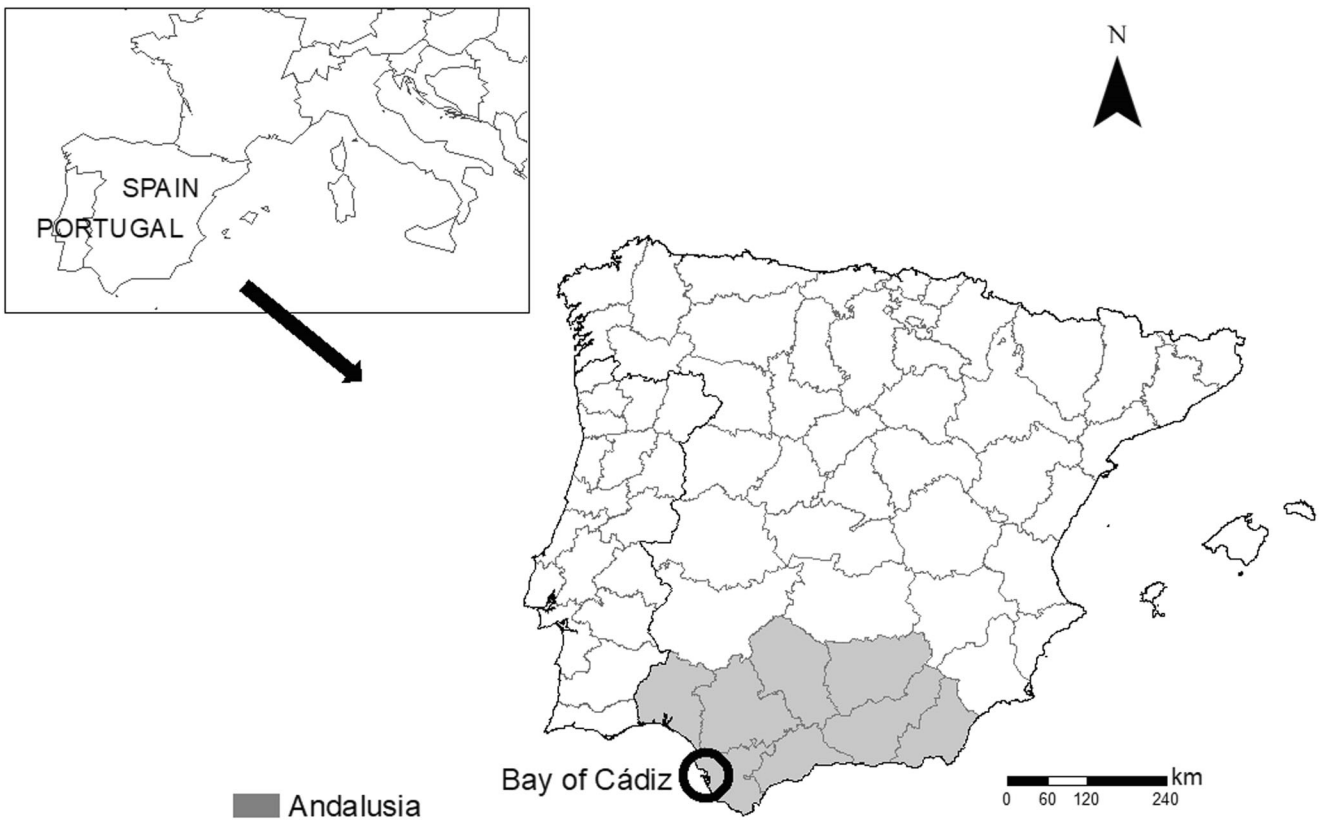

Fig. 1 Location of the study area. Iberian Peninsula (Portugal and Spain), Andalusian region and Bay of Cádiz

ringed in their breeding grounds and subsequently recovered in Spain and Portugal during winter. In this study, we refer to migration distance as the linear distance between the breeding and the wintering sites according to the recoveries of the ringed birds.

Records were considered to reflect wintering if the birds were recovered between 15th November and 31st January, since, after this month, migratory ospreys returning from their wintering grounds can also be observed in Iberia.

