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Identifying Important Atlantic Areas for the conservation of Balearic shearwaters: Spatial overlap with conservation areas

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ABSTRACT

Marine protected areas (MPAs) are considered one of the main tools in both fisheries and conservation management to protect threatened species and their habitats around the globe. However, MPAs are underrepresented in marine environments compared to terrestrial environments. Within this context, we studied the Atlantic non-breeding distribution of the southern population of Balearic shearwaters (*Puffinus mauretanicus*) breeding in Eivissa during the 2011-2012 period based on global location sensing (GLS) devices. Our objectives were (1) to identify overall Important Atlantic Areas (IAAs) from a southern population, (2) to describe spatio-temporal patterns of oceanographic habitat use, and (3) to assess whether existing conservation areas (Natura 2000 sites and marine Important Bird Areas (IBAs)) cover the main IAAs of Balearic shearwaters. Our results highlighted that the Atlantic staging (from June to October in 2011) dynamic of the southern population was driven by individual segregation at both spatial and temporal scales. Individuals ranged in the North-East Atlantic over four main IAAs (Bay of Biscay: BoB, Western Iberian shelf: WIS, Gulf of Cadiz: GoC, West of Morocco: WoM). While most individuals spent more time on the WIS or in the GoC, a small number of birds visited IAAs at the extremes of their Atlantic distribution range (i.e., BoB and WoM). The chronology of the arrivals to the IAAs showed a latitudinal gradient with northern areas reached earlier during the Atlantic staging. The IAAs coincided with the most productive areas (higher chlorophyll *a* values) in the NE Atlantic between July and October. The spatial overlap between IAAs and conservation areas was higher for Natura 2000 sites than marine IBAs (areas with and without legal protection, respectively). Concerning the use of these areas, a slightly higher proportion of estimated positions fell within marine IBAs compared to designated Natura 2000 sites, with Spanish and Portuguese conservation areas being the most visited. Our results support the current design of conservation areas in Spain and Portugal regarding the protection of adult breeders of this highly mobile species.

1. Introduction

Marine Protected Areas (MPAs) are spatially delimited marine areas that are managed for biodiversity conservation and they are considered as an effective tool to protect marine ecosystems, including management of activities such as fisheries (FAO, 2011; Rassweiler et al., 2012). In order to be effective, MPAs need to meet two requirements: a good design to encompass the most relevant biological and ecological processes and the implementation of best management practices (Agardy et al., 2011). These requirements can be met only when the scales of spatial and temporal variability, as well as the management and/or conservation challenges of the area of interest are previously known, which most often is not the case for marine ecosystems (Agardy et al., 2011; Crowder and Norse, 2008). When studying the protection of migratory species, the consideration of vast areas encompassing their distribution range as candidate MPAs is not feasible (Lascelles et al., 2014). Alternatively high use areas can be protected as long as they are interconnected through a network of MPAs (Agardy et al., 2011; Guidetti et al., 2013). Moreover, the design and management of existing MPAs should integrate the biological

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processes, bearing in mind that administrative borders are not relevant for biological processes (Guidetti et al., 2013).

In order to ensure the protection of the marine environment and its associated ecosystem and biological diversity in European coastal countries, the European Union created a legal framework named the Marine Strategy Framework Directive (MSFD) (Directive 2008/56/EC). The main objective of the MSFD is to achieve or maintain "good environmental status" in marine environment by 2020 by strengthening other existing legal instruments (Trouwborst and Dotinga, 2011). These legal instruments are the Bern Convention on the Conservation of European Wildlife and Natural Habitats (1979), the OSPAR (1992) Convention for the Protection of the Marine Environment of the North-East Atlantic, the Birds Directive in 1979 (updated, Directive 2009/147/EC) and the Habitats Directive in 1992 (Directive 92/43/EEC). These two latter Directives aim at protecting and preserving different European natural habitats, as well as the associated flora and fauna in order to assure the long-term survival of European biodiversity by the designation of Special Areas of Conservation (SACs, under the Habitats Directive) and Special Protection Areas (SPAs, under the Birds Directive). The whole set of protected areas identified through the two Directives are brought together in the Natura 2000 network, which is the main tool supporting the environmental policies in the European Union.

Despite of all these efforts focused on policy measures, conservation and protection in marine ecosystems, there is a lack of attention given to seabirds (as well as to other far-ranging marine organisms) in regard to the establishment of MPAs (e.g., Game et al., 2009). In the specific case of seabirds, they have often been overlooked when regarding marine conservation as they are rather regarded as organisms linked to land (Grémillet and Boulinier, 2009), even whether they spend a large proportion of their lifetime at sea. Despite the apparent difficulty to establish MPAs for them, several long-term studies have shown high site fidelity and well defined oceanographic habitats for different migratory marine populations and species. For example, species adapted to exploit highly clumped prey, can be found in areas of greatest food availability (Lascelles et al., 2012). Marine areas where different species overlap in distribution and habitat use are perfect candidates to become MPAs (Arcos et al., 2012; Lascelles et al., 2014). In fact, BirdLife International has developed the Important Birds Areas (IBAs) programme to identify the most relevant areas for bird conservation (BirdLife International, 2004; Heath et al., 2000). The identification of IBAs does not guarantee legal protection, but they are intended to guide legal conservation action afterwards. In the case of Europe, they can be particularly helpful in the process of designing the Natura 2000 network, and several Member States have designed a considerable proportion of their national IBAs as SPAs (BirdLife International, 2014a).

