

Habitat overlap between bottlenose dolphins and seabirds: a pilot study to identify high-presence coastal areas in the Tyrrhenian Sea

VALENTINA CAFARO¹, DARIO ANGELETTI¹, BRUNO BELLISARIO¹, ARMANDO MACALI¹,
CLAUDIO CARERE¹ AND JESSICA ALESSI^{2,3}

¹Dipartimento di Scienze Ecologiche e Biologiche, Centro Ittiogenico Sperimentale Marino, Università degli Studi della Tuscia, Borgo Le Saline, 01016 Tarquinia (VT), Italy, ²Dipartimento di Scienze della Terra, dell'Ambiente e della Vita (DISTAV), Università degli Studi di Genova, Corso Europa, 26, 16132 Genova (GE), Italy, ³Associazione Me.Ri.S. Mediterraneo Ricerca e Sviluppo, Via Milano 8, 92026 Favara (AG), Italy

The identification of foraging hotspots able to support the co-existence of multiple top predators provides a potential approach to addressing protection measures for marine ecosystems. In this study, we conducted visual surveys in the central Tyrrhenian Sea to determine areas with simultaneous presence of bottlenose dolphins, four species of seabirds (Audouin's gull, Yellow-legged gull, Yelkouan shearwater and Cory's shearwater), and baitballs occurring at the surface, indicating the presence of potential prey items. We also analysed their occurrence in relation to topography (depth, slope and distance from the shore) and seabed types. Kriging analysis identified areas with simultaneous presence of several marine top predators. Dolphin distribution appeared to be linked to gentle slope (6–10 m) and muddy seabed, possibly associated with prey distribution, whereas the four seabird species were more frequent in areas with a water depth of 100–150 m, gentle slope and muddy seabed, apart from Audouin's gull, which preferred a depth of 10–20 m. Baitball distribution was linked to depth (20–40 m), gentle slope (6–10 m) and muddy seabed. The overlapping presence of bottlenose dolphins, seabirds and baitballs allowed the identification of foraging areas, presumably representing biodiversity and productivity hotspots, located in waters of 50–100 m depth at the mouths of two rivers. This approach provides a promising tool for identifying highly productive coastal areas, and should also be recommended for wider-scale surveys.

Keywords: Bottlenose dolphin, seabird, top predator, habitat overlap, habitat preference

Submitted 11 June 2015; accepted 11 August 2015; first published online 9 September 2015

INTRODUCTION

Although ecologists have been studying species assemblages for decades, information on the structures of coastal and pelagic communities remains scarce (Verity & Smetacek, 1996; Thiebot & Weimerskirch, 2013). The distributions of marine birds and cetaceans are determined by their associations with specific physical and biological processes, at distinct spatial and temporal scales (Hunt & Schneider, 1987; Jaquet & Whitehead, 1996; Hyrenbach & Veit, 2003). These upper-trophic-level marine predators associate with specific water masses, hydrographic fronts (convergence and divergence zones), and other mesoscale features (reviewed by Hunt & Schneider, 1987; Schneider, 1991; Jaquet, 1996; Croll *et al.*, 1998). Horizontal gradients in water density and the degree of vertical stratification promote the aggregation of swimming prey in the proximity of these discontinuities, providing enhanced feeding opportunities for many marine predators

(Hunt *et al.*, 1990, 1996, 1998; Franks, 1992; Ribic & Ainley, 1997; Spear *et al.*, 2001). Foraging seabirds and cetaceans are also associated with bathymetric features, such as shallow banks and continental shelf-slope regions (Hunt & Schneider, 1987; Hunt *et al.*, 1996; Baumgartner *et al.*, 2001). In particular, continental shelf breaks and slopes appear to be highly productive habitats, which frequently support high densities of marine predators (Briggs *et al.*, 1987; Schoenherr, 1991; Springer *et al.*, 1996; Croll *et al.*, 1998).

Cetaceans and seabirds are top-level predators that serve as sentinels of the health and status of lower trophic levels in the marine ecosystem. They are therefore considered as key species in terms of monitoring and the implementation of marine conservation planning, and have often been used to promote the designation of reserve areas (Hooker & Gerber, 2004). Examination of areas of overlap among foraging habitats of different predators, together with a basic knowledge of their diets, the broader ecosystem and habitat variability should therefore allow the identification of hotspot features (Hooker & Gerber, 2004).

Seabirds have been shown to use the presence of hunting marine mammals as a means of detecting and accessing

Corresponding author:

D. Angeletti

Email: darioangeletti@unitus.it

prey patches. However, although these associations have been documented locally, e.g. in the Ebro delta (Witt *et al.*, 1982) and the Lagamar estuary (Santos *et al.*, 2010), their relevance at the ecosystem level remains unknown, mainly because they constitute relatively rare events or are difficult to detect (Thiebot & Weimerskirch, 2013). At large spatial scales, seabird prey items are not always accessible near the sea surface, and it has been well-documented that most seabirds seem to search actively for physical features, such as upwellings or oceanic frontal zones and shallow areas (Schneider, 1991; Hunt *et al.*, 1999; Bost *et al.*, 2009) that increase the accessibility of the target species near the surface. Nevertheless, the means by which seabirds locate and access prey patches that may occur several metres below the surface at smaller spatial scales remain unknown. It was recently suggested that marine mammals and seabirds may show commensalism in some areas when foraging at sea (Thiebot & Weimerskirch, 2013). Analysis of stomach contents revealed that fish and cephalopods were the major components of the diet of both dolphins and seabirds, particularly the fish species *Sardinia pilchardus*, *Merluccius merluccius* and *Belone belone*, and the cephalopods *Histioteuthidae* sp., and some species of *Sepidiidae* and *Ommastrephidae* (Astruc, 2005; Petry & Krüger, 2009; Alonso *et al.*, 2012).

The biodiversity of the marine ecosystem is changing rapidly as a result of climate change and human impacts, and specific measures to protect species and ecosystems are currently inadequate (Piraino *et al.*, 2002). Identification of foraging hotspots for predators, and the consideration of boundaries determined by oceanographic processes, are therefore pivotal to addressing the preservation of marine ecosystems. Many policies to date have been designed to protect cetaceans and seabirds. Among these, the Habitat Directive and the Birds Directive oblige all European member states to select, designate, and protect sites that support certain natural habitats or species as Special Areas of Conservation (SACs) and Special Protection Areas (SPAs, specifically aimed to the conservation of vulnerable birds species), with the aim of creating a network of protected areas across the European Union known as Natura 2000 (http://ec.europa.eu/environment/nature/natura2000/index_en.htm) (European

Commission 2008, 2009). However, the management of organisms that exhibit large spatial and temporal changes in distribution, such as cetaceans and seabirds, requires knowledge of their distributions and habitat preferences.

In this study, we conducted visual surveys in the central Tyrrhenian Sea between June 2013 and October 2014 with the aim of filling the knowledge gap regarding the presence of top predators in this coastal area. Sightings were analysed by geostatistical kriging, a technique previously used to obtain distribution maps of marine mammals (Alessi & Fiori, 2014), to evaluate the areas with the highest occurrences (high-presence areas) of bottlenose dolphins (*Tursiops truncatus*) (Montagu, 1821) and the seabirds Audouin's gull (*Larus audouinii*) (Payraudeau, 1826), Yellow-legged gull (*Larus michahellis*) (Nauman, 1840), Yelkouan shearwater (*Puffinus yelkouan*) (Acerbi, 1827) and Cory's shearwater (*Calonectris diomedea*) (Scopoli, 1769). The underlying assumption was that high-presence areas are of fundamental importance within a given zone, supporting non-random associations of megafauna species. We also aimed to highlight the possible relationships between the presence of the target species and environmental features, in order to provide tools that could be used to predict the distribution of top-level predators at unobserved sites (Franklin, 2009).

