Habitat suitability maps of bottlenose dolphin in the Greek Seas

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Abstract

The aim of the present study was the assessment of the summertime suitable habitat of the coastal population of *Tursiops truncatus* (bottlenose dolphin) in the Aegean and Ionian Seas. For this purpose Generalized Additive Models were applied to identify potential areas of bottlenose dolphins' distribution using probability of sardine presence and environmental data as proxies to define species habitat preferences. Results indicated higher bottlenose dolphins' presence at areas presenting shorter distance from shore, high sardine probability of presence and high concentration of chlorophyll-a. Subsequently, Geographic Information Systems (GIS) were used to determine the persistent and occasional habitat of the species. Areas suggested as persistent habitat for the species include enclosed seas, continental shelf waters, and waters surrounding islands.

Keywords: habitat modeling, *Tursiops truncates,* Geographic Information Systems, Generalized Additive Models, Eastern Mediterranean basin

1. Introduction

Bottlenose dolphin *(Tursiops truncatus*, Gervais, 1855; hereafter referred as 'bottlenose dolphin') is one of the most common cetaceans in the Mediterranean Sea where the species is predominantly 'coastal' or 'inshore' animal (Bearzi et al., 2008a). It is generally an opportunistic species that feeds on a wide range of prey species, mostly consisting of demersal prey (e.g. European hake, red mullet, European conger) (Bearzi et al., 2008a; Frantzis, 2009) as well as pelagic species depending on fish availability and abundance (e.g. Bearzi et al., 2006; Pirrodi et al., 2011; Holcer, 2012). For example, in certain areas like the central Adriatic (Holcer, 2012), the Inner Ionian Sea Archipelago (Bearzi et al., 2006; Pirrodi et al., 2011) and Amvrakikos Gulf (Bearzi et al., 2008a), small pelagics like European anchovy and European sardine are known to be an important part of its diet.

As a precautionary measure, in the Mediterranean Sea, due to a population decline of at least 30% over the last 60 years, the *International Union for the Conservation of Nature (IUCN*) has listed bottlenose dolphin as a Vulnerable species under the Red List of Threatened Species category (Bearzi & Fortuna, 2006). The need for identification and protection of special conservation areas are requested by the EU Habitats Directive, thus the identification of suitable areas for the species can be an important tool for conservation purposes. Existing work on habitat modeling focuses on the determination of factors related to species habitat instead of mapping (northern Adriatic: Bearzi et al., 2008b using environmental variables and bottom depth / North Evoikos Gulf: Bonizzoni et al., 2014 using mainly distance from fish farms and bottom depth). Here, we aim to assess and map the summertime suitable habitat for bottlenose dolphin using as proxies for its ecological preferences: sardine probability of presence, ecosystem productivity and distance from the coast. It should be clarified that we do not consider sardine as the only prey for bottlenose dolphins but along with productivity we assume it is a good proxy of potential prey availability within the coastal environment in the study area. Moreover, in the study area anthropogenic factors often related to the presence of the bottlenose dolphins, like fishing activity from most gears or the presence of fish farms, are carried out within the continental shelf, largely overlapping with sardine main distribution grounds.

2. Materials and methods

Bottlenose dolphins' sightings used (Table 1), were obtained from three different sources a) dedicated cetacean surveys of the Pelagos Cetacean Research Institute in the period 1994-2014 (Frantzis, 2009 unpublished data) and IFAW/MCR Song of the Whale Research Team in 2013 (Ryan et al., 2014), b) opportunistic data during the MEDIAS surveys carried out on board R/V Philia (HCMR unpublished data) and c) published data (Zafiropoulos & Merlini, 2001; Bearzi et al., 2008c; Dede & Öztürk, 2007). Data covered the summertime period 1990-2014 and was split in early summer (May, June, July) and late summer (August, September) observations. This allowed us to take any seasonal effect into account. In all surveys, cetaceans were identified by experienced observers on board and questionable observations were discarded from the dataset.

Generalized additive models (Hastie & Tibshirani, 1990) were applied to define the set of environmental and biotic factors that best describe bottlenose dolphin spatial distribution in the study area, during early and late summer for the period 2000-2013. This methodology requires presence / absence data. Thus, for modeling purposes survey locations at depths >400 m (although marine mammals surveys are scarce at deep waters, bottlenose dolphin distribution in the Greek Seas is known not to exceed the 250 m isobaths) (Frantzis, 2009) where available sightings only referred to the striped dolphin (*Stenella coeruleoalba*; Meyen 1833), were considered as absence locations for the species.

Table 1. Sightings of bottlenose dolphin used for analysis.

Source	Period covered	Month	Sightings
Surveys by Pelagos Cetacean Research Institute and IFAW/MCR	1990-1999	05-09	82
Song of the whale Research Team; Published references	2000-2014	05-09	163
MEDIAS research surveys (HCMR unpublished data)	2006-2013	05-09	31

Sardine probability of presence was available at an adequate spatial and temporal resolution for the entire Aegean and Ionian Seas from a published habitat suitability model (Tugores et al., 2011) and thus retrieved at the geographical coordinates of the respective marine mammals' presence/absence records from the available annual maps of the entire Greek Seas. Similarly, we retrieved chlorophyll-a concentration (Chl-a in mg/m^{-3}; http://oceancolor.gsfc.nasa.gov) as monthly averages and distance from the coast at the same grid resolution of 4x4 km as sardine probabilities.