Currently one of eight bird species is globally endangered and pelagic seabirds have suffered the highest rates of decline during the last 25 years (BirdLife International, 2013; Croxall et al., 2012). While the main threats at breeding colonies are the presence of alien invasive predators, habitat degradation and human disturbance, bycatch is the main threat at sea, followed by prey overfishing and pollution (Croxall et al., 2012). In Europe, this is especially true for the critically endangered Balearic shearwater (*Puffinus mauretanicus*), which has suffered severe population declines associated with a low adult survival rate (BirdLife International, 2015a; Genovart et al., 2016). The species breeds exclusively at the Balearic Islands, Menorca (northern populations), Mallorca-Cabrera (central populations) and Eivissa-Formentera (southern populations), but migrates to the NE Atlantic during the non-breeding season presumably to exploit highly rich productive areas (Arcos et al., 2011). Most of the previous work regarding the at-sea distribution of the species was performed during the breeding season in the western Mediterranean (Abelló et al., 2003; Arcos and Oro, 2002; Arcos et al., 2012; Meier et al., 2015; Louzao et al., 2006, 2011, 2012) and only a few studies have focused on non-breeding movements (Mouriño et al., 2003; Oppel et al., 2012; Wynn et al., 2007; Yésou, 2003). Some of these studies have provided the basis for marine IBA identification within the distribution range of the species, but few have provided an assessment of the use of sites by breeding adults (although see Guilford et al., 2012). For this reason, comprehensive studies analysing the spatial overlap of adult breeders with conservation areas (IBAs or Natura 2000 sites) would provide further insights to guide effective conservation efforts for the species.

Within this context, our main objective was to provide a broad understanding of the spatial and temporal Atlantic staging behavior of this endangered predator by using global location sensing (GLS). These devices were deployed on breeders belonging to a southern population located in the west coast of Eivissa, Balearic Islands. The specific objectives were: (i) to identify Important Atlantic Areas (IAAs) for the species using kernel density estimations; (ii) to ecologically describe the spatio-temporal patterns of the habitat use based on oceanographic information obtained from remote sensing; and (iii) to assess the spatial overlap of IAAs with conservation areas (Natura 2000 sites and IBAs). Our results could be used to guide and design effective conservation and management initiatives for the conservation of Balearic shearwaters during the non-breeding period in the NE Atlantic.

2. Material and methods

2.1. Study area and fieldwork procedures

Fieldwork to tag adult Balearic shearwaters was conducted in the breeding colonies of *Sa Conillera* and *Es Bosc* islets, within the *Reserves des Vedrà, es Vedranell* and *Illots de Ponent* (west of Eivissa Island, western Mediterranean, Fig. 1). We tagged 40 breeding birds with Mk19 Global Location Sensing loggers (GLS) manufactured by the British Antarctic Survey (Cambridge, UK), during the incubation period between the 3th and 7th of April 2011. GLS were ground calibrated in France during 4 days prior to deployment. Birds were captured while they were in their nest and placed into cloth bags for weighing and taking biometric measurements. A blood sample was taken to determine individual sex using molecular sexing (Morinha et al., 2012). Loggers (ca. 1.5g) were fitted to the metal bands on the leg of each bird using cable-ties and the total weight of the equipment was well below the recommended 3% of the weight of flying birds (Phillips et al., 2006): it ranged between 0.32% and 0.49%.

2.2. Geolocation-based data processing

Mk19 GLS loggers provide light intensity data, which are used to estimate bird location, and immersion data, which provides information on activity such as sitting on the water and flying (wet and dry states, respectively). To improve location reliability with advanced analytic tools, we used the automated data-processing method developed by Thiebot and Pinaud (2010) based on the *TripEstimation* package (Sumner and Wotherspoon, 2009) in R (R Development Core Team, 2015) and adapted to flying birds. Raw location estimations calculated from light data were first constrained by a land mask and spatial boundaries beyond which locations were unrealistic (longitude: 15ºW–10ºE, latitude: 25º–55ºN). The use of a land mask to constrain position estimations prevents the algorithm to provide estimations over land and, therefore, no position is discarded. Then Bayesian methods, including specific behavioural parameters (e.g., log-normal distribution of mean speed), and Markov Chain Monte Carlo simulations (to approximate the posterior position) were used. The mean ± SD speed threshold was set to $10 \pm 7\ \text{km h}^{-1}$ estimated from Global Positioning System (GPS) to constrain movement estimates (SEO/BirdLife, unpublished). The mean speed does not correspond to the usual instantaneous travel speed, but to the distance travelled during a 12-h period (Thiebot and Pinaud, 2010). At the end, the mean of all

