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Habitat modeling for cetacean management: Spatial distribution in the southern Pelagos Sanctuary (Mediterranean Sea)

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ABSTRACT

Effective management and conservation of wild populations requires knowledge of their habitats, especially by mean of quantitative analyses of their spatial distributions. The Pelagos Sanctuary is a dedicated marine protected area for Mediterranean marine mammals covering an area of 90,000 km^2 in the north-western Mediterranean Sea between Italy, France and the Principate of Monaco. In the south of the Sanctuary, i.e. along the Sardinian coast, a range of diverse human activities (cities, industry, fishery, tourism) exerts several current ad potential threats to cetacean populations. In addition, marine mammals are recognized by the EU Marine Strategy Framework Directive as essential components of sustainable ecosystems. Yet, knowledge on the spatial distribution and ecology of cetaceans in this area is quite scarce. Here we modeled occurrence of the three most abundant species known in the Sanctuary, i.e. the striped dolphin (*Stenella coeruleoalba*), the bottlenose dolphin (*Tursiops truncatus*) and the fin whales (*Balaenoptera physalus*), using sighting data from scientific surveys collected from 2012 to 2014 during summer time. Bayesian site-occupancy models were used to model their spatial distribution in relation to habitat taking into account oceanographic (sea surface temperature, primary production, photosynthetically active radiation, chlorophyll-a concentration) and topographic (depth, slope, distance of the land) variables. Cetaceans responded differently to the habitat features, with higher occurrence predicted in the more productive areas on submarine canyons. These results provide ecological information useful to enhance management plans and establish baseline for future population trend studies.

1. Introduction

Marine mammals are recognized by the EU Marine Strategy Framework Directive as an essential component of sustainable ecosystems, being highly sensitive and linked to ecosystem health (Hooker and Gerber, 2014), and considered as *umbrella species* (Wilcox, 1984). Indeed, the management of protected areas based on top predators distributions can be highly efficient, leading to higher biodiversity levels and more ecosystem benefits (Sergio et al., 2006, 2008). Consequently, protecting cetaceans and their habitats is a priority issue in marine management (Hooker et al., 2011).

In order to achieve this purpose the prerequisites are a solid knowledge of species-environment relationships and the identification of priority areas using robust analysis of existing information and data-bases (Pennino et al., 2013a). Habitat and species mapping is essential for both, management and conservation strategies of cetaceans, because it provides a clear picture of the distribution and extent of wildlife populations and thus facilitates managing their environment (Azzelino et al., 2012; Cribb et al., 2015; Forney et al., 2012; Mannocci et al., 2014).

Species-mapping has thus been increasingly used in recent years for conservation and management purposes, such as for the delimitation and implementation of marine protected areas (MPAs) (Cañadas et al., 2005). However, most of the identified MPAs focus on coastal regions, Whereas anthropogenic impacts and the non-sustainable use of marine resources is increasingly affecting offshore waters (Fossi et al., 2013; Correia et al., 2015). Moreover, although

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some of these MPAs include pelagic environments, these are largely inadequate for conservation of cetacean species, as they do not match with the home ranges of the species (Agardy et al., 2011).

The Pelagos Sanctuary is the only pelagic MPA in the Mediterranean Sea for marine mammals. It covers about 90,000 km^2 in the north-western Mediterranean Sea between Italy, France and the Principate of Monaco (Notarbartolo di Sciara et al., 2008). The largest part of the coastal area bordering on the Northern Sardinia holds large and medium-sized cities, ports of major fishery importance, and industrial areas. Furthermore, the entire coast encompasses important tourist destinations, thereby subject to considerable added human pressure during the summer time. As a consequence, a range of diverse human activities exerts several actual and potential threats to cetacean populations in the Sanctuary.

However, to date, knowledge on the spatial distribution of cetaceans in the south part of the Pelagos sanctuary is scarce, especially in offshore waters. Published data are mainly restricted to coastal areas and to a few regional hots-posts (e.g., the Archipelago de La Maddalena), where data collection is limited to a few miles from the coast and usually encompassing only some species (e.g., *Tursiops truncatus,* Pennino et al., 2013b, 2015, 2016). As a consequence, most of the local MPAs are also limited to coastal areas.

Our study aims to identify sensitive habitats, from an environmental point of view, for the three most abundant cetacean species in the Pelagos Sanctuary (Notarbartolo di Sciara et al., 2008): the striped dolphin (*Stenella coeruleoalba*), the bottlenose dolphin (*Tursiops truncatus*) and the fin whale (*Balaenoptera physalus*) using scientific sightings data collected from 2012 to 2014 during summer time. Bayesian site-occupancy models were used (i) to model the distribution of these species in relation with variables related to oceanography (sea surface temperature, net primary production, photosynthetically active radiation, chlorophyll-a concentration) and topography (depth, slope, distance to the land), and to identify their respective contribution, (ii) to predict and map cetacean's distribution in the entire study area. An improved understanding of the spatial distribution of cetacean species could help the management of regional MPAs by taking into account sensitive habitats.

