Accobams collaborative effort to map high-use areas by beaked whales in the Mediterranean

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INTRODUCTION

Previous information on beaked whales in the Mediterranean Sea (extracted and updated from IUCN Cuvier´s beaked whale draft Red List assessment, by A. Cañadas).

Cuvier's beaked whales inhabit both the western and eastern basins of the Mediterranean (Notarbartolo di Sciara 2002). Much of the current knowledge of this species in the Mediterranean has come from stranding data. Strandings have been reported in Albania, Algeria, Croatia, Egypt, France, Greece, Israel, Italy, Malta, Spain and Turkey, totalling 316 animals (Podestà *et al.* 2006). Twenty-six percent of the total animals recorded stranded in the Mediterranean have been in mass strandings involving 3 or more animals (Podestà *et al.* 2006). Strandings have been particularly numerous along the Ligurian and Ionian coasts, but it is important not to infer too much about species distribution or relative abundance from strandings data alone. Strandings data are subject to a variety of types of bias.

Cuvier's beaked whales seem to be relatively abundant in the eastern Ligurian Sea, off southwestern Crete and the Alboran Sea, especially over and around canyons (D'Amico *et al.* 2003; Frantzis *et al.* 2003; Ballardini *et al.* 2005; Scalise *et al.* 2005). They appear to be regular although less abundant inhabitants of the western Ligurian Sea (41 sightings in 16 years, Tethys Research Institute, unpublished data; 4.2% of 814 sightings during 10,000 km on effort from 1996 to 2000, Azzellino *et al.* 2008). Cuvier's beaked whales have been described as regular inhabitants of the Hellenic Trench (Frantzis *et al.* 2003), the southern Adriatic Sea based on frequency of strandings (Holcer *et al.* 2003) and the eastern section of the Alborán Sea (Cañadas *et al.* 2005). They also occur in the central Tyrrhenian Sea (Marini *et al.* 1992) and in Spanish Mediterranean waters (Gannier 1999; Raga and Pantoja 2004; M. Castellote, pers. comm.). They have been reported both from strandings and sightings in Israeli, Palestinian and Syrian waters (Aharoni 1944; Saad and Othman 2008; D. Kerem, pers. comm.). No information is available for the remaining areas of the Mediterranean.

There are two abundance estimates for this species in small portions of the Mediterranean Sea. In the Gulf of Genova (eastern Ligurian Sea) mark-recapture analysis (2002-2008) yielded an estimate of 96-100 animals (left and right side identifications respectively) from an open population (Rosso et al. 2009). In the northern Alboran Sea, spatial modelling of line transect data (1992-2007) yields an abundance estimate of 102 animals with a CV=32.1% (corrected for availability bias from a D-tagged animal in the Alboran Sea) (Oedekoven et al. 2009). Abundance estimates for the whole Alboran Sea have been obtained after analysis of the Sirena08 and MED09 survey cruises. Results highlight a relatively high density (compared to other areas of the world) of Cuvier´s beaked whales in the Alboran Sea (44 groups, 89 individuals in 846 km on survey effort in 2008-2009, for an encounter rate of 10.5 individuals per 100km of effort; unpublished data). A density estimate was obtained for the whole Alboran Sea from -0.5W to -6W: 0.025 animals per km2 with a CV of 32.1% and another estimate for the same area but only for depths greater than 500m: 0.062 animals per km2 with a CV of 44.2% (both estimates corrected for availability bias from a D-tagged animal in the Alboran Sea; Oedekoven et al. 2009) (unpublished data).

There are no data on trends for this species in the Mediterranean.

There are areas, especially in the southern portions of the basin, where Cuvier's beaked whales have not been recorded from either strandings or sightings. However, it must be borne in mind that their long dive times, usually inconspicuous appearance at the surface and typical avoidance of vessels make them difficult to spot (Heyning 1989). In addition, sighting effort and the efficiency of stranding networks vary throughout the Mediterranean: many areas have little or no effort to make and record sightings or to detect strandings.