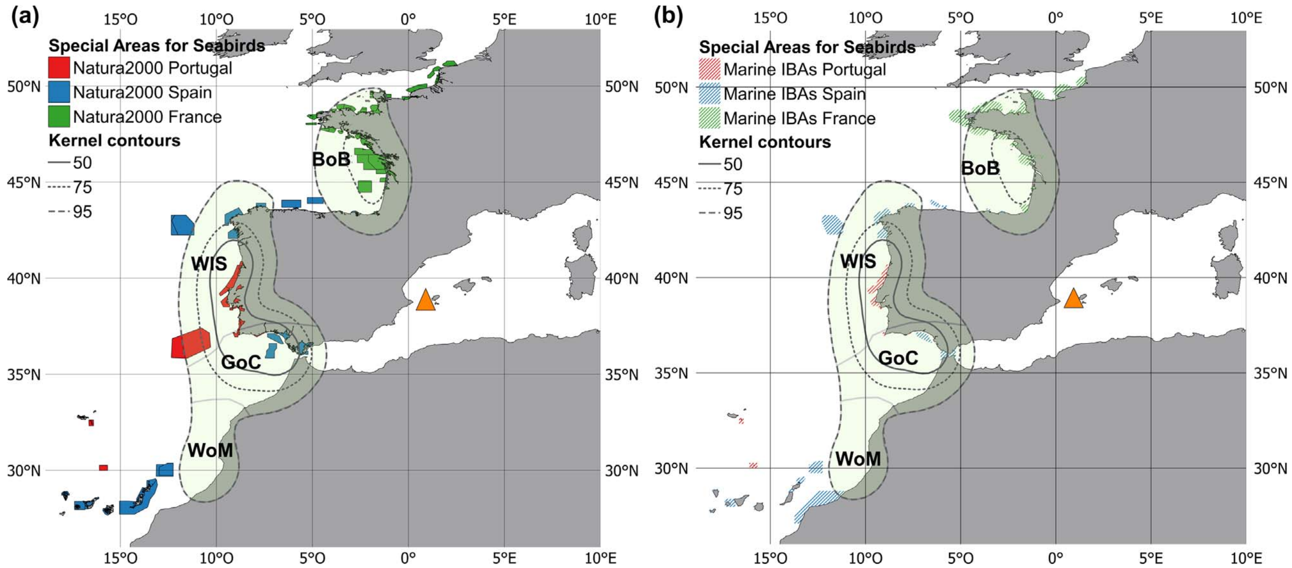

Fig. 1. Map of the post-breeding distribution range of Balearic shearwaters from southern populations in Eivissa, as well as the special areas for its conservation represented by (a) marine Natura 2000 sites and (b) marine Important Bird Areas by country (Portugal: red, Spain: blue, France: green). The identified Important Atlantic Areas (represented by the kernel density contours) are indicated as the Bay of Biscay (BoB), the Western Iberian Shelf (WIS), the Gulf of Cádiz (GoC) and the Western coast of Morocco (WoM). The orange triangle shows colony location. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

possible estimations for each position was estimated to obtain the most probable track with two locations per day, at sunrise and sunset (Thiebot and Pinaud, 2010).

Estimated positions were then spatially represented using the QGIS software (QGIS Development Team, 2014) and a first visual estimation of the dates of entering and leaving the Atlantic Ocean (migratory movements, Table 1) was performed using the Strait of Gibraltar as a longitudinal threshold line. These dates were further refined using immersion data to estimate the last nighttime colony visit (i.e., last day of breeding, LDCA in Table 1) and the first nighttime colony visit during the following breeding season (FDCA in Table 1). Periods of 7h during nighttime (i.e., from 20h00 to 03h00 GMT) in which loggers recorded continuous dryness were assumed to be colony visits. The estimation of the first nighttime colony visit was only possible when immersion memory was not full (see Table 1), as the part of the memory dedicated to immersion data fills faster than the one dedicated to light data. The dates estimated from immersion data were more reliable than those estimated from light-based positions (mean accuracy 186 ± 114 km, Phillips et al., 2004). Thus, when estimation of the migration dates from light data did not match with the likely periods to be at the colony, the whole dataset belonging to such an individual was discarded. In this way, only data from 16 individuals out of the 22 downloadable provided reliable estimates of locations for further analysis. We are aware that nighttime colony visits can be shorter than 7 hours and it decreases throughout the chick-rearing period (Rayner et al., 2012). However, our aim was not to strictly define the end of the breeding season, but to achieve a trade-off between the high positioning error of geolocation-based estimations and the identification of the Atlantic staging period.

Tracks were described and compared using a common set of parameters (Table 1): (1) the date of entering the Atlantic Ocean, (2) the date of leaving the Atlantic Ocean, (3) the staging duration in the Atlantic Ocean (from the first to the last day in the Atlantic), (4) last nighttime record of at least 7 h of continuous dryness before entering

Table 1
Non-breeding Atlantic phenology of southern populations of Balearic shearwaters. BP: Breeding Pair. BO: Breeding Output. S: Successful. US: Unsuccessful. UN: Unknown. EATL: Date of entering the Atlantic Ocean. LATL: Date of leaving the Atlantic Ocean. LLR: Last light record. WATL: Staging duration in the Atlantic Ocean (days). LDCA: Last date of a nighttime visit to the colony in 2011. FDCA: First date of a nighttime visit to the colony in 2011.LAR: Last activity record. TOC: time outside the colony between breeding periods. NA: Not available

Individual description			Sex	BO	Light data				Immersion data			
GLS	Band	BP id			EATL	LATL	LLR	ATL (days)	LDCA	FDCA	LAR	TOC (days)
19985	5086317		M	S	27/06/2011	01/11/2011	04/04/2012	127	27/06/2011	NA	08/11/2011	NA
19986	5086316		F	S	30/06/2011	16/11/2011	04/04/2012	139	24/06/2011	NA	05/11/2011	NA
19989	5086319		M	US	13/05/2011	18/10/2011	04/04/2012	158	30/04/2011	19/10/2011	03/12/2011	172
19991	5086321		F	US	24/06/2011	08/10/2011	04/04/2012	106	13/06/2011	23/10/2011	13/02/2012	132
19994	5086323	BP 1	M	US	24/05/2011	28/10/2011	04/04/2012	157	14/05/2011	NA	29/09/2011	NA
19995	5086325	BP 2	M	S	09/07/2011	27/10/2011	04/04/2012	117	07/05/2011	NA	12/11/2011	NA
19997	5086327		F	S	20/05/2011	27/10/2011	04/04/2012	160	15/05/2011	NA	13/10/2011	NA
23002	5086332		F	S	01/07/2011	24/11/2011	04/04/2012	120	01/05/2011	20/12/2011	07/01/2012	233
23005	5086334		M	S	24/06/2011	23/10/2011	05/04/2012	121	23/06/2011	31/10/2011	06/11/2011	130
23009	5086339		F	UN	20/06/2011	06/10/2011	05/04/2012	108	06/05/2011	18/10/2011	16/11/2011	165
23013	5086342		F	UN	16/06/2011	25/09/2011	05/04/2012	101	11/06/2011	03/10/2011	20/10/2011	114
23014	5086343		F	S	22/06/2011	07/10/2011	05/04/2012	107	20/06/2011	17/10/2011	20/01/2012	119
23016	5086345		F	S	13/06/2011	12/10/2011	05/04/2012	121	28/05/2011	NA	24/09/2011	NA
23017	5086346		F	S	20/06/2011	30/10/2011	05/04/2012	132	26/05/2011	19/11/2011	15/01/2012	177
23022	5049267	BP 1	F	US	19/05/2011	28/09/2011	05/04/2012	132	06/05/2011	30/10/2011	17/02/2012	177
23023	5049268	BP 2	F	S	30/09/2011	29/11/2011	06/04/2012	60	07/05/2011	NA	12/11/2011	NA

the Atlantic Ocean, (5) first nighttime record of at least 7 hours of continuous dryness after leaving the Atlantic Ocean, and (6) the duration of the non-breeding period (from the last to the first visit to the colony during the nighttime using the 7-h threshold). We performed a *t-student* test to verify the relationship between sex and duration of the Atlantic staging (females stayed longer on migration than males in Guilford et al. 2012).