MATERIALS AND METHODS

Data collection

The study area was located between Civitavecchia and Montalto di Castro along the Central Tyrrhenian coast. This area extends from 42.00° to 42.40°N and 11.20° to 11.80°E, and covers an area of 580 km². The continental shelf extends for 20 km from the coast (Figure 1).

Data were collected between June 2013 and October 2014 using eight linear transects covering 513 km, involving 60 h of observations (Figure 2). Observations were made from a 10-m-long sailing boat, equipped with an 28-horsepower inboard engine. A linear systematic sampling design at an average speed of 6 knots was followed, and the transects

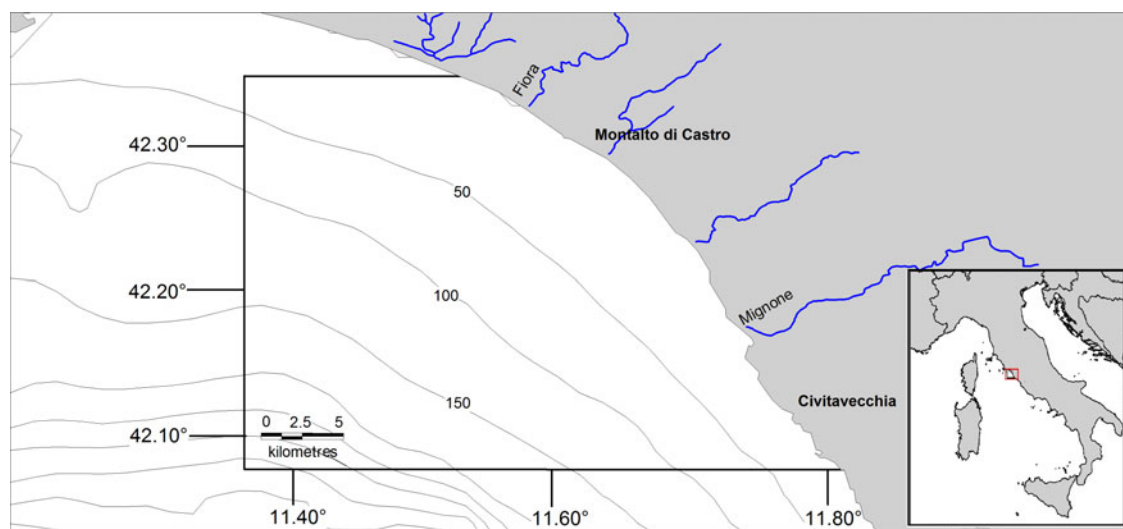


Fig. 1. Map of the study area showing Fiora and Mignone river basins (blue lines) and 50-m isobaths (black lines).

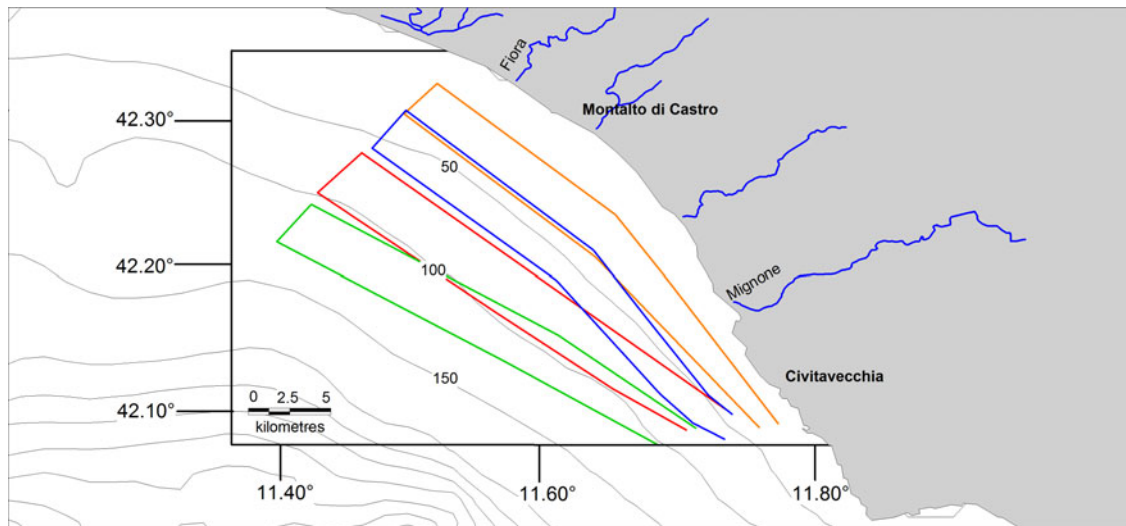


Fig. 2. Sampling design. Four linear transects at different depths are shown, each transect was followed twice.

were designed to cover the greatest possible distance in a day. All surveys were carried out in good sea conditions (Beaufort scale ≤ 3) and with good visibility. Survey effort was concentrated within water up to 150 m deep. Three trained observers scanned 360° around the boat, with and without binoculars. The real-time position of the vessel was recorded by GPS every 4 s. The geographic positions of bottlenose dolphins and seabirds were recorded when sighted, and the numbers of individuals of each species were counted (expressed as minimum, maximum and best-estimation number, the latter indicating the most likely number of individuals). Only seabirds exhibiting foraging behaviours were included in the analysis. Individuals were considered to be foraging when at least one individual was seen in contact with food, and other individuals were flying around at close distance. Seabirds in sustained flight were excluded from the analysis. Dolphin feeding behaviour was defined according to Bearzi *et al.* (1999): a dolphin feeding session was characterized by dives lasting 3–5 min, and occasionally up to 8 min. It was not possible to estimate the number of fish in a baitball, and only their geographic positions were therefore recorded.

Data analysis

KRIGING. Kriging is a technique initially developed for the earth sciences and subsequently applied in different scientific fields for non-stationary spatial and temporal variables, including in medicine (epidemic diffusion) (Carrat & Valleron 1992), physics (sound propagation) (Baume *et al.*, 2009) and biology. In biological contexts, kriging has been applied to define species densities and identify high-presence and high-use areas (Steffens, 1993; García & Dawson, 2003; Rufino *et al.*, 2005; Monestiez *et al.*, 2006; Alessi & Fiori, 2014). This technique can be applied to all species that do not exhibit static behaviour, including cetaceans and seabirds, and can be used to obtain accurate and unbiased high-resolution maps (Alessi & Fiori, 2014). Bottlenose dolphins and the seabird species considered in this study have similar prey preferences, in terms of both species and size, e.g. juvenile *S. pilchardus* and *M. merluccius* (Blanco *et al.*, 2001; Astruc, 2005; Bourgeois *et al.*, 2011). We also applied the kriging

approach to mapping baitballs at the surface, in order to visualize areas of potential-prey presence. The resulting distribution maps for the target species and potential prey species were superimposed to detect areas of overlap that may help to identify highly productive coastal areas with high biodiversity, able to support the simultaneous presence of several top predators feeding on the same prey stocks.

