Modelling habitat preferences for fin whales and striped dolphins in the Pelagos Sanctuary (Western Mediterranean Sea) with physiographic and remote sensing variables

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ABSTRACT

One of the needs of the Pelagos Sanctuary for the Conservation of Mediterranean Marine Mammals is information on critical habitats for cetaceans. This study modelled habitat use and preferences of fin whales and striped dolphins (the two most abundant species in the area) with the aim of providing this information, using sighting data collected between 1993 and 1999. The study area was divided into a 2′ latitude by 2′ longitude grid. The explanatory variables considered in the models were physiographic variables (mean, range and standard deviation of depth and slope, and distance from the nearest coastline) and remotely-sensed data (Sea Surface Temperature and Chlorophyll-*a* concentration). The former were calculated for each cell using GIS tools, while the latter were obtained from AVHRR and SeaWiFS sensors. Generalized Additive Models (GAMs) with multidimensional smoothers were used to model the distribution of fin whales and striped dolphins in relation to these variables, and Classification And Regression Trees were used for habitat characterization and predictive models. The GAMs were coupled with Generalized Estimating Equations (GEEs) to account for temporal autocorrelation in the errors and to help ensure model selection was reliable; the QIC statistic was used alongside GEE-based *p*-values. Bathymetric features were the most valuable predictors in the Pelagos Sanctuary area for both species. Sea Surface Temperature values were indicators of striped dolphin and fin whale presence, with both species showing a tendency to prefer colder waters (21–24 °C). Chl-*a* levels were selected by the GAM models only for striped dolphins, and with large associated uncertainty; this may be related to the relatively brief period examined (only 2 years) and/or to any functional relationship operating at a different geographical or temporal scale. The boosted classification trees however indicated an importance of Chl-*a* for both species. The techniques applied to this dataset proved to be valuable tools to describe habitat use and preferences of cetaceans, and the use of the remotely-sensed data can substantially improve the predictions. The results of this study will be used for assessing critical habitats within the Pelagos Sanctuary and will provide information for conservation and management in the Sanctuary.

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1. Introduction

The Pelagos Sanctuary (Fig. 1) is a wide Marine Protected Area (MPA) established in 2002 by a joint declaration between the Governments of France, Italy and Monaco (Notarbartolo di Sciara et al., 2008). The Sanctuary was inscribed in the SPAMI list within the framework of the Barcelona Convention, after the ratification process of the three signatory States. This MPA lies between south-eastern France, Monaco, northern Sardinia and north-western Italy, covering an area of almost 90,000 km^2. The area included in the Sanctuary comprises national waters of Italy, France and Monaco and adjacent international waters.

An overview of the creation of the Pelagos Sanctuary, including the steps leading to its establishment, insights to the management plans for the Sanctuary, and implications for the development of MPA networks in the Mediterranean Sea are detailed in Notarbartolo di Sciara et al. (2008).

Two cetacean species are most commonly found in the waters of the Sanctuary: the fin whale (*Balaenoptera physalus*) and the striped dolphin (*Stenella coeruleoalba*) (Notarbartolo di Sciara, 1994). Genetic

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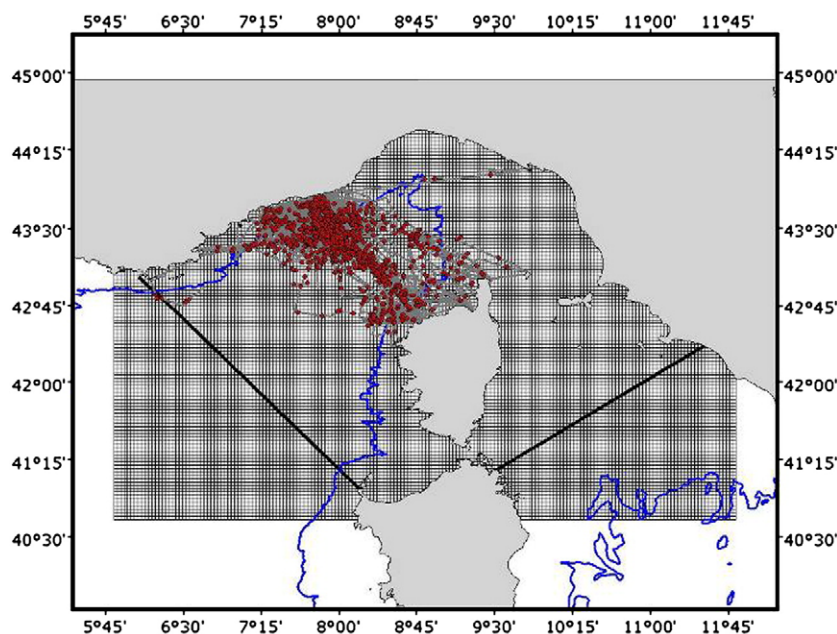
Fig. 1. The area of the Sanctuary (between the black diagonal lines) showing the 2000 m isobath, the grid cell used for the analyses and the sightings (fin whales and striped dolphins combined).