2.3. Identification of Important Atlantic Areas and their temporal use

We identified Important Atlantic Areas (IAAs) for Balearic shearwaters during the non-breeding period based on Kernel Density Estimation analysis. Kernel analysis is an appropriate approach for the identification of important areas for flying seabirds (Tancell et al., 2013; Delord et al., 2014). This analysis allows the estimation of Utilization Distribution (UD) contours that represent the area at different density distribution quantiles based on light-based locations (Péron and Grémillet, 2013; Delord et al., 2014). We used the *adehabitatHR* package (Calenge, 2006) to generate individual (Appendix I) and population-level density distributions using the *ad hoc* method for estimating the smoothing parameter (h=0.803). The coordinates system used was WGS84 with a cell size of 0.3º*0.3º. UD contours at 50%, 75% and 95% of kernel density distribution (Worton, 1995) are considered to be representative of the core areas, intense use area and overall habitat (i.e., distribution range), respectively.

To explore the temporal use of IAAs, we estimated the number of monthly visits (Nb. Visits), number of individuals that visited (Nb. Individuals) the different IAAs, as well as the staging duration (in days) of each individual within each IAA per month. We could therefore estimate the mean ± SD number of days spent in each IAA and month. The aim was to identify the specific months when shearwaters stayed longer in each IAA. We executed this analysis with the QGIS tool *count points in polygon* to assign individuals to the different IAAs and basic functions within the R environment to estimate the duration of each individual within each IAA (R Development Core Team, 2015). In addition, we explored the Atlantic staging strategy by plotting the IAAs visited by each individual on a 12-h basis, from the first to the last position in the NE Atlantic.

2.4. Oceanographic characterisation of Important Atlantic Areas

To ecologically characterize the Atlantic staging area, we used three environmental variables (Simons, 2015) and their spatial gradients, as these variables are relevant for defining the habitat preference of Balearic shearwaters during the breeding season (Louzao et al., 2006, 2012). The environmental variables were: sea surface temperature (SST, ºC), chlorophyll *a* concentration (CHL, mg m^{-3}) and bathymetry (BAT, m) as a proxy for water mass distribution, marine productivity and coastal-oceanic gradients, respectively. Since the first two variables are dynamic, we estimated their median for the overall Atlantic staging period (from July 2011 to October 2011, see Table 1). Since bathymetry is a static variable, it was extracted once. Additionally, we estimated their spatial gradients (CHLG, SSTG and BATG) by estimating their Proportional Change (PC) within a surrounding 3º×3º cell grid using a moving window as follows: PC=[(maximum value−minimum value)*100]/(maximum value). This dimensionless metric expresses the magnitude of change in each habitat variable, scaled to the maximum value (Louzao et al., 2006). Then, median values of these oceanographic variables were extracted for UD contours, from 5% to 95% each 5 percentage units (Péron et al., 2010). Based on previous distribution models for the species, we hypothesized that core habitats (i.e., UD contours < 50%) would be characterized by high CHL, low SST and low BAT values (Louzao et al., 2006, 2012).

Finally, we developed a Principal Component Analysis (PCA) to further explore the relationship between the proportion of positions of each individual within each IAA and the median values of the six oceanographic variables within the core habitat indicated by the 50% UD. We used the *prcom* function in R. We applied a log (x+1) transformation and standardize variables prior to the PCA. The scores and loadings shown in PCA biplots were estimated using the *ggbiplot* function from the *ggplot2* package (Wickham, 2009).

2.5. IAAs overlap with conservation areas

We studied the spatial overlap of Balearic shearwaters during their Atlantic staging with conservation areas. These areas were defined as either protected sites (Natura 2000, N2000 hereafter) or candidates for protection (marine IBAs, IBA hereafter). Geographic Information System layers for N2000s were obtained for France, Portugal and Spain from the European Environment Agency (2015). National IBA layers were obtained from the corresponding BirdLife partners (Portugal: Sociedade Portuguesa para o Estudo das Aves – SPEA, Spain: Sociedad Española de Ornitología - SEO/BirdLife; France: Ligue pour la Protection des Oiseaux- LPO). While BirdLife International has promoted basic guidelines for marine IBA delineation (BirdLife International, 2014b), the identification process of these sites is at different stages depending on the country. Hence, while Spain and Portugal currently have completed (or near complete) marine inventories, France has only identified seaward extensions to seabird colonies so far. Therefore, the results of this exploratory analysis have to be taken with caution when comparing French IBAs and N2000 with the other two countries.

The spatial overlap analysis was performed using the QGIS software (QGIS Development Team, 2014) at both population and individual levels. At the population level, the polygons of UD contour 75% were used to quantify the area (in km^2) overlapping the polygons corresponding to N2000 and IBAs. The UD contour of 75% was used (rather than the 50% UD contour) since the IAA of the Bay of Biscay was identified by this UD contour, which encompasses the coastal waters of France. The overlap with N2000 sites and marine IBAs was assessed by country. At the individual level, we estimated the number of positions over either N2000s or IBAs polygons by country using the QGIS tool *count points in polygon*.

3. Results

On March 2012, 28 loggers were recovered (recovery rate of 70%) but we obtained data for 22 tags. Nonetheless, after the geolocation-based data processing we further analysed a sample of 16 individuals.