ACCOBAMS initiative

Recalling ACCOBAMS purpose to reduce threats to cetaceans in the region and to improve our knowledge of these animals, the Fourth meeting of the Scientific Committee of ACCOBAMS (Monaco, November 2006) addressed the issue of the impact of anthropogenic noise on marine mammals in the Mediterranean Sea, further considering that the relationship between atypical mass strandings and military manoeuvres has been already proved in several parts of the world, including the Mediterranean (the last reported cases of atypical mass stranding in Almería, Spain in January 2006 and very recently in Italy in 2011).

In the specific case of Cuvier's beaked whales, *Ziphius cavirostris,* it was stressed that information on their distribution and habitat use in the Mediterranean is of fundamental importance for preventing further events of injury and death. Therefore, the Committee agreed that appropriate information on distribution and habitat use of Cuvier's beaked whales in the Mediterranean should be made available to interested parties (national Navies, NATO, seismic exploration companies etc.) to prevent the use of high intensity noise in potential high density or highly suitable areas for this species. It would also allow us to focus on potential areas with targeted survey effort.

Unfortunately, as stated in the Red List assessment developed for the Mediterranean and Black Sea Cetacean Assessment Workshop (March 2006), appropriate data on distribution and relative (or absolute) abundance of Cuvier's beaked whales in the Mediterranean are lacking. Therefore, the Scientific Committee agreed that a habitat use modelling exercise (e.g. see Cañadas *et al.*, 2005) should be attempted for the Mediterranean Sea (or, at least, for the areas where enough survey effort has been carried out to some extent) and Ana Cañadas was designated to co-ordinate this effort and undertake the analysis.

Collaborative effort

The modelling initiative is a collaborative effort with all those holding suitable effort and sightings data in the area. This represents an important step forward in two main ACCOBAMS actions: the preparation of the basin wide survey, and the development of the

ACCOBAMS sightings database. In other words, this exercise could also serve as a 'test' for the running of a sightings and effort database at the regional level. In addition, it will require the creation of grids of cells for the entire area, the collection of appropriate environmental covariates, and it will provide very valuable information for the design of the basin-wide survey.

This work has used habitat preference modelling as tool for data analysis. The approach uses physical and environmental data to help explain variation in cetacean distribution and predict areas that are important for target species.

METHODS

Data collection and compilation

Many persons and Institutions have contributed data to this initiative, totalling 336,709 km of survey effort in good to moderate searching conditions (Beaufort 3 or less) which yielded 272 sightings of beaked whales including 582 individuals, covering a time span of 21 years, from 1990 to 2010.

Table 1 shows the contributors to this initiative, and the effort (in km) and sightings data available for modeling (in good searching conditions). Fig. 1 shows the bathymetry of the Mediterranean Sea, Fig. 2a shows the track lines of effort, Fig. 2b shows the density of effort; and Fig. 3 shows both effort and sightings of beaked whales together. The ownership of the data remains with the contributors.

Data organization

A grid of cells with a resolution of 0.2º (22.2x22.2 km; 494 km^2) was built, and a number of geographical and environmental covariates were associated to each grid cell, namely: latitude, longitude, mean depth, standard deviation of depth, slope, aspect, distance from the 1000m depth contour, distance from the 2000m depth contour, average sea surface temperature and standard deviation of the mean in three ways: throughout the year, for summer months (June to September) and for non-summer months (October to May) for the period 1992-2006 (available from http://las.pfeg.noaa.gov/oceanWatch/oceanwatch_safari.php). The size of the grid was chosen as a trade-off between limiting the number of grid cells for computational reasons and the resolution of the available covariates. The total number of grid cells was 6,881.

All effort was divided into equal segments as far as possible of 18.5 km long on average to have a similar resolution as the grid cells, which are 22.2x22.2 km in size. Each segment was assigned to a grid cell according to the position of its middle point, and the covariates associated to that grid cell were then associated too to that segment.

Two sets of data were prepared for the modelling:

a) Segments set: The full set of segments, totalling 23,658, each one with the associated covariates, the number of groups and the total number of animals detected in each segments.

b) Grid cells set: The effort in each grid cell was approximated by summing up the length of all segments associated with each cell. This means that some portions of some segments will actually be in adjacent cells to the cell to which the segment has been assigned, but this should not make much difference at the spatial scale being modelled. The number of groups and individuals assigned to each grid cell (according to in which segment they were detected and to which grid cell such segment was assigned) were also added up. The total number of grid cells with effort in them was 2,016 i.e. about 30% of the total.