We used the approach described by Alessi & Fiori (2014). The study area was superimposed on a grid with $1 \times 1 \text{ km}^2$ cells using Mapinfo GIS software. The coordinates (latitude/longitude) of the centre of each cell were extracted and the numbers of sightings of bottlenose dolphins, seabirds (without distinction of species) and baitballs were determined, resulting in three datasets. In contrast to Alessi & Fiori (2014), we used the number of sightings instead of encounter rate, considering that the sampling effort was uniform throughout the study area. Datasets were analysed separately by ordinary kriging using Surfer[®] software (Golden Software Incorporation, Golden, CO, USA), which automatically generates an experimental variogram. Kriging is a generalized least-square regression technique that allows description of the spatial prediction and provides a measure of predictive error (Gan *et al.*, 2010). The ordinary kriging formula can be expressed as follows (ESRI, 2001):

$$Z(s) = \mu + \varepsilon(s)$$

where $s = (X, Y)$ is a location and $Z(s)$ is the number of sightings at that location. The model is based on a constant mean μ for the data and random errors $\varepsilon(s)$ with spatial dependence. Kriging is an exact interpolator based on the weighted average of the observed data to estimate $Z(s)$ function, where $s(X, Y)$ is a generic point of plain to estimate, from a number of known values, close together. The interpolation formula can be expressed as follows:

$$\hat{z}(s_o) = \sum_{i=1}^N \lambda_i Z(s_i)$$

where (s_o) is the measured number of sightings at the i^{th} location; λ_i is the weight of the measured value $Z(s_i)$ at the

location; s_0 is the prediction location; and n is the number of measurements used for the estimate (Alessi & Fiori, 2014).

Surfer generates an experimental variogram using an input dataset with geographic coordinates corresponding to the position value of the variable z . The variogram plays an important role in the appearance and behaviour of the resulting model (Gringarten & Deutsch, 2001). In this study, we chose the model type visually and assessed it statistically using cross-validation statistics, as described by Alessi & Fiori (2014). We checked the accuracy of the model by evaluating the mean error (ME), the goodness of the prediction method (precision) by the root mean square error (RMSE), and compared predicted and real errors by the mean squared deviation ratio of residuals with kriging variance (MSDR).

The chosen models were used to create an image map in Surfer. The raster image was subsequently georeferenced using Mapinfo Professional using the data limits supplied by Surfer. The extent of habitat overlap between bottlenose dolphins and seabirds was calculated by superimposing their computed presence areas. The presence of baitballs generated by the kriging method was also added to identify the distribution and extent of biodiversity and productivity habitat hotspots.

Habitat preferences

Species–habitat relations were tested using chi-squared analysis, as described by Ingram & Rogan (2002). The values of maximum depth, slope, seabed type and distance from the shore were determined for each grid cell created using GIS Mapinfo. We considered six depth classes and the cells were classified accordingly as: 0–20 m, 21–40 m, 41–60 m, 61–80 m, 81–100 m or 101–150 m (Figure 3). Slope was calculated based on the difference between maximum and minimum depth, and assigned to one of seven classes: 0, 1–5 m, 6–10 m, 11–15 m, 16–20 m, 21–25 m and 26–30 m

(Figure 4). We downloaded the data related to the type of substrate from the catalogue EUSeaMap (<http://jncc.defra.gov.uk/euseamap>) (Figure 5). Cartography was subsequently georeferenced using Mapinfo. The distance from the shore for the centre of each cell was calculated using the MapInfo tool 'Distance Calculator'. For each category, the total number of sightings of a single species and of baitballs was calculated as the sum of the number of sightings for cells with the same range of maximum depth, slope, seabed type and distance from the shore. For each parameter, the distribution of sightings (observed distribution) within the various classes was compared with a uniform distribution (expected distribution).

RESULTS

Sightings

During the transects, we made eight sightings of bottlenose dolphin, 47 of Yellow-legged gull, six of Audouin's gull, 38 of Yelkouan shearwater, 16 of Cory's shearwater and 24 baitballs. Group sizes differed among species (Table 1). The number of sightings of seabirds only refers to foraging seabirds. However, although dolphins in three of the eight sightings were not foraging, we included all eight sightings because of the small sample size.

Presence areas

We calculated the presence areas for each species and for baitballs. All the resulting variograms reached a limit value as the lag distance increased, indicating that the function represented by the variogram was stationary or near stationary. We fitted the variograms using exponential and linear models in all five cases. In every case the two models were

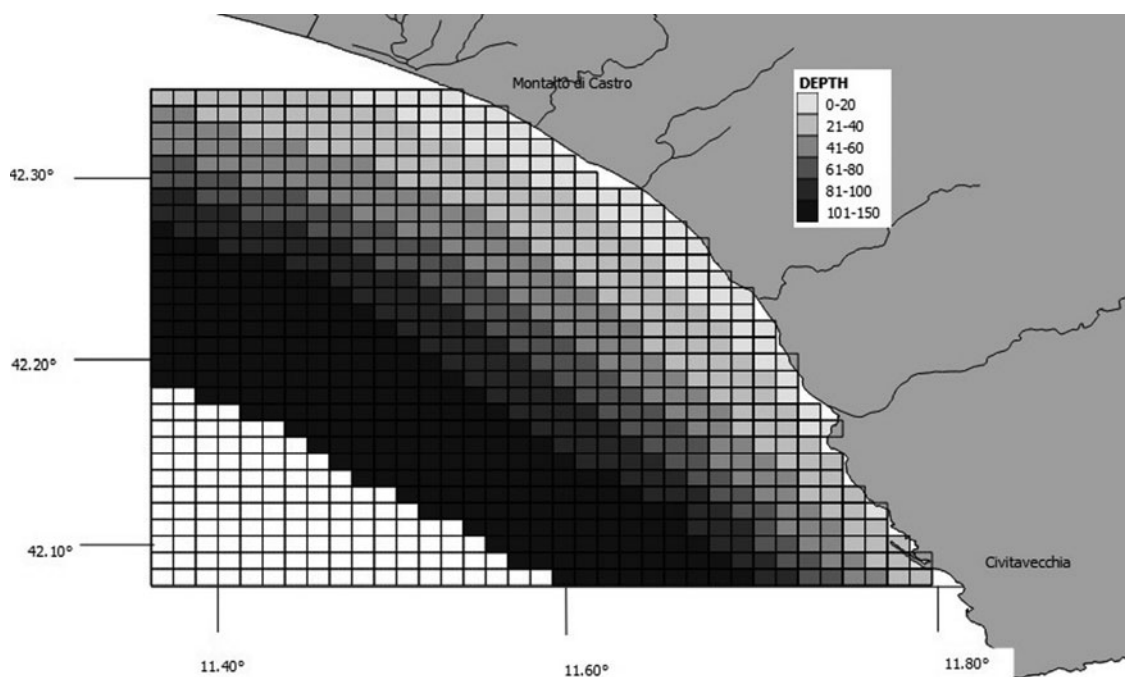


Fig. 3. Map showing grid cells and corresponding bathymetric bands.

