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Predicting bottlenose dolphin distribution along Liguria coast (northwestern Mediterranean Sea) through different modeling techniques and indirect predictors

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ABSTRACT

Habitat modeling is an important tool to investigate the quality of the habitat for a species within a certain area, to predict species distribution and to understand the ecological processes behind it. Many species have been investigated by means of habitat modeling techniques mainly to address effective management and protection policies and cetaceans play an important role in this context. The bottlenose dolphin (*Tursiops truncatus*) has been investigated with habitat modeling techniques since 1997. The objectives of this work were to predict the distribution of bottlenose dolphin in a coastal area through the use of static morphological features and to compare the prediction performances of three different modeling techniques: Generalized Linear Model (GLM), Generalized Additive Model (GAM) and Random Forest (RF). Four static variables were tested: depth, bottom slope, distance from 100 m bathymetric contour and distance from coast. RF revealed itself both the most accurate and the most precise modeling technique with very high distribution probabilities predicted in presence cells (90.4% of mean predicted probabilities) and with 66.7% of presence cells with a predicted probability comprised between 90% and 100%. The bottlenose distribution obtained with RF allowed the identification of specific areas with particularly high presence probability along the coastal zone; the recognition of these core areas may be the starting point to develop effective management practices to improve *T. truncatus* protection.

1. Introduction

Habitat modeling for marine mammals has made considerable advances in the past decades. The application of statistical models to understand and predict relationships between species and their environment has become more and more frequent in the literature (Redfern et al., 2006). Habitat models have a number of important applications for the conservation and management of wild species (Guisan and Zimmermann, 2000; Thomas et al., 2004; Thuiller et al., 2004; Redfern et al., 2006; Kremen et al., 2008; Mouton et al., 2011). In particular, habitat models can be used (i) to predict species occurrence on the basis of habitat variables, (ii) to improve the understanding of species-habitat relationships and (iii) to quantify habitat requirements (Ahmadi-Nedushan et al., 2006).

Habitat modeling techniques are based on the assumption that, for each species, there is an ideal set of environmental variables (signature) that makes the presence of animals more likely. Guisan and Zimmerman (2000) classified variables into three main categories: 1) resources (e.g. matter and energy consumed); 2) condition variables (e.g. variables of physiological importance, pH, temperature) and 3) indirect variables (e.g. depth, slope, distance from coast). While resources and condition variables are expected to change in time, indirect variables are often static variables mainly associated with geomorphologic characteristics of the (investigated) area and thus represent a solid base to understand and to predict animals' distribution and preferences. Many studies have shown that cetacean distribution can be closely linked to underwater topography such as water depth and seabed gradient (Watts and Gaskin, 1986; Ross et al., 1987; Selzer and Payne, 1988; Frankel et al., 1995; Gowans and Whitehead, 1995; Baumgartner, 1997; Raum-Suryan and Harvey, 1998; Karczmarski et al., 2000; Ferguson and Barlow, 2001; Bailey and Thompson, 2006; Ferguson et al., 2006; Azzellino et al., 2008; Blasi and Boitani, 2012).

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Aiming at outlining relationships between cetaceans' presence and environmental variables, a number of different techniques have been applied to cetacean–habitat modeling (Redfern et al., 2006). Most studies exploring the relationship of distribution patterns with environmental variables are based on statistical regression, in which the presence/absence or abundance of cetaceans is regressed with a set of predictor variables (Baumgartner, 1997; Moses and Finn, 1997; Tynan, 2004). An important statistical development of the last thirty years has been the advances in regression analysis provided by generalized linear models (GLMs) and generalized additive models (GAMs) (Guisan et al., 2002). These statistical approaches are able to verify the existence of respectively linear and non-linear relationships between a response variable and a set of predictor variables. The ability of these tools to handle non-linear data allowed the development of ecological models that better represent the underlying data, and hence increase our understanding of ecological systems (Guisan et al., 2002). More recently, new techniques based on machine learning techniques have been applied in a number of different fields aiming at more reliable and accurate prediction of habitat uses. Among these Random Forest (RF) models (Breiman, 2001; Cutler et al., 2007) are a machine learning technique based on an automatic combination of decision trees (Breiman et al., 1984). Several studies applied random forest techinque to habitat modeling (Cutler et al., 2007; Siroky, 2009; Kampichler et al., 2010) demonstrating the possibility to apply this methodology for studies on species distribution.