The rationale to create the Grid cells set is that using segments as sampling units, 99% of them are zeros and only 1% have positive observations in them. This extremely large proportion of zeros in the dataset makes the explanation of such variability very difficult. On the other hand, when grid cells are used as sampling units, the proportion of zeros, still being extremely large, is lower: 95.7%. In addition, by adding up all the effort and sightings in each grid cell, those grid cells with the presumably preferred features (covariate values) will have very often some positive value in them, while in the case of segments, even segments passing over identical features (i.e. over the same grid cell) will have some positive observations but largely zeros. This variability is much more difficult to explain by the models.

Data analysis

Preliminary analysis

Four different approaches were undertaken initially for modelling the habitat usage by beaked whales, one using the Segments set and three using the Grid cells set. The Segments model and one of the Grid cells models used number of animals detected as response variable and the amount of effort per segment/grid cell as offset. Another grid cells model used presence/absence as response variable (weighted by effort) and the last model used the same presence/absence but adding a second step modelling the group sizes and multiplying both results together to get a relative index of density.

Models were fitted using package ‘mgcv’ version 1.4-1.1 for R version 2.11.1 (http://cran.r-project.org). Automated model selection by a stepwise procedure is not possible with quasi-Poisson error structure. Therefore, manual selection of the models was done using three indicators:

(a) the GCV (General Cross Validation score) which is in practice an approximation to AIC (Wood 2000) and in which smoothing parameters (in terms of number of knots and degrees of freedom) are chosen by the software to minimize the GCV score for the model, unless they are directly specified - in the case of the presence/absence binomial model the UBRE score (Un-Biased Risk Estimator) was used instead;

(b) the percentage of deviance explained; and

(c) the probability that each variable is included in the model by chance.

Final analysis

After reviewing the results from the four approaches and consulting with the data contributors and other experts, I decided to chose the Grid cells model using animals as response variable as the final model to be reported. This model fitted better than the other models (explained more variability) and incorporated more information in one single step. This was a one step model using grid cells with effort as sampling units and animals as response variable, using the total effort assigned to each grid cell as offset. This was modelled using a Generalized Additive Model (GAM). A Poisson error distribution was not considered appropriate for the response variable due to over-dispersion. Therefore, a quasi-poisson family was used, with variance proportional to the mean, with a logarithmic link function. Only grid cells with a minimum of 1.85 km of effort in them were used in the models.

Predictions of relative density were produced over all the grid cells of the Mediterranean Sea, according to the values of the covariates used in the final model.

A non-parametric bootstrap with replacement with 400 iterations was used to generate 95% Confidence Intervals for the results. Even if in this work we are not interested in the actual numbers of density/abundance, the Confidence Intervals can be plotted in GIS to show which are the areas that even at the lowest 95% show up as important or with predicted high use by the model.

RESULTS

The best model selected three covariates: depth, average sea surface temperature, and latitude, with a total deviance explained of 57.8%. Table 2 shows the details for this model. Fig. 4 shows the smoothed functions of the covariates selected in this model. Fig. 5 shows the predicted encounter rate of beaked whales individuals in the Mediterranean based on this model, and Fig. 6 shows the beaked whale sightings overlying this prediction. Fig. 7 and 8 show the lower and upper 95% Confidence Intervals respectively.

DISCUSSION

It is very important to highlight that this analysis used a compilation of 21 years of data, collected from a variety of survey platforms (including ship-based surveys with several different vessels and aerial surveys), by observers with different levels of experience, with very heterogeneous coverage of the different areas of the Mediterranean Sea, and with both good and moderate sighting conditions. In particular, there are large areas where there are little or no data. Therefore, this analysis should be considered as a preliminary exploration and the results should be taken with considerable caution. The results need to be validated when a proper systematic survey is performed in the Mediterranean Sea.