3.1. Atlantic phenology

Regarding the timing of migration, Balearic shearwaters entered the Atlantic Ocean on the 20th of June (range: 13th of May–30th of September; Table 1). On average (± SD), the Atlantic non-breeding staging period lasted 121 ± 30 days and shearwaters left the Atlantic Ocean on the 27th of October (range: 25th of August–23rd of December) (Fig. 2). The duration of the Atlantic staging was not related to sex (*t*=-0.9534, *df* =11.505, *p-value*=0.36). An individual (GLS number 23023, Table 1) differed from the overall pattern described above, since it left the Mediterranean Sea in October and returned at the end of November. Therefore, its Atlantic staging only lasted 60 days and it was restricted to areas adjacent to the Strait of Gibraltar, namely the Gulf of Cádiz and the western coast of Morocco.

3.2. Identification of Important Atlantic Areas and their temporal use

Four main IAAs were identified based on the visual inspection of individual 50%, 75% and 95% UD contours (Fig. 1): the Bay of Biscay (BoB), the Western Iberian Shelf (WIS), the Gulf of Cádiz (GoC) and the Western coast of Morocco (WoM), from north to south. Regarding both the number of visits and the number of individuals, the GoC and

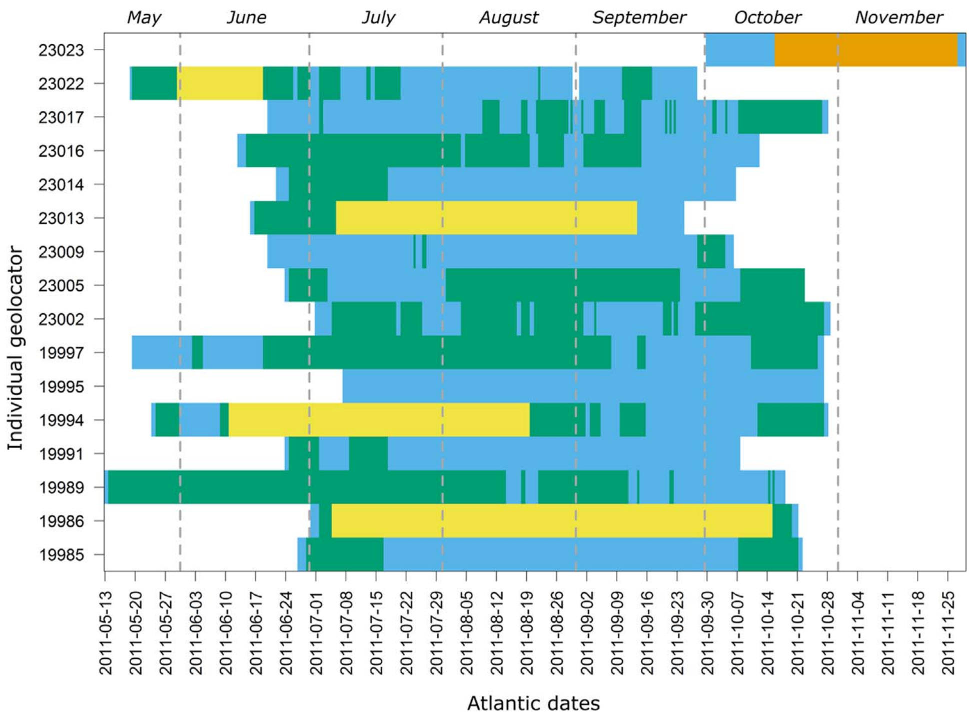

Fig. 2. Atlantic chronology of 16 individuals of Balearic shearwaters from southern populations on Eivissa. The Atlantic chronology is represented by the elapsed time since the first date of departure from the Mediterranean Sea (13/05/2011) and the first day of returning to the Mediterranean Sea (29/11/2011), considering all individual geolocators. Vertical dashed grey lines represent the beginning of each month (from May to November). The color code represents each of the four main Important Atlantic Areas derived from kernel analysis. Blue: Gulf of Cádiz. Green: Western Iberian Shelf. Yellow: Bay of Biscay. Orange: Western of Morocco. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

the WIS were visited more frequently during the whole non-breeding period compared to the BoB and the WoM areas, which were identified as extreme areas along the latitudinal gradient (Fig. 2). Indeed, only four individuals (three females and a male) visited the northern area and only one individual reached the southern area (Fig. 2).

Concerning the chronology and length of the visits to IAAs, the GoC was mostly visited in July and individuals spent 36 days per visit (on average) in this area (Table 2). The WIS was mostly visited in June and individuals spent on average 28 days, (Table 2). Regarding the BoB, it was mostly visited in July and shearwaters spent on average 99 days, as well as in June (Table 2). In the case of the WoM, it was only visited by one individual, spending 42 days (Table 2). The proportion of days during the non-breeding season that individuals spent in the different IAAs varied greatly (Fig. 2) possibly describing different Atlantic staging strategies.

Table 2
Monthly chronology of Important Atlantic Areas characterised by the number of monthly visits and average time (in days) spent during the 2011 non-breeding period. Number of monthly visits (Nb. Visits), number of individuals that visited (Nb. Individuals) the different areas, mean ± SD number of days spent in areas (Mean ± SD Nb. Days). BoB: Bay of Biscay. WIS: Western Iberian Shelf. GoC: Gulf of Cádiz.

Months	IAA	Nb. Visits	Nb. Individuals	Mean ± SD (days)
June	GoC	13	11	5 ± 9.53
June	WIS	8	7	28 ± 22.73
June	BoB	1	1	69
July	GoC	15	9	36 ± 38.4
July	WIS	9	6	4 ± 4.56
July	BoB	2	2	99 ± 41.35
August	GoC	11	5	2 ± 2.09
August	WIS	12	6	12 ± 14.63
September	GoC	21	10	10 ± 8.34
September	WIS	12	8	6 ± 8.2
October	GoC	9	7	1 ± 0.57
October	WIS	6	5	13 ± 6.37
October	WoM	1	1	42

3.3. *Oceanographic characterisation of Important Atlantic Areas*

Regarding the oceanographic characterisation of the Atlantic habitat use, the median values of the three oceanographic variables extracted for UD contours from 5% to 95% showed that core habitats (UD < 50%) were characterized by high CHL, low SST and low BAT values, as well as to high values of all three spatial gradients (Fig. 3). This means that Balearic shearwaters from southern populations on Eivissa visited mainly areas of high primary productivity in the Northeast Atlantic during the boreal summer (see Appendix II).