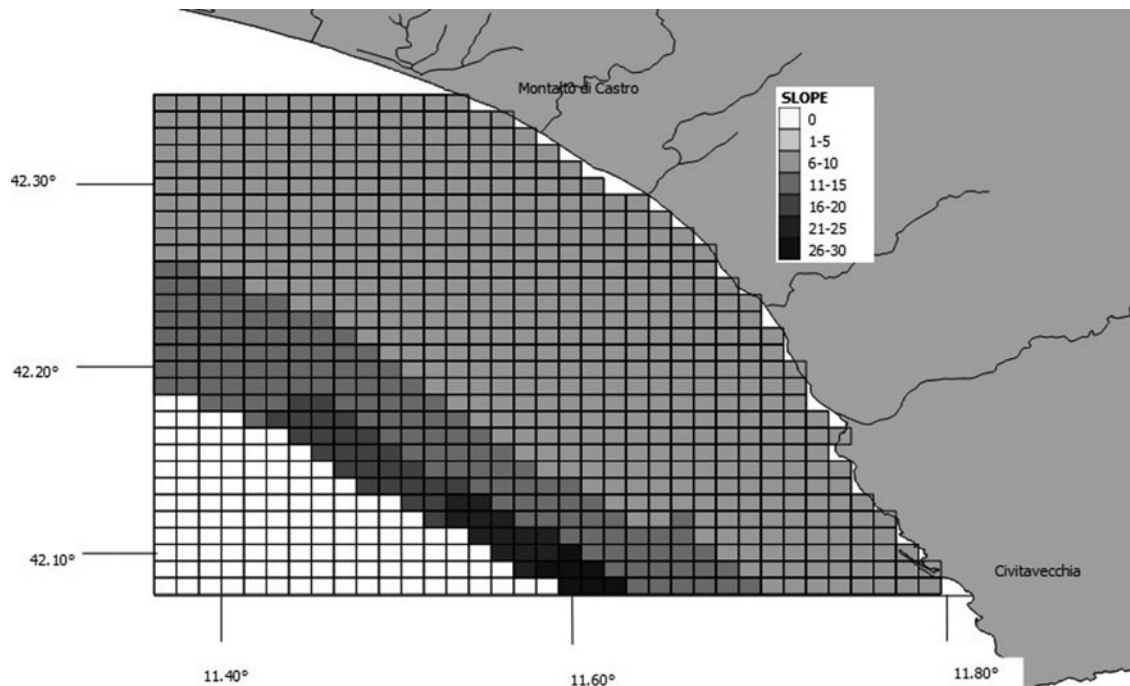


Fig. 4. Map showing grid cells and corresponding slope classes.

combined into a single model to generate the best fit for the data (Figure 6). The results of cross-validation analysis are shown in Table 2. All the results indicated that the model was valid and could thus be used to construct the map (Figure 7). The bottlenose dolphin map showed a well-defined presence in front of Montalto di Castro, in waters of 20–70 m depth, accounting for an area of 276 km². Yellow-legged gulls were almost uniformly distributed, but were most frequent in

front of Montalto di Castro and the harbour at Civitavecchia. The map for Audouin's gull showed two well-defined presence areas with a total extent of 67 km², in waters of 10–40 m depth. The Yelkouan shearwater map also showed two well-defined presence areas, with the main area in front of Montalto di Castro, at a depth of 40–150 m, covering 174 km². Cory's shearwaters showed a larger presence area (268 km²) extending parallel to the coast over the whole

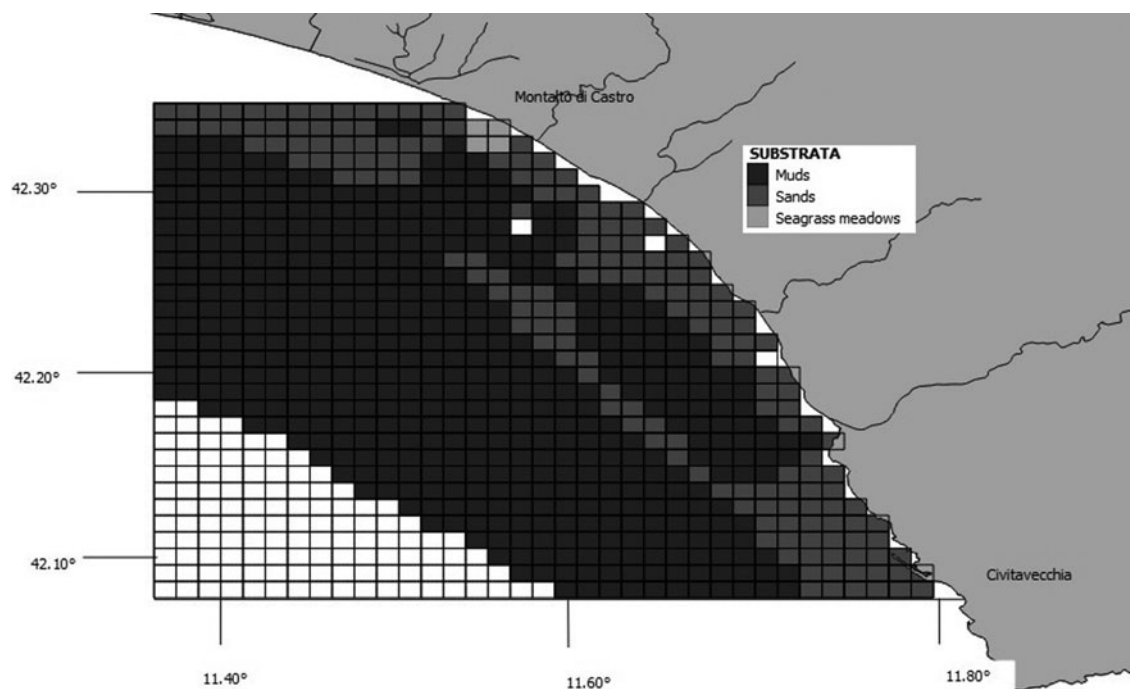


Fig. 5. Map showing grid cells and distribution of substrata. Copyright JNCC. EUSeaMap: <http://www.jncc.gov.uk/EUSeaMap>. Information contained here has been derived from EUSeaMap Consortium webGIS data (<http://www.jncc.gov.uk/page-5040>) which is made available under the pilot project for the European Marine Observation Data Network (EMODnet), funded by the European Commission's Directorate-General for Maritime Affairs and Fisheries (DG MARE).

Table 1. Group size of each study species. Median \pm 50 percentile are listed.

Species	Group size	
	Median	\pm 50 percentile
<i>Tursiops truncatus</i>	6.35	5.5
<i>Larus audouinii</i>	16	9
<i>Larus michahellis</i>	10	2
<i>Puffinus yelkouan</i>	6	2
<i>Calonectris diomedea</i>	2	1

study area, with a depth range of 50–150 m. The map for baitballs showed that they were patchily distributed over a total area of 320 km², with the highest occurrence in front of Civitavecchia and at the mouth of the Fiora river. The computed areas for dolphins, seabirds and baitballs overlapped by 57%, while those for dolphins and baitballs overlapped by up to 61% (Figure 8).

Habitat preferences

Bottlenose dolphins were more frequently associated with muddy substrates and gentle slopes (6–10 m) (Table 3).

Yellow-legged gulls, Yelkouan shearwaters and Cory's shearwaters also foraged significantly more frequently over muddy substrates. However, the seabird species appeared to be affected differently by depth: Yellow-legged gulls and shearwaters mostly ranged from 100–150 m depth, while Audouin's gulls preferred waters of 20–40 m depth. Moreover, all seabirds species were associated with seabed slopes of 6–10 m (Table 3). Only Yelkouan and Cory's shearwaters were significantly affected by distance from the shore, being observed at 10–20 km. Baitballs were significantly more frequent at depths of 20–40 m, and over gentle slopes (6–10 m) and muddy substrates.