Nevertheless, although the model approach chosen fitted the data better, all approaches used in preliminary analysis yielded similar results, giving some confidence in the robustness of the model predictions.

The best model highlights three areas with the highest relative density of beaked whales: the Alboran Sea, the Northern Ligurian Sea, and the Hellenic Trench and north of Crete. These areas are well represented also in the lower 95% confidence interval. In addition, the Tyrrhenian Sea, the Southern Adriatic Sea and some areas to the north of the Balearic islands and south of Sicily show relatively high predicted density compared to the rest of the Mediterranean. There is additionally an area in the far east of the Mediterranean, in front of Syria, with a relatively high prediction, but this area has no survey effort; this area should be explored before any conclusions about the relative abundance of beaked whales are drawn.

The main areas highlighted as important (Alboran Sea, Ligurian Sea, Hellenic Trench) are supported by a large proportion of the available data giving some confidence that these are genuinely high-use areas. Also, these areas are in agreement with previously reported information on beaked whales in the Mediterranean, as shown in the introduction. In particular, the large "hot spot" in the Alboran Sea shown by this model, coincides very neatly with the results of the preliminary analysis in the Alboran Sea, both in terms of relatively very high density and in terms of the distribution pattern in this area (unpublished data).

Much less confidence can be accorded to many areas of low predicted relative density because of the lack of effort data. In particular, the south-eastern Mediterranean where very little or no survey effort was available, should not be considered as "beaked whales free" area, but rather survey effort should be placed there to assess the presence or otherwise of these species in the area. In other words, it is extremely important to highlight that predictions in areas of little or no effort (see Fig. 2b) are useful only in an exploratory context. In addition, the low or very low density attributed by the model to the northern part of the Hellenic Trench highlights the fact the current results by no means can be a "green light" for high levels of noise pollution (such us military sonar, seismic survey, etc.) in areas that did not come out as hotspots by the model. In the northern part of the Hellenic Trench where densities appear to be low according to the model, major disasters have occurred in the past by two mass strandings and one single stranding totalling 30 individuals occurring during three independent military exercises with sonar use (Frantzis 1998, 2004, in prep.).

The exploratory analysis conducted here has generated model predictions of relative density throughout the Mediterranean. Although the accumulated dataset is remarkable in its temporal and spatial coverage, it is nevertheless limited in quantity and quality for reasons described above. The results show some predicted high-use areas that are well supported by effort data and observations of animals, and some low-use areas that are well supported by effort data without observations. However, predictions of high or low use in areas with little or no effort data must be treated with considerable caution. Future work could be focussed in two ways. More data collection in areas of predicted high use supported by the available data would increase sample size and lead to improved models. However, more important is the need for a basin-wide survey to generate data with sufficient spatial coverage to allow increased confidence in the model predictions over the whole Mediterranean and to provide contrast in the data from high and low density areas across a range of environmental covariates to improve model fitting and prediction.

REPORTING

An earlier version of this report was submitted to the ACCOBAMS Scientific Committee for review. The review by the Scientific Committee generated some recommendations about the results and their potential use for conservation/management advice, taking into consideration the limitations described above.

Section of the Report of the 7th Meeting of the Scientific Committee of ACCOBAMS:

51. Ana Cañadas presented SC7_Doc15. The modeling initiative is a collaborative effort with all those holding suitable effort and sightings data in the area. This work has used habitat preference modeling as tool for data analysis. The approach uses physical and environmental data to help explain variation in cetacean distribution and predict areas that are important for target species. A list with all data contributors to this initiative was provided.

52. The best model selected three covariates: depth, average sea surface temperature, and latitude, with a total deviance explained of 57.8%. Maps with the predicted relative densities of beaked whales in the Mediterranean were presented. The best model highlights three areas with the highest relative density of beaked whales: the Alboran Sea, the Northern Ligurian Sea, and the Hellenic Trench and north of Crete. In addition, the Tyrrhenian Sea, the Southern Adriatic Sea and some areas to the north of the Balearic Islands and south of Sicily show relatively high predicted density compared to the rest of the Mediterranean. Nevertheless, it is very important to highlight that this analysis used a compilation of 21 years of very heterogeneous data. In particular, there are large areas where there are little or no data. Therefore, this analysis should be considered as a preliminary exploration and the results should be taken with considerable caution.