Regarding the PCA, the proportion of total explained variance within the first two principal components was 36.5% and 28.3%. Loading factors on PC1 (Fig. 4) indicated that the first axis was related positively mainly to SSTG and CHL, and negatively related to SST and the proportion of positions in the GoC. Therefore PC1 indicated that individuals spending more time in the GoC were related to warmer areas (higher SST values) with low water mass variability and productivity (lower SSTG and CHL values, respectively). Loading factors on PC2 indicated that this axis was related to positive values of CHLG and BATG and negatively to the time spent in the BoB. Therefore, PC2 summarised individuals spending less time in the northern IAA were related to frontal systems (i.e., higher values of CHLG) and associated to topographical features (higher values of BATG).

3.4. *Spatial overlap between shearwater distribution and conservation areas*

At the population level, we estimated that 9.8% and 7.4% of the Atlantic distribution of Balearic shearwaters was occupied by N2000 sites and marine IBAs, respectively (Fig. 1). These percentages corresponded to a surface of 34,268 km^2 (N2000) and 25,600 km^2 (IBAs) of a total of 347,900 km^2 covered by the 75% UD. Concerning N2000 sites by country, French, Spanish and Portuguese N2000 sites covered the 30.4%, 42.7% and 26.9% of shearwater distribution,

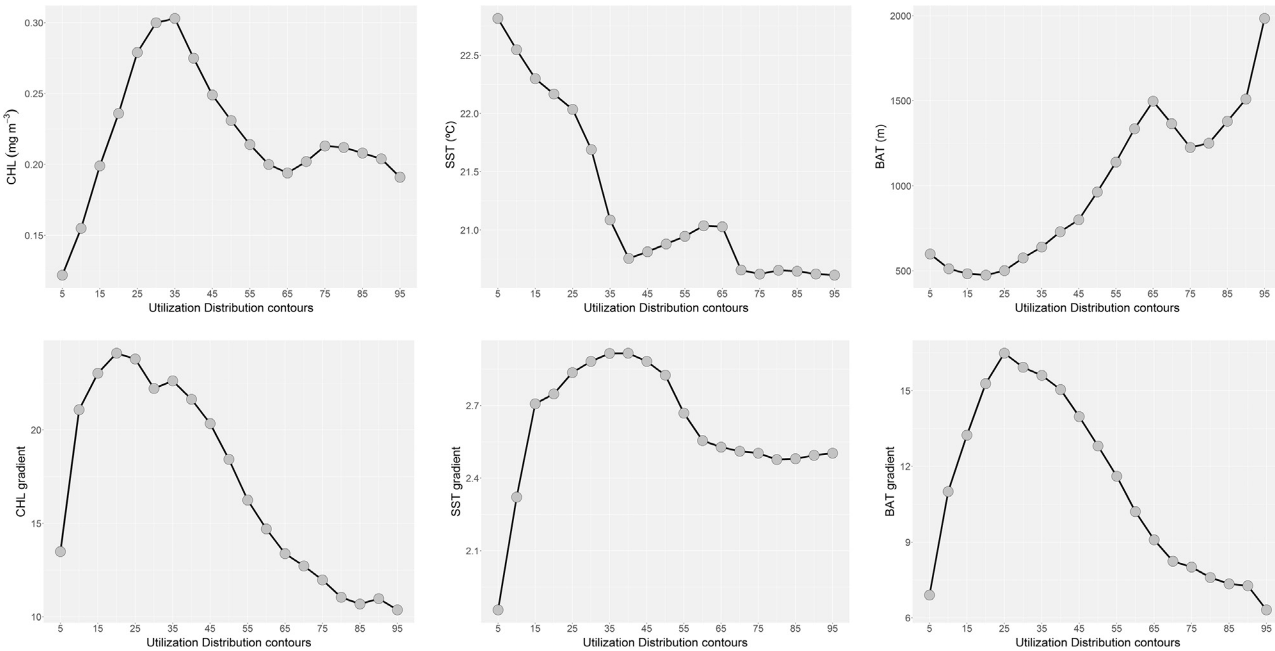

Fig. 3. Oceanographic characterization of Important Atlantic Areas for Balearic shearwaters from a southern populations in Eivissa represented by the average values of sea surface chlorophyll *a* concentration (CHL, mg m^{-3}), sea surface temperature (SST, ºC) and bathymetry (BAT, m), as well as their spatial gradients extracted for each kernel density contour (from 5% to 95%, every 5 percentage units).

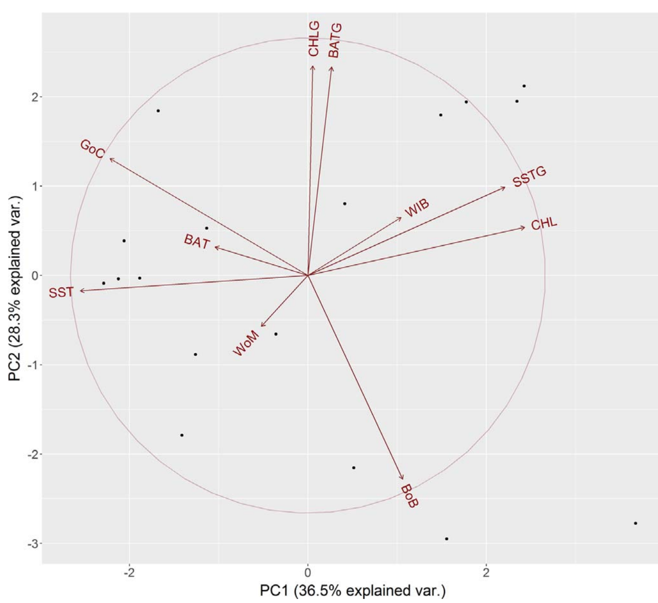

Fig. 4. PCA biplot of the proportion of individual positions within each IAA and the median values of oceanographic variables within the core habitat indicated by the 50% UD. Each black point corresponds to individual scores and the brown arrows variable loadings. BoB: Bay of Biscay. WIS: Western Iberian Shelf. GoC: Gulf of Cádiz. WoM: Western coast of Morocco. CHL: sea surface chlorophyll *a* concentration (mg m^{-3}). CHLG: CHL gradient. SST: sea surface temperatures (ºC). SSTG: SST gradient. BAT: bathymetry (m). BATG: BAT gradient. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