DISCUSSION

Assessing the extent of spatial overlap between marine top predator habitats allows us to understand the distribution and locations of local biodiversity and productivity hotspots. In the current study, the baitball map showed two well-defined areas of presence, one of which was located in front of Sant'Agostino village, coincident with an offshore fish farm. Residual food from fish-farm cages is known to attract wild fish species (Díaz López *et al.*, 2005) such as grey mullet (*Mugil*

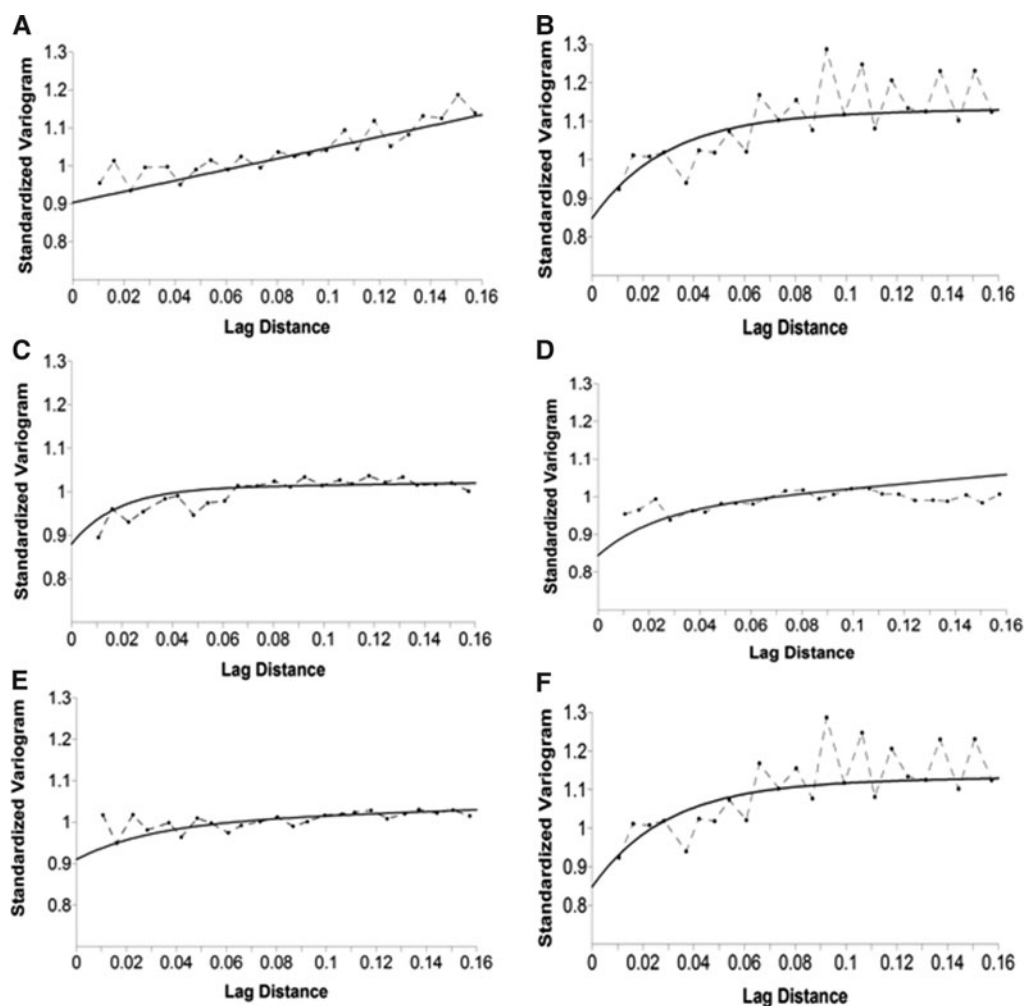


Fig. 6. Empirical variograms of species datasets (dashed line and dot) and fitted curve (black line) for (A) bottlenose dolphin; (B) Audouin's gull; (C) Cory's shearwater; (D) Yellow-legged gull; (E) Yelkouan shearwater; and (F) baitballs.

Table 2. Cross-validation statistics of bottlenose dolphins, seabirds and baitball datasets: Mean Error of Residual Z (ME) must be close to zero indicating the accuracy of the model; Root Mean Square Error of residual (RMSE) must be close to zero to confirm the precision of the model; and Mean Squared Deviation Ratio of residuals (MSDR) must be close to one to show that the prediction model is unbiased. If the RMSE value is close the average SE value, the Z values were predicted correctly (with high accuracy).

	ME		RMSE		MSDR		Average SE	
	Est. Z	Res. Z	Est. Z	Res. Z	Est. Z	Res. Z	Est. Z	Res. Z
Bottlenose dolphins	0.01139	0.00015	0.02149	0.10539	1.39042	1.00000	0.01823	0.10539
Yellow-legged gull	0.05891	0.00023	0.08532	0.24289	1.91111	1.00000	0.06171	0.24289
Audouin's gull	0.00759	0.00009	0.02212	0.08643	1.13338	1.00000	0.02078	0.08643
Manx shearwater	0.02011	0.00013	0.03433	0.15751	1.52210	1.00000	0.02783	0.15751
Cory's shearwater	0.04757	0.00013	0.07769	0.22963	1.60011	1.00000	0.06141	0.22963
Baitballs	0.020346	0.00037	0.03023	0.14148	1.82801	1.00000	0.02235	0.14148

cephalus), salema (*Sarpa salpa*) and pilchards (*S. pilchardus*). Notably, the overlap between dolphin, seabird and baitball areas covered approximately 295 km², including an overlap between dolphin and baitball areas of 61%. This suggests that the area of overlap may represent an important feeding spot for bottlenose dolphins, even though this species can also easily access other deep-living prey items that are not visible from the surface. Compared with dolphins, seabirds rely more on prey near the water surface. The areas mapped for Cory's shearwater and Yellow-legged gull almost totally covered the areas for baitballs. Further, seabird areas appeared to extend between the two main baitball areas, suggesting the presence of an ecological corridor between two foraging sites.

Dolphin and seabird foraging were most frequent at the mouths of the two most important river basins in the area, the Fiora and Mignone. This is in agreement with previous studies that documented high numbers of bottlenose dolphins

at the mouths of rivers, such as the Magra river (Ligurian Sea) (Alessi & Fiori, 2014), the Shannon estuary (Ireland's west coast) (Ingram & Rogan, 2002) and the Lagamar Delta (Brazil) (Santos *et al.*, 2010). Rivers play an important role, at a small scale, in affecting water temperature and salinity values and in defining sediment distribution. Nutrient loads from rivers, together with local variations in temperature, can produce algal blooms and subsequent secondary production processes, which can in turn sustain animals at higher trophic levels.

The results of this study highlight the presence of concentrations of species at various levels of the trophic chain, including the coexistence of different marine top predators. As reported by Ingram & Rogan (2002) for other locations, the identification of foraging sites for top predators is fundamental in defining critical areas for the implementation of specific protection measures, while also recognizing that