analyses suggest that the Mediterranean and eastern North Atlantic populations of both species are isolated from each other, with little gene flow between the two geographical areas (Bérubé et al., 1998; Calzada & Aguilar, 1995; Gaspari, 2004; Gaspari et al., 2007; Palsbøll et al., 2004). A first line transect survey, conducted in 1991 over most of the western Mediterranean, and a second survey in 1992, concentrating on the Ligurian Sea, provided population estimates for both species. The first survey conducted in the western portion of the basin yielded the following estimates: fin whale 3500 individuals (95% CI 2130–6027) and striped dolphin 117,880 (95%CI=68,379–214,800) (Forcada et al., 1994, 1996). The second survey in the Ligurian Sea estimated 901 fin whales (95%CI 591–1374) and 25,614 striped dolphins (95%CI=15,377–42,658) (Forcada et al., 1995).

Fin whales and striped dolphins in the Mediterranean are exposed to a number of anthropogenic threats. Some threats, such as acoustic and chemical pollution (Aguilar, 2000; Fossi et al., 2003), and habitat degradation may affect both species (Notarbartolo di Sciara & Gordon, 1997), while other anthropogenic pressures may be more species-specific. For example, fin whales are specifically threatened by collisions with vessels (Panigada et al., 2006), and disturbance by boats (Jahoda et al., 2003) while entanglement in fishing gear is marginal (Cagnolaro & Notarbartolo di Sciara, 1992; Notarbartolo di Sciara et al., 2003). Ship strikes are rather common in Mediterranean waters, particularly in the Pelagos Sanctuary and adjacent waters (Panigada et al., 2006) and most likely represent the major cause of non-natural mortality for fin whales. Striped dolphins, on the contrary, do not seem to be particularly affected by ship strikes but rather have faced, and continue to face though to a lesser extent than previously, severe threats due to bycatch in pelagic driftnets (Di Natale, 1995; Notarbartolo di Sciara, 1990; Podestà & Magnaghi, 1989). Although driftnets were banned by the European Union in 2002, a reduced Italian fleet still uses them illegally (Pace et al., 2005), as do the French *tonnaille* vessels (Imbert et al., 2001, 2002), and a large Moroccan fleet (Tudela et al., 2005), causing significant striped dolphin mortality.

The Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and contiguous Atlantic area (ACCOBAMS), entered into force in 2001, recognizes that creation of MPAs can aid in ensuring a favorable conservation status of cetaceans within the Agreement area: *Parties shall endeavour to establish and manage specially protected areas for cetaceans corresponding to the areas which*

serve as habitats of cetaceans and/or which provide important food resources for them.

Several studies have described cetaceans' distribution and habitat preferences by linking their presence to different habitat variables. Cetaceans' studies have focused on their relationships with sea temperature (e.g. Baumgartner et al., 2001; Brown & Winn, 1989; Cañadas et al., 2005), physiographic variables – such as benthic topography – (e.g. Baumgartner, 1997; Cañadas et al., 2002, 2005; Ingram et al., 2007; Panigada et al., 2005), currents and frontal systems (e.g. Johnston et al., 2005a,b; Mendes et al., 2002; Tynan, 1998), primary production cycles (Littaye et al., 2004) and prey distribution (Baumgartner et al., 2003; Jaquet & Gendron, 2002; Macleod et al., 2004; Woodley & Gaskin, 1996). More recently, scientists have integrated oceanographic and prey measurements to describe the habitats of large whales (e.g. Friedlaender et al., 2006; Murase et al., 2002). To gain better insights into the ecology of cetaceans in dynamic and changing environments, the environmental features affecting the presence and occurrence of cetaceans need to be addressed at different scales (Hastie et al., 2005). A thorough review on the different approaches conducted elsewhere on marine mammals was recently published by Redfern et al. (2006) and by Ballance et al. (2006) focusing on the Eastern Tropical Pacific.

This study aims to model habitat use and preference of fin whales and striped dolphins in the Pelagos Sanctuary, using both physiographic (depth, slope, distance from the coast) and remotely-sensed variables (Sea Surface Temperature SST, Chlorophyll-*a* concentration Chl-*a*), in order to assess areas of particular importance for these two species. The results of this study will provide information for conservation and management actions in the Sanctuary, underlining how remote sensing data could play a concrete role in the study and management of dynamic marine environments.

2. Materials and methods

2.1. Study area

The study area includes the continental shelf and offshore waters of the western Ligurian and Corsican Seas and lies between the port of Saint Raphael (43°25′N, 6°50′E) on the French coast, Cape Mele (43°55′N, 8°10′E) on the Italian coast and Cape Corse (43°00′N, 9°25′E) and Girolata (42°20′N, 8°35′E) on the island of Corsica (Fig. 1). This area