This study is focused on the application and comparison of different techniques for the analysis of the distribution of common bottlenose dolphin (*Tursiops truncatus* Montagu, 1821). Bottlenose dolphins are known to be among the most widely distributed cetaceans, occurring in both hemispheres (Wells and Scott, 2009). In Mediterranean, the bottlenose dolphin distribution is commonly confined to the continental shelf within the 200 m isobath, with a preference for shallow waters of less than 100 m depth and show a residential attitude with excursions usually within a distance of 80 km (50 km on average) (Gnone et al., 2011). The shallow water preference of the bottlenose dolphin could be related to the feeding habits of the species, preying mostly on benthic and demersal fishes (Voliani and Volpi, 1990; Orsi Relini et al., 1994; Silva and Sequeira, 1997; Mioković et al., 1999; Blanco et al., 2001; Santos et al., 2001). Since they mainly behave as coastal cetaceans, bottlenose dolphins are increasingly exposed to a variety of human activities through the proliferation of littoral development. Threats to dolphins in near-shore environments include the loss of suitable habitat, increasing vessel traffic and tourism, entanglement in fishing gear or in marine debris, noise pollution, environmental contaminants and disease. This is why bottlenose dolphin has been included in the IUCN red list of threatened species being listed among species under the "least concern" category and classified as Vulnerable in the last IUCN report on the Status of Cetaceans in the Mediterranean and Black Sea (Reeves and Notarbartolo di Sciara, 2006).

Since the conservation of a species depends on the understanding of the relationship between populations and their habitat (Cañdas et al., 2005), modeling *T. truncatus* distribution may help to understand which habitats are used with higher frequency, which environmental features (biotic or abiotic) are the most important determinants for the species distribution and, in turn, suggest and develop management practices to improve their conservation.

The aim of this study is the identification of the more reliable technique to predict the relationship between a set of indirect variables and the distribution of the bottlenose dolphin.

The spatial distribution of *T. truncatus* was investigated in the east Ligurian coast (north-west Mediterranean Sea) by means of three different statistic techniques: GLM, GAM and RF.

The study area is completely included in the International Pelagos Sanctuary for the protection of marine mammals (Notarbartolo di Sciara et al., 2008). The Pelagos Sanctuary is a 90.000 km^2 Marine Protected Area (MPA) established in 2002 by a joint declaration between the Governments of France, Italy and Principality of Monaco (Notarbartolo di Sciara et al., 2008). The Sanctuary hosts eight resident cetacean species: Balaenoptera physalus, Physeter macrocephalus, Grampus griseus, Globicephala melas, Tursiops truncatus, Stenella coeruleoalba, Delphinus delphis and *Ziphius cavirostris*. Compared to other Mediterranean regions, the area is characterized by high levels of offshore primary productivity maintained by upwelling circulation (Viale, 1991; Barale and Zin, 2000). Moreover, all MPA is characterized by the strong presence of human activities generating possible threats for cetaceans, that varies from acoustic (i.e. vessel noise, military sonar exercise, seismic survey) (Notarbartolo di Sciara et al., 2008) and chemical pollution (Monaci et al., 1998; Aguilar, 2000; Fossi et al., 2003), habitat degradation, entanglement in fishing gear, disturbance by boat i.e. whale watching, pleasure and fishing boats (Jahoda et al., 2003), and collisions with vessels (Panigada et al., 2006).

For this study four predictive physiographic variables were identified: depth, distance from coast, distance from 100m bathymetry and slope. These were tested by means of the three chosen techniques aiming at the best prediction of *T. truncatus* distribution and at the identification of the most influencing variables determining the animals' distribution.

2. Materials and methods

2.1. Study area

The study area is located in the Ligurian Sea (NW Italy) and stretches from the eastward limits of the city of Genoa (9- 06′ 04″ E – 44- 22′ 38.21″ N) to Punta Bianca, La Spezia (9- 58′ 24.19″E – 44- 02′ 50.28″ N). This area is characterized by a marked bathymetric heterogeneity with a small and extremely steep continental shelf in the western sector and a bathymetric profile more and more smoothed moving eastward (Fig. 1). As a consequence the edge of the platform (~200 m depth) runs almost parallel to the coastline at a distance of about 10 km from Portofino promontory to Cinque Terre while in the western sector it moves offshore reaching more than 25 km wideness.

The area is characterized by a marked seasonal variability in the main current field which is also highly influenced by waters flowing northward on both sides of Corsica in roughly equivalent fluxes and connecting in the Gulf of Genoa. These flows interact in a turbulent way and mix together to form the Ligurian current (Millot, 1987). This current moves westward remaining close to the coast and then continues along the Provence continental shelf (Taupier-Letage and Millot, 1986). The strong counterclockwise circulation at the centre of the Ligurian Sea causes the coastal upwelling of deep waters that supports a spring primary production, higher than the average for the western Mediterranean, with mesotrophic conditions in March–May and oligotrophic conditions in the summer and winter months (Viettia et al., 2010).

A high level of urbanization characterizes the coastline except for small portions such as Portofino and Cinque Terre where both terrestrial and marine protected areas have been established in the late nineties.

The area has undergone an impressive amount of development in the last century. This phenomenon has been mainly driven by the construction of massive infrastructures (commercial harbors, roads and railways) and later by an impressive increase (started in the 1960s) in tourism pressure and population density on the coastal