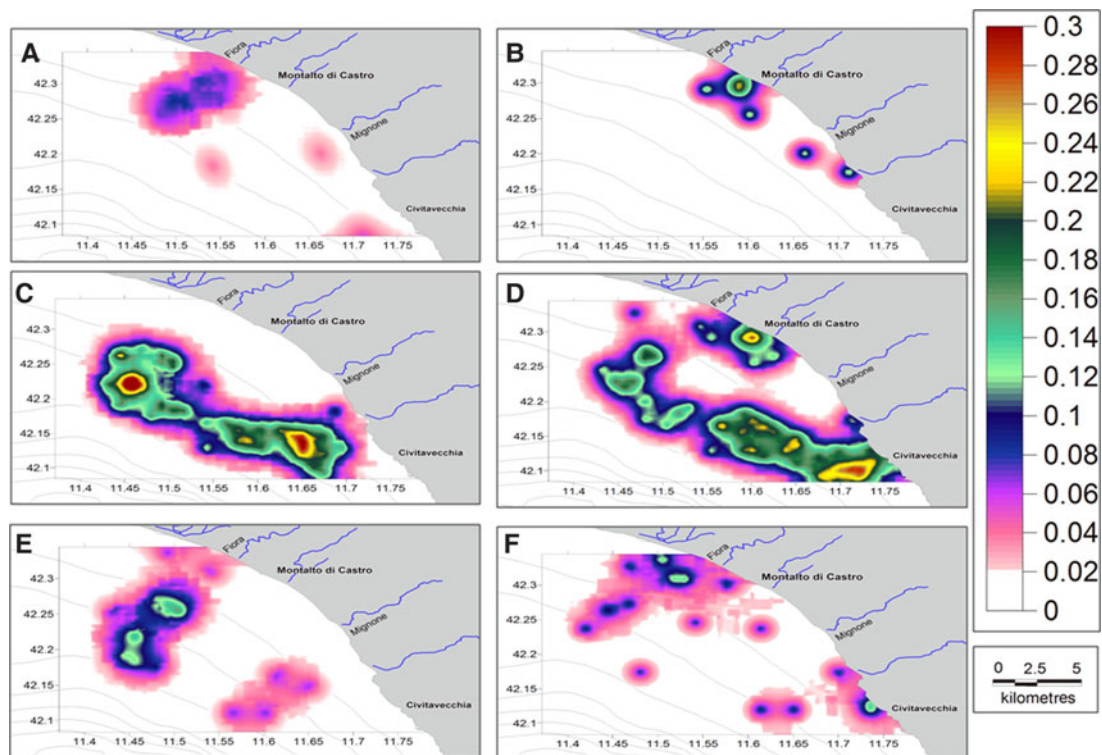


Fig. 7. Map showing the areas of species presence obtained by kriging analysis. The colour scale shows different probabilities of encounters with (A) bottlenose dolphin; (B) Audouin's gull; (C) Cory's shearwater; (D) Yellow-legged gull; (E) Yelkouan shearwater; and (F) baitballs.

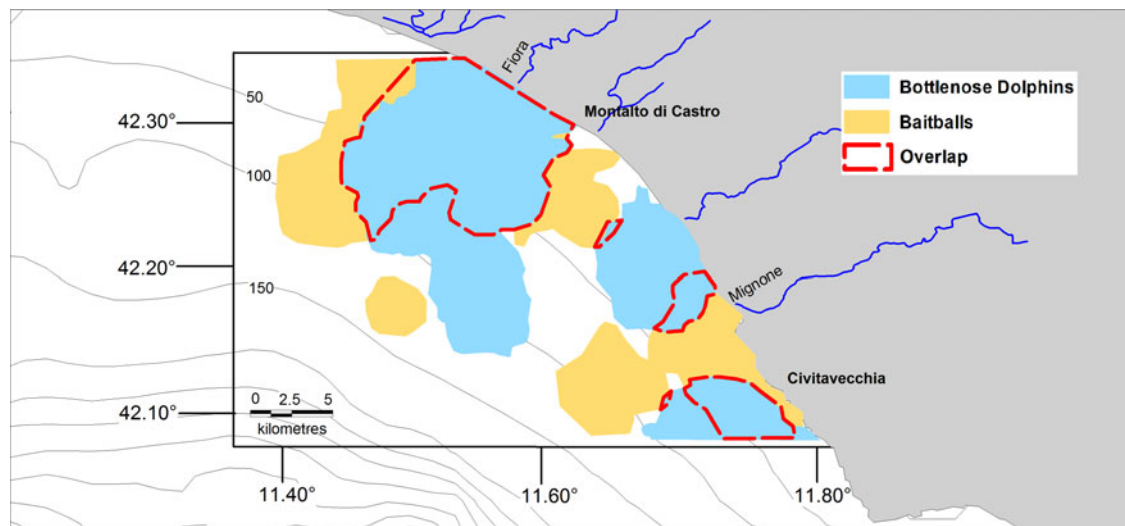


Fig. 8. Map showing overlap between baitball (yellow) and bottlenose dolphin areas (light blue). The river basins are shown (blue lines).

these areas may represent important foraging sites for breeding seabirds, not far from their nesting sites (Cecere *et al.*, 2014). Shearwater foraging and breeding areas were shown to be closely related at Mediterranean colonies (Linosa island, La Maddalena and Tuscan Archipelagos), given that the period of parental care lasts for about 3 months (Burger, 1980), and the presence of suitable foraging areas is crucial for offspring survival. Consequently, the depletion of foraging areas would force adults to seek new nesting areas, or lead to the local extinction of breeding colonies (Cecere *et al.*, 2014).

The areas more frequented by the study species were associated with different environmental characteristics. The distribution of bottlenose dolphins was affected by the presence of a muddy seabed, while the other variables had no significant influence. This might be an indirect effect of hake distribution, which is also associated with a muddy seabed (Sinopoli *et al.*, 2012) and is the most abundant prey item of bottlenose dolphins in terms of biomass, based on an analysis of stomach contents (Astruc, 2005). However, the small sample size means that further studies are needed to confirm these preliminary results.

Recent studies have used predictive models to estimate bottlenose dolphin distributions, e.g. Generalized Additive Models and Generalized Linear Models, using depth, slope and distance from the coast as static variables, and including other dynamic factors such as sea surface temperature (SST), sea surface salinity (SSS) and chlorophyll *a* (Canadas *et al.*, 2002; Azzolin *et al.*, 2011; Arcangeli *et al.*, 2013).

These studies showed that bottlenose dolphins displayed heterogeneous habitat choices in different areas. Unfortunately, we did not have access to high-resolution data for SSS, SST and chlorophyll *a* for our small coastal study area, and we were therefore only able to analyse the static variables. Our study identified seabed type and slope as the only significant factors affecting bottlenose dolphin distribution. Regarding seabirds, Yellow-legged gulls and shearwaters were associated with a specific depth range (50–150 m) and muddy substrate, in accord with the ecological features of these species as generalist feeders on pelagic fish and some cephalopods that inhabit deep, muddy seabeds (Quetglas *et al.*, 1998). The presence of Audouin's gulls was not affected by seabed type, but they preferred gentle slope (6–10 m) and 20–40 m depth. Audouin's gulls have a very selective diet, feeding on clupeids known to be present within this depth range (Oro, 1998). Notably, all the parameters that affected baitball distribution also affected most of the study species, suggesting that the distribution of top predators was directly linked to both the presence and distribution of the baitballs, as well as to the geomorphological features. The distribution of top predators has been shown to reflect prey abundance, especially when the distributions of more than one top predator overlap (Ballance *et al.*, 1997). Because seabirds and dolphins are highly mobile species, they are able to choose highly productive areas (Ballance *et al.*, 1997). Furthermore, seabirds and cetaceans share several features that affect their relationships with oceanographic characteristics and water masses.

Table 3. Results of χ^2 test with significance level of 5% ($P = 0.05$) highlighted in bold.

Species	Max depth		Slope		Seabed type		Distance from the shore	
	χ^2	<i>P</i>	χ^2	<i>P</i>	χ^2	<i>P</i>	χ^2	<i>P</i>
<i>Tursiops truncatus</i>	3.666	0.549	27.000	0.000	27.000	0.033	0.666	0.717
<i>Larus audouinii</i>	20.000	0.000	15.000	0.020	6.000	0.059	1.000	0.607
<i>Larus michahellis</i>	16.957	0.000	124.426	0.000	65.766	0.000	2.213	0.331
<i>Puffinus yelkouan</i>	50.737	0.000	117.105	0.000	106.211	0.000	8.579	0.014
<i>Calonectris diomedea</i>	19.250	0.011	70.625	0.000	48.000	0.000	9.125	0.010
Baitballs	11.750	0.006	33.875	0.000	24.000	0.003	4.625	0.099

Although the mechanisms responsible for species–habitat associations are not completely understood, it is known that the relationships between seabirds, cetaceans and environmental characteristics may be indirect, likely mediated by the responses of their prey to these environmental features (Ballance *et al.*, 2006).