Data analysis

Population trends

Trends in wintering ospreys in Andalusia and the Bay of Cadiz, as well as trends in the number of birds migrating over the Strait of Gibraltar, were quantified. Because a trend may be described by the geometric mean rate of population change over time (Link and Sauer 1997), if the trend is linear, the geometric mean rate of change can be estimated by fitting a linear regression to the logarithm of the annual counts (Farmer and Hussell 2008). We estimated the magnitude and significance of the trends in wintering and migratory ospreys by fitting log-linear models (Martín et al. 2016b) using generalized least squares (GLS) (package nlme in R; Pinheiro et al. 2017). GLS generalizes ordinary least squares to the case where the residuals have a normal distribution with an arbitrary covariance matrix. In these extended linear models, the errors are allowed to be correlated in such a way that we can directly model temporal autocorrelation. Temporal autocorrelation (ACF) and partial temporal autocorrelation (PACF) functions for all the models were inspected to identify the form of the temporal autocorrelation structure. In case any significant autocorrelation was detected, this autocorrelation structure was specified in the GLS models; thus there was no remaining autocorrelation in the residuals of the final models (Box et al. 2008). The annual rate of change over the study period was then measured from the coefficient of the *year* variable in the regression models and multiplied by 100. This result represents the annual percentage change in the population and linear change in the log scale (Dunn and Hussell 2009). We used Akaike's information criteria, AIC (Akaike 1973), to identify the most robust and parsimonious (avoiding over-fitting) among the different ARIMA models (i.e., the model with the lowest AIC) that we tested. If several models had low and similar AIC values (delta AIC < 2), then we selected the model without temporal autocorrelation that showed the lowest AIC (Burnham and Anderson 2002).

Main origins and age of wintering ospreys in Iberia

We analyzed differences in frequency of the ringed ospreys recovered in Spain (SEO database) and Portugal (Catry et al. 2010) in relation to the "grand totals" record of ringed ospreys (EURING, accessed on 4th January 2018; https://euring.org/data-and-codes/ringing-totals) per breeding country by means of χ^2 *test*. To allow for correct approximation of χ^2, we grouped all the breeding countries with null recoveries in a new group named "others". Additionally, we used survival rates reported by Wahl and Barbraud (2013) to estimate the age structure of a theoretical European breeding population of osprey. Then, we compared this age structure with the proportion of birds recovered during winter in Spain for each age class by means of χ^2 *test*. We considered three different age classes (< 1 yr, 1–2 yr, > 2 yr) that were meaningful according to the life history of the species, i.e. juveniles, immature birds and adult breeding birds (Wahl and Barbraud 2013). Although these rates refer to a relatively new established population, which may not represent all the other osprey's populations across Europe due to density-dependence effects on survival, this is the only available detailed analysis per age class on this species in Europe.

All analyses were performed using R 3.4.1 (R Core Development Team).

Results

Census results

During the census in January 2017, we detected the presence of wintering ospreys at 28 Portuguese and 71 Spanish sites (Fig. 2 and Table 1; see also Table S1 and Fig. S1 in the Supplementary Material). We collected a minimum of 204 confirmed field sightings of wintering ospreys in Spain and 155 in Portugal. These records were mostly observed (more than 75% of the individuals) in the provinces of Cádiz, Huelva and Seville (in Spain) and in the districts of Santarém, Setúbal, Faro, Aveiro and Lisbon (in Portugal). The Andalusian region contained 77% of the ospreys wintering in Spain and 44% of all the Iberian wintering birds. Main waterbodies selected by ospreys for wintering in Spain were the Doñana Natural Site (which includes a set of four interdependent water bodies i.e., Doñana, Isla Mayor, Isla Menor and Isla Minima; 45 birds; see Table S1 in the Supplementary Information), the Bay of Cadiz (36 birds) and Marismas del Odiel (14 birds). Regarding wintering ospreys in Portugal, the Tejo River (56 birds) and the estuaries of Aveiro (29 birds), Formosa (23 birds), Sado (20 birds) and Tejo (14 birds) were the sites with the largest number of birds, representing more than 75% of the total birds recorded in Portugal. The wintering population of ospreys in the Iberian Peninsula is distributed both in coastal marshes and lagoons as well as in natural and artificial inland water bodies. Up to 75% of the birds were observed at natural water bodies whereas 25% of the ospreys were found at reservoirs (Table S2, see the Supplementary Material).