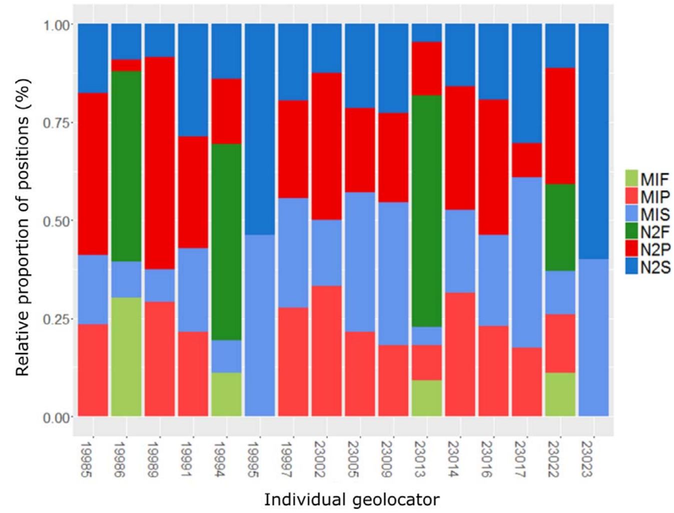

Fig. 5. Relative proportion of positions by conservation area for individual birds (each bar is represented by the corresponding individual geolocator number), which match the existing Natura 2000 sites and marine IBAs. Conservation areas are colour-coded. MIS: Marine Important Bird Areas of Spain; N2S: Natura 2000 sites of Spain; MIP: Marine Important Bird Areas of Portugal; N2P: Natura 2000 sites of Portugal; MIF: Marine Important Bird Areas of France; N2F: Natura 2000 sites of France. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

respectively. Regarding marine IBAs, French, Spanish and Portuguese designated areas covered the 41.8%, 29.7% and 28.5% of the distribution of the species.

Regarding individual use, N2000 sites were less visited (in terms of number of positions) than marine IBAs (47.6% *versus* 52.4%, respectively). By country, shearwaters visited in a higher proportion both Portuguese and Spanish N2000s (39% and 35%, respectively) and IBAs (48% and 40%, respectively) than French conservation areas (26% and 12% for N2000 and IBAs, respectively)(Fig. 5).

4. Discussion

4.1. Spatial and temporal Atlantic staging strategies

At the population level, Balearic shearwaters from southern populations in Eivissa left the Mediterranean Sea between the mid of May and the end of June, after completing the breeding season, potentially to exploit more productive waters in the North-East Atlantic Ocean during the boreal summer. The Atlantic phenology of Balearic shearwaters from southern populations on Eivissa (from 2011) contrasted with a previous study of birds from the central populations (namely from Mallorca in 2010; Guilford et al., 2012). We found differences in the duration of the Atlantic staging period (4 *versus* 3 months for southern and central populations, respectively) and the Atlantic leaving date, which was a month earlier for central shearwaters (the 27th of October 2011 versus the 27th of September 2010). All 16 individuals but 4 came back to the Mediterranean during the month of October. In contrast to results obtained by Guilford et al. (2012), the duration of the Atlantic staging was not influenced by sex. Differences in the Atlantic phenology and sex-related migration duration between southern and central populations could be explained by differences in the sex proportion of the present study (5 males *versus* 11 females), by inter-annual variability (2010/2011 for central population *versus* 2011/2012 for southern population), by different migration strategies used by each colony as suggested by Guilford et al. (2012) and the use of different time thresholds to identify colony visits.

Regarding Important Atlantic Areas, similar areas were identified for both southern and central populations from the western of Morocco, Gulf of Cádiz, western Iberian Shelf and the Bay of Biscay (present study, Guilford et al., 2012). Likewise, our results also suggest individual variability in the Atlantic staging dynamics, since we observed spatial and temporal segregation in breeding individuals of the southern population. Regarding temporal segregation, adult breeders could visit different IAAs during their Atlantic staging: while the strategy of most individuals was to spend more time in the Western Iberian Shelf and the Gulf of Cádiz, a few others showed different strategies, spending more time at the extremes of their Atlantic distribution range (i.e., Bay of Biscay and west Morocco). In addition, we found an overall latitudinal gradient in relation to the timing of arrival to the IAAs: the northern areas were reached earlier during the Atlantic staging. Birds spent more time in the Bay of Biscay during June and July, the Gulf of Cádiz in July, the Western Iberian Shelf in June and August and the Western of Morocco in October. At the individual level, internal factors could decide foraging destination, and external factors such as food availability and wind could constrain decision making (Nathan et al., 2008).

Regarding spatial segregation, our results are consistent with Guilford et al. (2012) who suggested a sex-related differential migration patterns since mainly breeding females visited the northernmost IAA from both southern and central populations. In our study, three females and one male travelled to the BoB. This IAA could be also an important area visited by non-breeders (Guilford et al., 2012) given the few adult breeders visiting these area where thousands of individuals are occurring yearly (Jones et al., 2015; Wynn et al., 2007). In many bird species the migration strategy and the staging areas differ between age classes (Péron and Grémillet, 2013) and such a situation may occur in the Balearic shearwater (Guilford et al., 2012). However, our sample size was limited and more research would be required to understand individual heterogeneity in migration strategies at both population and species level.