Previous studies have indicated that marine mammals and seabirds not only use a small set of locations but also a limited range of tidal conditions, within which they capture their prey (Johnston *et al.*, 2005; Bertrand *et al.*, 2008; Stevick *et al.*, 2008). Most fish that are prey for cetaceans are, in turn, also predators and their behaviour thus switches between escape from predators and their own feeding needs (Scott *et al.*, 2010). The study of top predators and their relationships can thus help us to understand the statuses of populations at different trophic levels, and consequently to make inferences at the ecosystem level regarding the protection of ecologically relevant areas. From a conservation perspective, the study of static habitat features could provide an initial basis for identifying potentially important areas of coastal systems that deserve protection through the designation of wildlife reserves (Yen *et al.*, 2004).

The results of kriging analysis appeared to be consistent with the ecological characteristics of the study species and with previous studies. This approach, applied at a local level in the current study, thus seems to represent a promising tool for addressing the conservation issues of Mediterranean coastal marine ecosystems in terms of larger-scale surveys with bigger sample sizes.

ACKNOWLEDGEMENTS

This work formed part of a Master's thesis in Nature Conservation carried out by Valentina Cafaro. We are grateful to Marco Marcelli for support with data analysis and thesis co-supervision, to Enzo Savo and Emiliano De Santis for help in field identification of seabirds during some transects. We also thank Carlo Catoni for useful information on shearwater movement ecology. The authors are grateful to all the people involved in the surveys, in particular to Paolo Cipriani, Alessandro Carlini, Riccardo Vela, Anastasia Pintavalle and Sara Canensi.

CONFLICT OF INTEREST

None.

REFERENCES

- Alessi J. and Fiori C. (2014) From science to policy – a geostatistical approach to identifying potential areas for cetacean conservation: a case study of bottlenose dolphins in the Pelagos sanctuary (Mediterranean Sea). *Journal of Coastal Conservation* 18, 1–10.
- Alonso H., Granadeiro J.P., Paiva V.H., Dias A.S., Ramos J.A. and Catry P. (2012) Parent offspring dietary segregation of Cory's shearwaters breeding in contrasting environments. *Marine Biology* 159, 1197–1207.
- Arcangeli A., Marini L. and Crosti R. (2013) Changes in cetacean presence, relative abundance and distribution over 20 years along a trans-regional fixed line transect in the Central Tyrrhenian Sea. *Marine Ecology* 34, 112–121.
- Astruc G. (2005) *Exploitation des chaînes trophiques marines de Méditerranée par les populations de cétacés*. Ecole Pratique des Hautes Etudes, Master thesis, Montpellier, France.
- Azzolin M., Galli A., Giacomini C., Giovannini A., Ronchetti F. and Papale E. (2011) Assessing the influence of environmental and anthropogenic factors on distribution of bottlenose and striped dolphin in Ionian Greece. *Biologia Marina Mediterranea* 18, 172–173.
- Ballance L.T., Pitman R.L. and Reilly S.B. (1997) Seabird community structure along a productivity gradient: importance of competition and energetic constraint. *Ecology* 78, 1502–1518.
- Ballance L.T., Pitman R.L. and Fiedler P.C. (2006) Oceanographic influences on seabirds and cetaceans of the eastern tropical Pacific: a review. *Progress in Oceanography* 69, 360–390.
- Baume O., Gauvreau B., Bérengier M., Junker F., Wackernagel H. and Chilès J.P. (2009) Geostatistical modeling of sound propagation: principles and a field application experiment. *Journal of the Acoustical Society of America* 126, 2894–2904.
- Baumgartner M.F., Mullin K.D., May L.N. and Leming T.D. (2001) Cetacean habitats in the northern Gulf of Mexico. *Fisheries Bulletin* 99, 219–239.
- Bearzi G., Politi E. and Notarbartolo di Sciarra G. (1999) Diurnal behaviour of free-ranging bottlenose dolphins in the Kvarneric (northern Adriatic Sea). *Marine Mammal Science* 15, 1065–1097.
- Bertrand A., Gerlotto F., Bertrand S., Gutierrez M. *et al.* (2008) Schooling behaviour and environmental forcing in relation to anchovy distribution: an analysis across multiple spatial scales. *Progress in Oceanography* 79, 264–177.
- Blanco C., Salomon O. and Raga J.A. (2001) Diet of the bottlenose dolphin (*Tursiops truncatus*) in the western Mediterranean Sea. *Journal of the Marine Biological Association of the United Kingdom* 81, 1053–1058.
- Bourgeois K., Vorenger J., Faulquier L., Legrand J. and Vidal E. (2011) Diet and contamination of the Yelkouan Shearwater *Puffinus yelkouan* in the Hyères archipelago, Mediterranean Basin, France. *Journal of Ornithology* 152, 947–953.
- Bost C.A., Cotté C., Bailleul F., Cherel Y., Charrassin J.B., Guinet C., Ainley D.G. and Weimerskirch H. (2009) The importance of oceanographic fronts to marine birds and mammals of the southern oceans. *Journal of Marine System* 78, 63–376.
- Briggs K.T., Tyler W.B., Lewis D.B. and Carlson D.R. (1987) Bird communities at sea off California 1975 to 1983. *Studies in Avian Biology* 11, 1–74.
- Burger J. (1980) The transition to independence and post fledging parental care in seabirds. In Burger J., Olla B. and Winn H. (eds) *Behavior of marine organisms. Perspectives in research, volume 4: marine birds*. New York, NY: Plenum Press, pp. 367–447.
- Canadas A., Sagarminaga R. and Garcia-Tiscara S. (2002) Cetacean distribution related with depth and slope in the Mediterranean waters off southern Spain. *Deep Sea Research Part I* 49, 2053–2073.
- Carrat F. and Valleron A.J. (1992) Epidemiologic mapping using the 'Kriging' method: application to an influenza-like epidemic in France. *American Journal of Epidemiology* 135, 1293–1300.
- Cecere J.G., Gaibani G. and Imperio S. (2014) Effects of environmental variability and offspring growth on the movement ecology of breeding Scopoli's shearwater *Calonectris diomedea*. *Current Zoology* 60, 622–630.
- Croll D.A., Tershy B.R., Hewitt R.P., Demer D., Fiedler P.C., Smith S.E., Armstrong W., Popp J.M., Kiekhefer T., Lopez V.R. and Urban J. (1998) An integrated approach to the foraging ecology of marine birds and mammals. *Deep-Sea Research II* 45, 1353–1371.