Table 1 Census results of wintering ospreys in the Iberian Peninsula in January 2017. Counts recorded in the Bay of Cadiz ("Bahia de Cádiz") are included within the counts in the Andalusian region (see also Table S3 in the Supplementary Material)

Country	Region	Number of birds
Portugal	Aveiro	23
	Beja	3
	Braga	3
	Bragança	0
	Castelo Branco	0
	Coimbra	2
	Évora	5
	Faro	24
	Guarda	0
	Leiria	1
	Lisboa	18
	Portalegre	5
	Porto	1
	Santarém	39
	Setúbal	29
	Viana do Castelo	2
	Vila Real	0
	Viseu	0
Spain	Andalucía	160
	Asturias	4
	Aragón	0
	Cantabria	3
	Castilla-La Mancha	?
	Castilla-León	0
	Cataluña	7
	Extremadura	10
	Galicia	14
	La Rioja	0
	Madrid	0
	Murcia	0
	Navarra	0
	País Vasco	0
	Valencia	6
	Portugal	155
	Spain	204
	TOTAL	359

Trends in wintering and migratory populations

The inspection of the temporal autocorrelation functions (ACF and PACF) for the regression models showed no significant autocorrelation at any time lag for the time series of wintering ospreys in Andalusia. However, we detected a temporal dependency in the case of ospreys wintering in the Bay of Cadiz, as well as for ospreys migrating over the Strait of Gibraltar. The latter time series also showed evidence of non-stationarity. An AR(1) autocorrelation structure was enough to take into account the temporal autocorrelation in the Bay of Cadiz wintering data. An autocorrelation structure of first order AR(2) and three moving average terms MA(3) properly modeled the autocorrelation structure and eliminated the non-stationarity of the migratory population dataset (Tables 2 and 3). All the studied osprey populations showed significantly increasing trends (Fig. 3). There is considerable agreement in the trends for the studied wintering populations (annual rate of change for Andalusian osprey wintering population, 4.3%; for Bay of Cadiz population, 5.6%) and the trend of those birds migrating over the Strait of Gibraltar (annual rate of change, 5.37%).

Ringed birds

Ringing recoveries on wintering ospreys came from 61 individuals in Spain and 11 in Portugal (Table 4). All the birds except for a 6-yr-old female were ringed as chicks at their nests. In accordance with the census results, most of the ringed birds recorded in Spain during the winter were recovered in Cadiz (28%) and Huelva (35%) provinces. The main origins of the birds were Germany (41% of the recoveries), Sweden (24%) and Great Britain (18%). According to the χ^2 test results, the frequency of birds recovered from Finland and Sweden, as well as from other countries (Belarus, Denmark, Italy, Netherlands, Poland and Switzerland) was lower than expected, whereas recoveries from France, Germany, Norway, Spain and Great Britain were more frequent ($\chi^2 = 215.33$, df = 7, $P < 0.0001$; Fig. 4). Since available data on "grand totals" from birds ringed in Norway and France were not updated (see Table S3 in the Supplementary Material), results for these countries must be interpreted with caution. Based on the low number of recoveries of ringed birds of known sex ($N = 17$), we did not detect differences in the frequency of recovered males and females per country. Regarding the age of the birds recovered in Spain, 49% of the ospreys were younger than 1 year, 26% were immature birds (1–2 year) whereas 25% were > 2 years. The theoretical age structure estimated was consistent with data provided by other authors (Poole 1982; see Table S4 in the Supplementary Material). Comparisons between age structure of the birds recovered during winter and age structure of the breeding population showed that immature (1–2 yr) birds were recovered nearly as expected according to the theoretical breeding population age structure. In contrast, adult birds (> 2 yr) were less frequently observed whereas juveniles were recovered in a higher proportion than expected ($\chi^2 = 19.70$, df = 2, $P < 0.0001$; Fig. 5).