4.2. Oceanographic characterisation of the Atlantic staging

The IAAs of Balearic shearwaters during the boreal summer coincide with the most productive areas in the North-East Atlantic (Arístegui et al., 2009; Cravo et al., 2010; McGregor et al., 2007; Wollast and Chou, 2001), as did previous geolocation-based observations (Guilford et al., 2012). The core habitat of southern Balearic shearwaters was characterized by productive waters over the continental shelf in association to frontal systems. Previous studies have shown a similar association of the species during the non-breeding season (Oppel et al., 2012), as well as during the breeding season in the western Mediterranean (Arcos et al., 2012; Louzao et al., 2006, 2012) using different and more precise location methods (i.e., at-sea surveys and satellite transmitters). Even though GLS-based inferred positions are of low precision, our initial hypothesis of core oceanographic habitat characterization matched previous knowledge.

Balearic shearwaters, however, might not exploit all Important Atlantic Areas, and might prefer particular sub-areas within the IAAs. The combination of light-based estimations with activity data would provide activity maps to identify high use areas within the proposed IAAs (Dias et al., 2012). Our exploratory analysis relating the proportion of positions within each IAA and oceanographic variables could shed some light on this issue. In fact, the Gulf of Cádiz was related to higher temperatures and less productive waters, whereas the northern IAA was related to frontal systems and topographical features. Nevertheless, the present study only considered one season and oceanographic habitat stability should be analysed combining multiple years in order to better define the oceanographic features associated to the possible different Atlantic staging strategies.

4.3. Spatial overlap with conservation areas

The spatial overlap analysis between the Balearic shearwater Atlantic distribution and the existing conservation areas revealed that 39% of estimated positions were located in Portuguese N2000 sites, while the 35% were located in Spanish N2000 sites and 26% of estimated positions in French N2000 sites. These results might provide some input to some policy instruments such as the Marine Strategy Framework Directive (Directive 2008/56/EC), which states *inter alia* that the development of an ecologically coherent and representative network of MPAs is required in order to achieve a “good environmental status” by 2020 (Trouwborst and Dotinga, 2011). Currently, France is extending its network of N2000 sites offshore in order to protect seabirds and marine mammals (Delavenne et al., 2014). These data may help in the identification of major important areas for the conservation of marine megafauna such as marine mammals and seabirds, including the Balearic shearwater.

Marine IBAs covering the Atlantic distribution of the Balearic shearwater were more visited than Natura 2000 sites. By country, Spanish marine IBAs were the most visited followed by Portugal and France. These results reflect the different stage of the IBA designation process occurring in each country. At the same time, the results support the marine IBA programme as a good initiative to propose marine SPAs as part of the N2000 network (Arcos et al., 2012; Birdlife International, 2014a, 2014b). In fact, some marine IBAs in Portugal and Spain were designed, *inter alia*, for Balearic shearwater, while in France no site was designed for this species (Birdlife International, 2015b). Despite the positive results presented here, we acknowledge the limitations of light-based geolocation (Phillips et al., 2004), and the small number of individuals tagged in this study. Nonetheless, geolocators are currently the only cost effective option for tracking the year-round movements of relatively small seabirds, such as the Balearic shearwater, and have provided valuable information on Atlantic habitat use presented here.

At present this medium-sized seabird is listed as Critically Endangered (IUCN, 2015), based on a severe decline as inferred from demographic data, with an unusually low adult survival (Genovart et al., 2016). Threats increasing adult mortality are therefore of particular concern, with fisheries bycatch being the most relevant threat at sea in both the Mediterranean and Atlantic areas (Arcos, 2011; ICES, 2013). A recent study on seabird bycatch in Portuguese waters for the period 2010–2012 demonstrated that the most impacting fishing gear for Balearic shearwaters was purse-seining, followed by longlining (Oliveira et al., 2015). In order to implement effective protection within MPAs, fishing activity should be assessed within the boundaries of each MPA as a priority. Next steps would require the introduction of mitigation measures within the monitoring and management plans of MPAs to prevent shearwater bycatch. For this reason, international organisms such as Regional Fisheries Management Organizations (i.e., stakeholders) should also be involved in the design of effective conservation plans within MPAs design and implementation.

5. Conclusions

The present study assessed the Important Atlantic Areas visited by Balearic shearwaters from southern populations in Eivissa during their non-breeding period in the NE Atlantic. Our results support current knowledge on the Atlantic spatial and behavioral dynamics of this endangered top predator and provide evidence of individual heterogeneity in migration patterns. Further investigation would require the identification of important areas of the species according to (1) different life stages (Péron and Grémillet, 2013), (2) different periods of the year, i.e. breeding and non-breeding period (Arcos et al., 2012) and (3) different populations.

Moreover, the identification and assessment of the main threats occurring over their important areas is needed to implement proper regulation measures (Arcos, 2011). Our results showed an overlap of Important Atlantic Areas for breeders with existing MPAs in different countries. However, MPAs in isolation are unlikely to solve the range of threats to this species. Therefore, it is necessary to design and implement a network of MPAs enabling an effective protection and recovery of this highly mobile species (Directive 2008/56/EC; Young et al., 2015). Multilateral Environmental Agreements (MEA) signed by different states and international organisations should be considered as an effective way to guide transboundary conservation initiatives (Directive 2008/56/EC; Lascelles et al., 2014). Regarding threats faced by the species, the Regional Fisheries Management Organizations should also be included in MEAs to work together in reducing the risk of extinction of Balearic shearwaters (Delord et al., 2014; Directive 2008/56/EC; Lascelles et al., 2014). Moreover, other anthropogenic threats (i.e., the development of marine renewable energies; Garthe and Hüppop, 2004; Masden et al., 2010) or climate change (Wynn et al., 2007; Gómez-Gesteira et al., 2008) will also increase the pressure on the Balearic shearwater, requiring an assessment of cumulative threats and appropriate management of existing MPAs.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.dsr2.2016.11.011.

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