- Díaz López B., Marini L. and Polo F. (2005) The impact of a fish farm on a bottlenose dolphin population in the Mediterranean Sea. *Thalassas* 21, 53–58.
- ESRI (2001) *Using ArcGIS geostatistical analyst Program*. Redlands, CA: ESRI Press.
- European Commission (2008) Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). *Official Journal of the European Union* L164, 19.
- European Commission (2009) Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds. *Official Journal of the European Union* L20, 7.
- Franklin J. (2009) *Mapping species distributions: spatial inference and prediction*. Cambridge: Cambridge University Press.
- Franks P.J.S. (1992) Sink or swim: accumulation of biomass at fronts. *Marine Ecology Progress Series* 82, 1–12.
- Gan W., Chen X., Cai X., Zhang J., Feng L. and Xie X. (2010) Spatial interpolation of precipitation considering geographic and topographic influences – A case study in the Poyang Lake Watershed, China. In *Geoscience and Remote Sensing Symposium (IGARSS)*, 2010 I.E. International, pp. 3972–3975.
- García C. and Dawson S.M. (2003) Distribution of pantropical spotted dolphins in Pacific coastal waters of Panama. *Latin American Journal of Aquatic Mammals* 2, 29–38.
- Gringarten E. and Deutsch C.V. (2001) Teacher's aide: variogram interpretation and modeling. *Journal of the International Association for Mathematical Geology* 33, 507–534.
- Hooker S.K. and Gerber L.R. (2004) Marine reserves as a tool for ecosystem based management: the potential importance of megafauna. *Bioscience* 54, 27–39.
- Hunt G.L. Jr., Coyle K.O., Hoffman S., Decker M.B. and Flint E.N. (1996) Foraging ecology of the short-tailed shearwaters near the Pribilof Islands, Bering Sea. *Marine Ecology Progress Series* 141, 1–11.
- Hunt G.L. Jr., Harrison N.M. and Cooney R.T. (1990) The influence of hydrographic structure and prey abundance on foraging of least auklets. *Studies of Avian Biology* 14, 7–22.
- Hunt G.L., Mehlum F., Russel R.W., Irons D., Decker M.B. and Becker P.H. (1999) Physical processes, prey abundance, and the foraging ecology of seabirds. In Adams N.J. and Slotow R.H. (eds) *22nd International Ornithological Congress*. Durban: BirdLife South Africa, pp. 2040–2056.
- Hunt G.L. Jr., Russel R.W., Coyle K.O. and Weingartner T. (1998) Comparative foraging ecology of planktivorous auklets in relation to ocean physics and prey availability. *Marine Ecology Progress Series* 167, 241–259.
- Hunt G.L. Jr. and Schneider D.C. (1987) Scale-dependent processes in the physical and biological environment of marine birds. In Croxall J.P. (ed.) *Seabirds: feeding biology and role in marine ecosystems*. Cambridge: Cambridge University Press, pp. 7–41.
- Hyrenbach K.D. and Veit R.R. (2003) Ocean warming and seabird assemblages of the California Current System (1987–1998): response at multiple temporal scales. *Deep-Sea Research II* 50, 2537–2565.
- Ingram S.N. and Rogan E. (2002) Identifying critical areas and habitat preferences of bottlenose dolphins *Tursiops truncatus*. *Marine Ecology Progress Series* 244, 247–255.
- Jaquet N. (1996) How spatial and temporal scales influence understanding of sperm whale distribution – a review. *Mammal Reviews* 26, 51–65.
- Jaquet N. and Whitehead H. (1996) Scale-dependent correlation of sperm whale distribution with environmental features and productivity in the south Pacific. *Marine Ecology Progress Series* 135, 1–9.
- Johnston D.W., Westgate A.J. and Read A.J. (2005) Effects of fine-scale oceanographic features on the distribution and movements of harbour porpoises *Phocoena phocoena* in the Bay of Fundy. *Marine Ecology Progress Series* 295, 279–293.
- Monestiez P., Dubroca L., Bonnin E., Durbec J.P. and Guinet C. (2006) Geostatistical modelling of spatial distribution of *Balaenoptera physalus* in the Northwestern Mediterranean Sea from sparse count data and heterogeneous observation efforts. *Ecological Modelling* 193, 615–628.
- Oro D. (1998) Audouin's gull *Larus audouinii*. In Ogilvie M.A. (ed.) *The birds of the Western Palearctic* updated, volume 2. Oxford: Oxford University Press, pp. 47–61.
- Petry M.V. and Krüger L. (2009) Diet and ingestion of synthetics by Cory's shearwater *Calonectris diomedea* off southern Brazil. *Journal of Ornithology* 150, 601–606.
- Piraino S., Fanelli G. and Boero F. (2002) Variability of species' roles in marine communities: change of paradigms for conservation priorities. *Marine Biology* 140, 1067–1074.
- Quetglas A., Alemany F., Carbonell A., Merella P. and Sánchez P. (1998) Some aspects of the biology of *Todarodea sagittatus* (Cephalopoda: Ommastrephidae) from the Balearic Sea (western Mediterranean). *Scientia Marina* 62, 73–82.
- Ribic C.A. and Ainley D.G. (1997) The relationships of seabird assemblages to physical habitat features in Pacific equatorial waters during spring 1984–1991. *ICES Journal of Marine Science* 54, 593–599.
- Rufino M.M., Maynou F., Abelló P., Gil de Sola L. and Yule A.B. (2005) The effect of methodological options on geostatistical modeling of animal distribution: a case study with *Liocarcinus depurator* (Crustacea: Identifying areas for cetacean conservation through geostatistics Brachyura) trawl survey data. *Fisheries Research* 76, 252–265.
- Witt H.H., Stempel N., De Juana E. and Varela J.M. (1982) Geschlechtsunterschiede bei Korallenmowe (*Larus audouinii*) nach messbaren Merkmalen. *Die Vogelwarte* 31, 457–460.
- Santos M.C.O., Oshima J.E.F., Pacífico E.S. and Silva E. (2010) Feeding associations between Guiana dolphins, *Sotalia guianensis* (Van Béneden, 1864) and seabirds in the Lagamar estuary, Brazil. *Brazilian Journal of Biology* 70, 9–17.
- Schneider D.C. (1991) The role of fluid-dynamics in the ecology of marine birds. *Oceanography and Marine Biology Annual Review* 29, 487–521.
- Schoenherr J.L. (1991) Blue whales feeding on high concentrations of euphausiids around Monterey Submarine Canyon. *Canadian Journal of Zoology* 69, 583–594.
- Scott B.E., Sharples J., Ross O.N., Wang J., Pierce G.J. and Camphuysen C.J. (2010) Sub-surface hotspots in shallow seas: fine-scale limited locations of top predator foraging habitat indicated by tidal mixing and sub-surface chlorophyll. *Marine Ecology Progress Series* 408, 207–226.
- Sinopoli M., Fanelli E., D'Anna G., Badalamenti F. and Pipitone C. (2012) Assessing the effects of trawling ban on diet and trophic level of hake, *Merluccius merluccius*, in the southern Tyrrhenian Sea. *Scientia Marina* 76, 677–690.
- Spear L.B., Balance L.T. and Ainley D.G. (2001) Response of seabirds to thermal gradients in the tropical Pacific: the thermocline versus the Equatorial Front. *Marine Ecology Progress Series* 219, 275–289.
- Springer A.M., McRoy C.P. and Flint M.V. (1996) The Bering sea green belt: shelf-edge processes and ecosystem production. *Fish Oceanography Journal* 5, 205–223.

- Steffens F.E.** (1993) Geostatistical estimation of animal abundance in the Kruger National Park, South Africa. In: Soares A. (eds) *Geostatistics Tróia '92*. Dordrecht: Kluwer, pp. 887–897.
- Stevick P.T., Incze L.S., Kraus S.D., Rosen S., Wolff N. and Baukus A.** (2008) Trophic relationships and oceanography on and around a small offshore bank. *Marine Ecology Progress Series* 363, 15–28.
- Thiebot J.B. and Weimerskirch H.** (2013) Contrasted associations between seabirds and marine mammals across four biomes of the southern Indian Ocean. *Journal of Ornithology* 154, 441–453.
- Verity P.G. and Smetacek V.** (1996) Organism life cycles, predation, and the structure of marine pelagic ecosystems. *Marine Ecology Progress Series* 130, 277–293.
- and
- Yen P.P., Sydeman W.J. and Hyrenbach K.D.** (2004) Marine bird and cetacean associations with bathymetric habitats and shallow-water topographies: implications for trophic transfer and conservation. *Journal of Marine Systems* 50, 79–99.
- Correspondence should be addressed to:**
D. Angeletti
Dipartimento di Scienze Ecologiche e Biologiche, Centro
Ittiogenico Sperimentale Marino, Università degli Studi della
Toscana, Borgo Le Saline, 01016 Tarquinia (VT), Italy.
email: darioangeletti@unitus.it