The final model was selected based on the minimization of the Akaike Information Criterion. The degree of smoothing was chosen based on the restricted maximum likelihood estimation. The final model was evaluated for its predictive performance using the initial data (modeled dataset) in addition to records not included in the model selection (non-modeled dataset) involving a) year 2014 and b) period 1990-1999. Due to lack of adequate satellite environmental data for the period 1990-1999, sardine probability of presence was estimated based on the respective available information for June and September 2003. For validation purposes, we estimated the receiver operating characteristic curve and the area under the curve (AUC). Sensitivity (proportion of observed positives correctly predicted) and specificity (proportion of observed negatives correctly predicted) indices were also used for model evaluation (Guisan & Zimmermann, 2000).

The final model was applied in a predictive mode to obtain annual habitat suitability maps over a wider grid at a GIS resolution of 4 km for the period 2003-2008 (practically indicating areas with suitable conditions to support dolphins' presence). Subsequently, the mean average probability estimates and the respective standard deviation were estimated at each grid point being the basis for defining the preferential and occasional dolphins' habitat (limits used for occasional: mean >0.25, standard deviation >0.05 and for preferential: mean >0.75, standard deviation <0.05).

3. Results

Modeling results indicated higher bottlenose dolphins' presence at areas presenting shorter distance from the shore, high sardine probability of presence and high concentration of chlorophyll-a, explaining 72.6% of the total variation. Sardine probability of presence alone explained 61% of the total variation verifying that it operates as a good proxy for the habitat preferences of the species. The season effect was also found significant. Model validation generally showed good model fit (AUC ~0.98 for modeled dataset and ~0.82 for non-modeled dataset). Habitat allocation maps of bottlenose dolphins' habitat showed summertime favorable areas that largely coincide with the areas of known records for the period 2000-2014, as well as past records for the period 1990-2000 (Fig. 1).

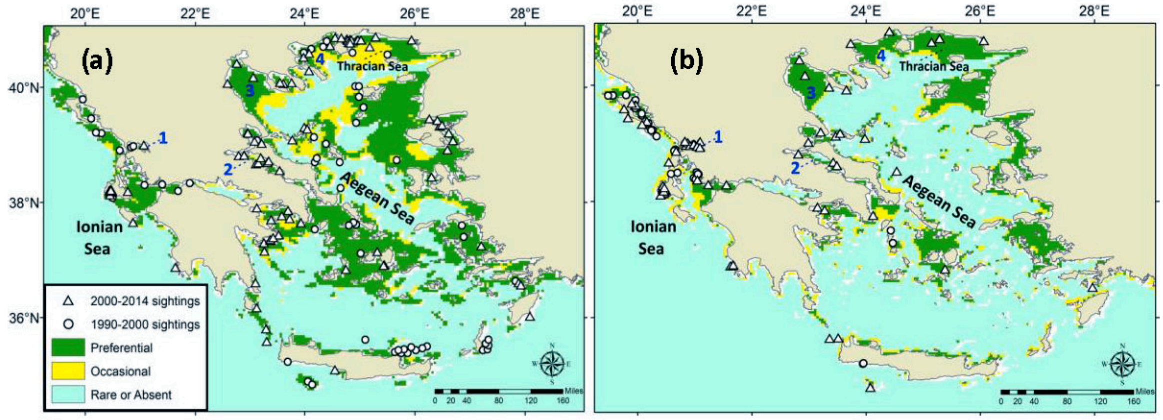

Fig. 1. *Tursiops truncatus*: Habitat allocation maps for (a) early and (b) late summer in the period 2003-2008. Sightings for the periods 1990 - 2000 and 2000 – 2014 are also shown. 1: Amvrakikos Gulf, 2: North Evoikos Gulf, 3: Thermaikos Gulf, 4: Strymonikos Gulf.

4. Conclusions/Discussion

Areas suggested as preferential habitat for the species are dominated by enclosed seas, continental shelf waters, and waters surrounding islands, in accordance to Bearzi et al., (2008a and references there in) as well as closed basins like Amvrakikos Gulf and North Evoikos Gulf also in accordance to Bearzi et al., 2008c and Bonizzoni et al., 2014, respectively. Moreover, the seasonal effect was found significant and modeling results showed shrinkage of the preferential and occasional habitat from early to late summer towards more coastal areas. Bottlenose dolphin's calving season (peak in July and August, Bearzi et al., 1997) is known to coincide with the major use of coastal waters (Evans et al., 2003) that assure the protection of the young ones. This could explain the seasonal shift in species habitat. Although further research is needed, the knowledge of the suitable habitat of the species over extended areas can be very important for the development and management of conservation plans.

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