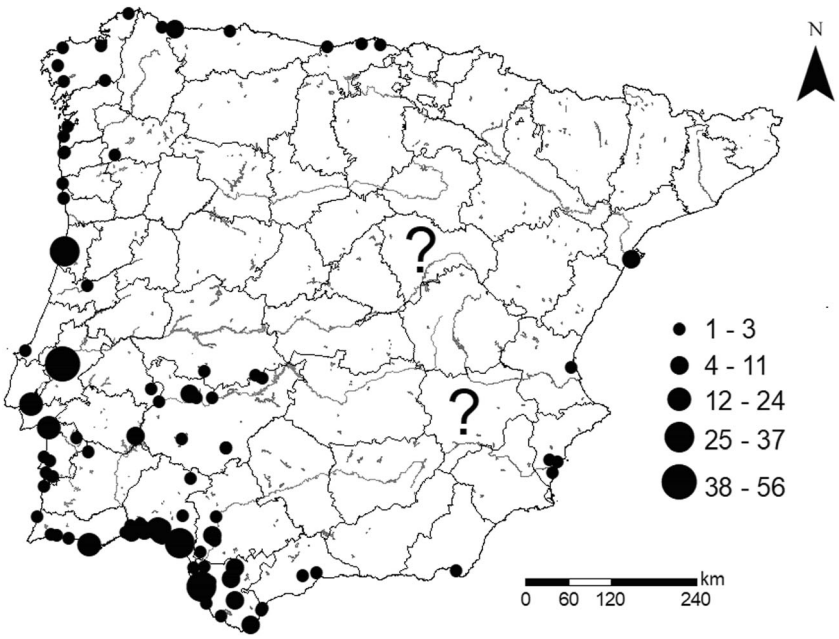

Fig. 2 Wintering osprey population size and distribution in the Iberian Peninsula (winter 2016–2017). All districts (Portugal) and provinces (Spain) were surveyed except for "Guadalajara" and "Albacete" in Spain. Districts/provinces and location of water bodies are shown in the map

Discussion

In this study, we show that the number of wintering ospreys has been increasing in southern Spain over the last 16 years. The magnitude of this increase is similar to the rate of change of Western European ospreys, as derived from annual counts of ospreys migrating over the Strait of Gibraltar. Recoveries of ringed birds in the Iberian Peninsula during winter indicate a reduction in the migration distances of Central and Northern European ospreys, making these birds winter at higher latitudes more than before. According to our results, this reduction in the migration distance was fairly uniform among different breeding populations in western Europe, but it did not affect all age classes equally, and we found that juvenile birds were more prone to winter at higher latitudes compared to adult birds.

Distribution numbers and trends

Wintering ospreys in the Iberian Peninsula, as with many wintering wading bird species from northern Europe (Domínguez 1990) occur mainly at locations on the Atlantic coast. Although the Portuguese osprey wintering population is mostly distributed in coastal water bodies, an important number of the Spanish wintering birds, specifically those ospreys

Table 2 Model selection among different ARIMA structures for models with temporal autocorrelation in the residuals. (a) Migratory population over the Strait of Gibraltar; (b) wintering population in the Bay of Cadiz. MA, moving average model; AR, autoregressive model. No significant autocorrelation was found for the time series of wintering ospreys in Andalusia. Best fit model without temporal autocorrelation pattern is underlined

	Df	Log.lik	AIC	Delta AIC
(a)				
Basic model	3	− 11.11	28.21	0.00
MA1AR1	6	− 8.18	28.36	0.15
MA1AR2	6	− 8.18	28.36	0.15
AR1	4	− 10.69	29.38	1.17
MA3AR2	8	− 6.78	29.56	1.35
AR2	5	− 10.31	30.63	2.42
MA2AR2	7	− 9.77	33.54	5.32
(b)				
AR1	4	− 8.73	25.47	0.00
Basic model	2	− 10.93	27.86	2.40

Table 3 Log-generalized least-square models to the time series of the (a) osprey wintering population in Andalusia; (b) in the Bay of Cadiz; and (c) of the osprey migratory population over the Strait of Gibraltar. Best fit models for ospreys through the Strait of Gibraltar and for ospreys wintering in the Bay of Cadiz included temporal correlation and moving average structures (see Table 2)