2. Material and methods

2.1. Study area

The study area includes the continental shelf (0–200 m depth) and offshore waters (200–3000 m depth) of the Northern Sardinia waters and lies between the port of Cala Gavetta (41°12′57″N/09°24′57″E) in the Eastern side of the island, and the port of Alghero (40°33′28″N/8°19′19″E) in the Western side (Fig. 1). This area covers approximately 5500 km^2. It is characterized by a narrow continental shelf, a prominent cyclonic circulation occurring throughout the year, and a strong north-westerly winds (Mistral).

2.2. Sampling methods

The study area was surveyed in June from 2012 to 2014 using a motorized-sailing boat, at a speed of 8–10 knots. Quadruple-observer surveys were conducted by experts during light hours from 6.00 A.M. to 8.00 P.M. Observers scanned with the naked eye and used binoculars (7 × 50 and 8 × 42), at an eye height of 3 m above the sea level, for the identification and group size estimations. A GPS, logged to a computer equipped with "*Mapsource*" software collected positional information every minute.

The sea state (using the Beaufort's scale) and wind intensity were recorded every 30 minutes or whenever any of these values changed. Data were collected following the distance sampling protocol (Buckland et al., 2001). Information recorded included species identification, calf/juvenile presence, group size (maximum, minimum, or exact number if possible), and behavior of the focal animal identified.

In order to avoid harassment of cetaceans we observed them from a safe and respectful distance, avoiding approaching them closer than 30 m, using binoculars or telephoto lenses to get a good view of the animals. If cetaceans approached the boat, we maintained its course, avoid abrupt changes in direction or speed to avoid running over or injuring the animals.

2.3. Data preparation

A grid of 4 × 4 km cells were created for the studied area using the grid index features tool in ArcGIS version 10.2.2. Cell size was determined by the size of the study area and the overall coverage of survey effort in order to ensure adequate spatial replication (MacKenzie and Royle, 2005). Each grid cell constituted a sampling unit, or site.

The amount of search effort in a grid cell, wind intensity and Beaufort sea state were considered to be the main variables acting on detection probability. Search effort was quantified as the number of times that a cell was visited. Grid cells with less than 2 visits were then removed from the analysis in order to reduce the risk of false absences (visited cells where species were present but not recorded). For the wind intensity, direction and sea state values, a weighted average was calculated for all the grid cells.

2.4. Environmental variables

Seven environmental variables were considered as potential and/or already known predictors of cetacean species distribution (Azzelino et al., 2012; Cribb et al., 2015; Panigada et al., 2008; Pirotta et al., 2011; Ready et al., 2010), selected for being known to affect the foraging habitat selection of species and/or the distribution of their main prey. These included four oceanographic variables - Sea Surface Temperature (SST in °C), Photosynthetically Active Radiation (PAR in μn), Chlorophyll-a concentration (CHL in mg/m^{-3}) and Net Primary production (NPP in mg C/m^{-3}/day) - and three topographic covariates - depth (in meters), slope (in degrees) and distance to land (in meters) (Appendix S1 in Supplementary material).

In particular, SST, PAR and CHL were used as a proxy for the phytoplankton biomass (Raitsos et al., 2008). The SST, PAR and CHL data were derived from the aqua-MODIS sensor, as daily values with a resolution of 2 km (http://oceandata.sci.gsfc.nasa.gov/). We obtained NPP with Windows Image Manager Software (Kahru, 2010) using CHL, SST, PAR and the vertically generalized productivity model (Behrenfeld and Falkowski, 1997).

Two temporal resolution were considered for oceanographic variables: (1) a short-term resolution, corresponding to daily time period, (2) a climatological resolution corresponding to the averaged monthly variables.

Topographic covariates have frequently been used as predictors of cetacean species distribution (Mannocci et al., 2014; Panigada et al., 2008). Depth (m), slope (degrees) and distance to land (m) were retrieved from the MARSPEC database, (http://www.marspec.org). MARSPEC is a world ocean dataset with a spatial resolution of 0.01 × 0.01 decimal degrees (~1 km) developed for marine spatial ecology (Sbrocco and Barber, 2013).

In order to have the same spatial resolution, all environmental data were gridded at 4 × 4 km using the '*raster*' package (Hijmans, 2015) in the R software (R Development Core Team, 2015).

Collinearity between explanatory environmental variables was checked using a Draftsman's plot and the Pearson correlation

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