	Estimate	Std. error	*t* value	*P* value
(a)				
(Intercept)	− 82.053	21.188	− 3.873	0.002
Year	0.043	0.011	4.085	0.002
(b)				
(Intercept)	− 110.313	41.189	− 2.678	0.017
Year	0.056	0.021	2.752	0.014
(c)				
(Intercept)	− 103.525	46.087	− 2.246	0.039
Year	0.054	0.023	2.337	0.033

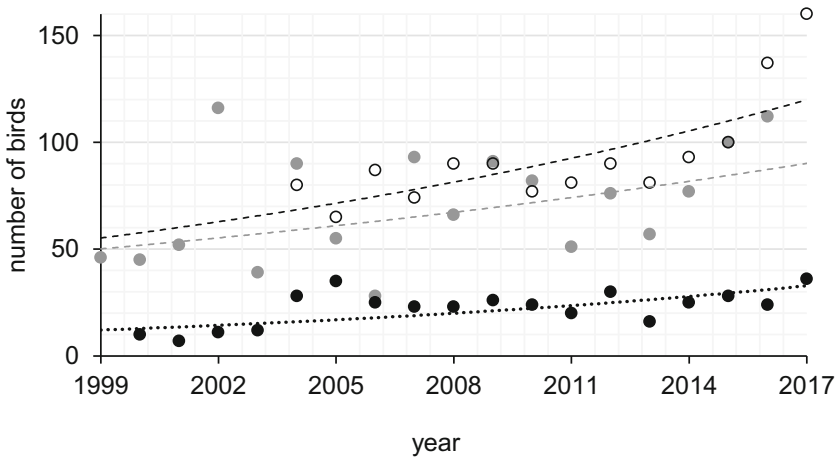

Fig. 3 Trends in the wintering population of osprey in Andalusia (white dots); in the wintering population of osprey in the Bay of Cadiz (black dots); and in the osprey migratory population (grey dots). Trends are measured as the back-transformed slope of the log-generalized linear regression models to the time series of annual osprey counts

wintering in Cadiz province, can be found at artificial reservoirs. Reservoirs are frequently occupied by ospreys in most of their breeding range, but they are a relatively new ecosystem for ospreys in Iberia (Casado and Ferrer 2005). Although the destruction of the natural habitats available for the ospreys in the Iberian Peninsula during the first half of the twentieth century could have limited the occurrence of ospreys in Portugal and Spain, artificial reservoirs offer new available habitats for this species in Iberia, both for wintering and for breeding individuals (Casado and Ferrer 2005).

Reservoirs contain an important stock of native and exotic fish (Mancini et al. 2009); thus, they provide new feeding opportunities for ospreys (Fuentes et al. 1998). Most of the dams built in Spain (96%) were finished before 1999 and only 4% were built since 2000. Although habitat availability provided by reservoirs existed prior to the observed increases in the osprey wintering population in Iberia, the use of artificial impoundments may have contributed to the observed changes in the migratory behaviour of the European ospreys.

Our counts largely exceed the most recent estimations of ospreys wintering in the Iberian Peninsula (Moreno-Opo 2012). According to our results from the Andalusian region, which encompassed more than the 40% of the Iberian wintering osprey population, during the last 16 years, ospreys regularly observed during winter have increased by around 4% if all the Andalusian region is considered, with an increase of about 6% in Bay of Cadiz, one of the largest wintering populations in Iberia, led only by the Doñana Natural Site. The national censuses carried out in Portugal by *Aves de Portugal* during the last three years also support a positive trend in the numbers of ospreys wintering there (unpublished data), although this increase is possibly related to a better monitoring coverage of the country.

Increases in the European breeding population size of ospreys observed in our results from migratory birds are supported by censuses conducted in different areas across Europe. The decline of ospreys breeding in Europe in the 19th and 20th centuries, caused mainly by habitat loss and direct persecution, has been followed by population increases, both in terms of population size and of spatial distribution (Dennis 2016). Compared to numbers from the 1980s, osprey breeding pairs in Europe and the Middle East have almost doubled in the early twenty-first century, although the largest European populations (in Sweden, Finland and Russia) appear to be stable, and negative trends were observed in Poland, as well as in southeastern Europe and northern Africa (Schmidt-Rothmund et al. 2014). According to our results from migratory counts at the Strait of Gibraltar, the rate of change in the

Table 4 Summary of the ringing recoveries on wintering ospreys recovered in Spain and Portugal

Breeding country	Number of recoveries in Spain	Number of recoveries in Portugal	Total number of recoveries
Finland	4	0	4
France	2	0	2
Germany	27	2	29
Norway	2	1	3
Spain	2	0	2
Sweden	12	5	17
Great Britain	10	3	13

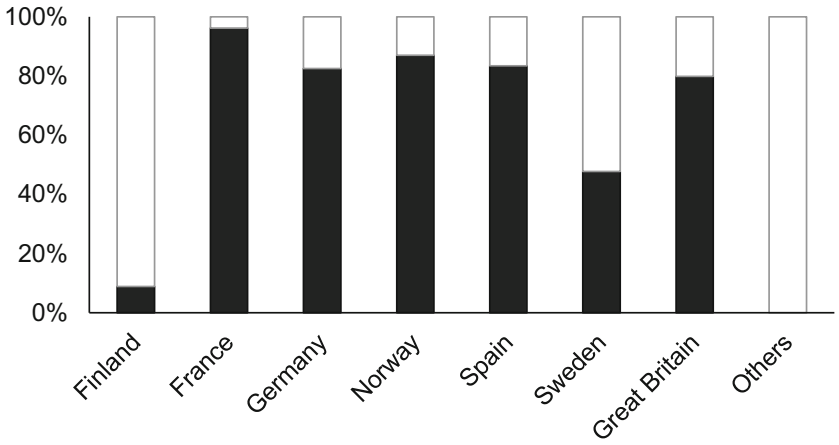

Fig. 4 Ratio between observed (white bars) and expected (black bars) frequencies of recovered ospreys per age class ($\chi^2 = 19.70$, df = 7, $P < 0.0001$)

number of wintering birds in southern Spain and the trends observed in the breeding population of western Europe are of similar magnitude (annual rate of 5%, in 1999–2016) supporting a relationship between the recovery of the European breeding population and the increases in the number of wintering birds. However, the rise in numbers of ospreys breeding in western Europe has probably been underestimated using migratory counts, because a growing number of ospreys are shortening their migratory routes and no longer crossing the Strait of Gibraltar (Link and Sauer 1997). In contrast, released birds in the framework of the different reintroduction projects across Iberia (Muriel et al. 2010; Palma et al. 2019; Galarza 2019) have likely contributed to increase the counts of ospreys migrating over the Strait of Gibraltar.

Although long-term data series of wintering ospreys are not available for the whole of the Iberian Peninsula, it is widely recognized that more and more ospreys spend the winter in the Iberian Peninsula instead traveling further south to Africa (Triay and Siverio 2008; Gil and Valenzuela 1997; Sanz 1997; Dennis 2008). Occasional winter observations, mainly of Swedish and Finnish ospreys, were detected in central and southern Europe before 1973 (Österlöf 1977) although real wintering did not take place (Glutz von Blotzheim et al. 1971). Our results showed that a growing number of individuals, currently about 3% of the total breeding population estimated for western Europe (BirdLife International 2015), are behaving as short-distance migrants, mostly traveling to wintering grounds in Spain and Portugal. Similarly, there is also a continent-wide increase in osprey populations and a northerly shift in the areas where ospreys overwinter in North America (Bierregaard et al. 2016), supporting that the shortening of the migration distances shown in our study is a global-scale phenomenon.

As with other long-distance migrant species breeding in temperate regions and specifically raptors, ospreys are shortening their migrations likely in relation to climate and other land use changes (Martín et al. 2014, 2016b). Shorter migration distance is expected to enhance the survival rates of individuals (Klaassen et al. 2014), therefore contributing to the increase in the number of birds exhibiting this behaviour and, in the long term, increasing the numbers of the ospreys wintering in Iberia.

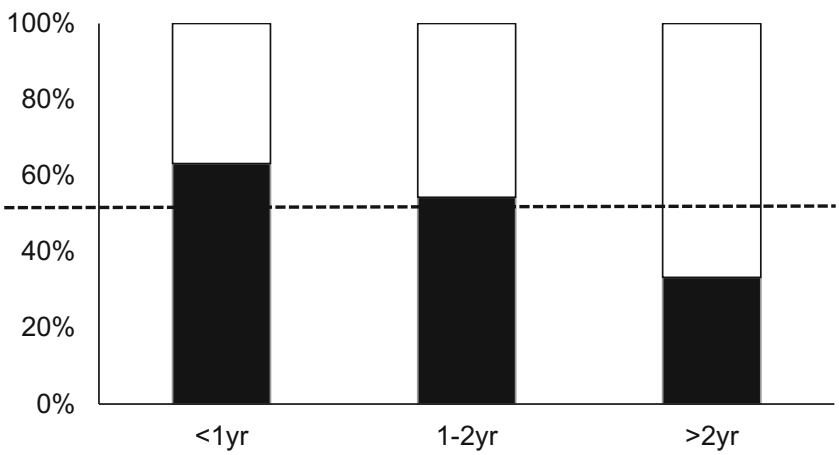

Fig. 5 Ratio between observed (black bars) and expected (white bars) frequencies of recovered ospreys per ringing country ($\chi^2 = 215.33$, df = 2, $P < 0.0001$). < 1 yr, juveniles; 1–2 yr, immature; > 2 yr, adult birds

Age- and population-specific shortening of the migration distance

Differences in the response of migratory birds among populations and among fractions within the same population (Cristol et al. 1999) imply differential costs of climate change (Wood and Kellerman 2015), leading to differential selection among populations and groups within the same population.

Records of ospreys ringed at their breeding grounds and subsequently recovered in Spain and Portugal during winter showed that wintering birds in Iberia come from almost any point of the species breeding range across western Europe (BirdLife International 2017). Our results showed that most of the birds wintering in Spain and Portugal breed in Germany, Great Britain and possibly in France. Ospreys ringed at breeding sites from Finland and Sweden, however, were found less frequently than expected in Iberia during winter. Ringed ospreys breeding in Sweden and Finland are frequently recovered in Spain during autumn migration (SEO/BirdLife 2012) because most Swedish birds and some Finnish individuals migrate along the western migratory flyway (Österlöf 1977). However, breeding birds in these countries may also migrate through the central and eastern migratory flyways (Österlöf 1977), reaching Africa over the Strait of Messina in Italy and over the Bosphorus, respectively (Porter and Beaman 1985). Moreover, lower proportion of recoveries detected from "other countries" (i.e., Belarus, Italy, Netherlands and Switzerland) is likely related to the extirpation of the osprey from these countries during the mid-twentieth century. Therefore, in contrast to results from other European raptor species showing a reduction in migratory distances related to the latitude where the birds breed (Martín et al. 2014), the observed reduction in the osprey migration distance seems to be fairly uniform among different breeding populations across western Europe.

European ospreys usually remain in their wintering areas in Africa during their first and second years before returning to their breeding areas once they reach two years old (Cramp and Simmons 1980; Poole 1989; Monti et al. 2018). However, according to ringed birds recovered in Spain, ospreys wintering in Iberia are mostly juvenile and immature birds, whereas adult birds were observed in lower proportion than expected, suggesting adult ospreys are responding differently to the ecological conditions at their wintering grounds compared to juvenile birds. Previous studies have shown the ability of juveniles of long-lived and long-distance migrant species to alter their migratory patterns according to environmental conditions, allowing these inexperienced birds to respond to climate change (Martín et al. 2016a, b). Adult and juvenile ospreys seem to follow a similar migration pattern during autumn although juvenile birds appear to migrate later (Österlöf 1977). It is known that juvenile birds tend to migrate further south than adults in many raptor species. However, this does not seem to be the case among ospreys, and a comparison of the proportion of juvenile and adult birds in western Africa during winter did not show differences between age classes (Österlöf 1977). In contrast to adult birds of other raptor species, which are shortening their migration distance more than juveniles in response to climate change (Martín et al. 2014), according to our results, juvenile ospreys show a stronger tendency to winter at higher latitudes than adult birds. One possible explanation for this could be related to the experienced gained by older individuals. On the basis of their previous experience, ospreys usually return to the same wintering location year after year (Poole 1989). With no previous experience, juvenile ospreys could try out a variety of stop-over sites before deciding their preferred wintering location and, therefore, be more likely to explore new wintering locations at higher latitudes.

Whatever the reason, most juvenile ospreys remain within their wintering grounds in Africa throughout the year (Cramp and Simmons 1980; Poole 1989; Monti et al. 2018). If the juvenile birds wintering in Iberia also remain once winter is over, they could play an important role in the future recovery of the species in continental Spain and Portugal by means of the reinforcement of the recently reintroduced breeding population through a conspecific attraction mechanism (Poole 1989; Thibault and Bretagnolle 2001).

Other short-distance and non-migratory osprey populations

Ospreys breeding in the Mediterranean basin number less than 100 breeding pairs distributed within Corsica, the Balearics, Morocco and Algeria, and about 20 additional pairs belonging to the recent reintroduction projects in the Iberian Peninsula (Dennis 2016). Ospreys breeding in the Mediterranean islands and North Africa are frequently resident or short-distance migrants which mainly winter in the Mediterranean basin coasts (Monti et al. 2018) thanks to the mild winter conditions and fish availability in these areas (Poole 1989). In contrast, breeding birds belonging to reintroduced populations in Spain and Portugal showed a long-distance migratory pattern similar to birds from the donor populations (in Finland, Germany, Scotland and Sweden). Although some other individuals have been found to be year-round residents after the reintroduction (Muriel et al. 2010), from the 129 young ospreys reintroduced in southern Spain, ringed and released between 2003 and 2009, only six non-migratory young birds remained in the reintroduction areas, whereas the reintroduced breeders left the area after the breeding (Muriel et al. 2010). It is probable that year-round resident birds of the recently reintroduced breeding population in continental Spain and Portugal are also contributing to increase the wintering population of the ospreys in Iberia by attracting new wintering birds that have originated in northern and central Europe, as well as short-distance migrants from the Mediterranean islands through a conspecific attraction mechanism (Poole 1989; Thibault and Bretagnolle 2001). However, the information provided by the recoveries of ringed ospreys

indicates that these Mediterranean populations play a minor, if any role, in the observed trends in the number of wintering ospreys in the Iberian Peninsula, because most of the wintering birds originated in northern and central Europe and none of the recoveries from birds ringed in the Mediterranean basin (i.e., two adult ospreys ringed in Spain) belonged to birds that were born or released in the framework of any reintroduction project in Spain and Portugal. In addition, the main wintering areas in the Iberian Peninsula identified in our study (i.e., water bodies located in Cadiz and Huelva provinces) were also historical sites with high densities of ospreys during winter before the reintroduction project started in 2003, showing numbers about ten times higher than average densities in other Spanish regions during winter before 1990 (Ferrer and Casado 2014). Moreover, the wintering distribution of ospreys in the Iberian Peninsula covers a wider spatial range compared to the reintroduced breeding population. Specifically regarding southern Spain, birds of the recently established breeding population only occurred in six different water bodies (Muriel et al. 2010), whereas wintering ospreys in our study were observed in a total of 22 (data for year 2017).

Implications for osprey conservation

Ospreys usually return to the same wintering location year after year (Poole 1989). Therefore, the identification of sites used by ospreys during winter is of major importance to preserve those areas from threats that represent a potential mortality risk, such as habitat loss, pollution and direct persecution (Newton 1979). Because osprey habitat requirements during winter appear to be similar to those needed during the breeding period, the wintering distribution here reported could also be a useful tool when identifying new areas for future reintroduction projects (Casado and Ferrer 2005) if required. Together with protection, habitat management of these areas can also benefit the growing number of wintering ospreys as well as the increase and expansion of the breeding population in the Iberian Peninsula.

The osprey is a conspicuous species, and its suitable habitat is easily identifiable. In this context, public participation becomes an excellent tool to maintain a non-expensive monitoring of the species covering the level of a large area, such as the Iberian Peninsula. This long-term monitoring will allow us to track the future changes in the population size and the migratory behaviour of this species across western Europe.

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