53. Giuseppe Notarbartolo di Sciara remarked that the result of five years of work based on a large base of data should be considered sufficiently robust to provide recommendations that can be used for management and mitigation purposes. He further suggested that a Working Group be created to formulate the consequences of Ana Cañadas' report.

54. After having met, the Working Group proposed the following:

a. a large portion of slope and deep waters (deeper than 600 m) throughout the Mediterranean contained suitable *Ziphius* habitat;

b. based on existing knowledge of noise disturbance thresholds, beaked whales should not be exposed to received levels greater than SPL 140 dB re 1 μPa @ 1 m;

c. it was therefore recommended to apply a safety buffer around the preferred habitat mentioned in a) so that the threshold would not be exceeded.

55. The Scientific Committee approved the outcome of the Working Group.

56. Ana Cañadas informed the Committee that after consultation with all the data providers, she was going to produce a final report inclusive of the Scientific Committee recommendations, for wider circulation, as appropriate.

This report, as outcome from the Scientific Committee review, has been sent to all participants for their final agreement on the outcome, and a final report, with the authorship of all participants (data analyst and data providers), will be finalized for the Secretariat of ACCOBAMS. On the basis of this report and the recommendations of the SC, the ACCOBAMS Secretariat will distribute it to interested parties (Member States, Navies, NATO, seismic exploration companies etc.), if considered appropriate.

If appropriate, the final report may be prepared for submission to a peer reviewed journal, with the authorship of all participants (data analyst and data providers).

AKNOWLEDGEMENTS

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Table 1. Data contributors

Source	Base	Survey area	Survey type	Years	Effort (km)	Animals
Tethys Research Institute	Italy	Ligurian Sea	Ship-based	1990 - 2006	78,298	32
Pelagos Institute	Greece	Hellenic Trench & Aegean	Ship-based	1998 - 2006	10,365	63
GREC	France	Western Mediterranean	Ship-based	1997 - 2004	20,924	12
CRC - Marineland	France	Western Ligurian Sea	Ship-based	2001 - 2004, 2007	8,646	0
IFAW	UK	Southern Mediterranean	Ship-based	2003 - 2004	6,904	0
IFAW	UK	Southern Mediterranean	Ship-based	2007	8,631	10
Oceana	Spain	Western Mediterranean	Ship-based	2006	6,819	0
Barbara Mussi	Italy	Island of Ischia (Italy)	Ship-based	2004 - 2006	7,076	0
Tethys Research Institute	Italy	Northern Adriatic Sea (Italy)	Ship-based	2003 - 2006	4,807	0
Tethys Research Institute	Italy	Ionian Sea (Italy)	Ship-based	1991 - 1994	12,864	9
Tethys Research Institute	Italy	Strait of Messina (Italy)	Ship-based	2005 - 2006	5,529	2
University of Valencia	Spain	Eastern Spain	Aerial survey	2000 - 2002	23,081	4
SMRU	UK	Balearic Islands (Spain)	Ship-based	2003 – 2006	6,212	3
General Secretariat of Maritime Fisheries (SGPM)	Spain	Alboran Island	Ship-based	2002 - 2010	2,750	40
SEC-ANSE	Spain	South-eastern Spain	Ship-based	2003, 2005	4,432	0
Alnitak	Spain	Northern Alboran Sea	Ship-based	1992 - 2010	66,578	106
Alnitak	Spain	Alboran Sea and coasts of Morocco	Ship-based	2009	2,410	15
Marina Pulcini	Italy	Southern Italy	Ship-based	1993 - 1996	869	28
CNRS	France	Line France - Algeria	Ferry	2006 - 2007	7,363	0

Table 1. Data contributors (cont.)

Source	Base	Survey area	Survey type	Years	Effort (km)	Animals
NURC	Italy - US	North-Western Mediterranean	Ship-based	2005	1,380	7
NURC-WHOI	Italy - US	Western Mediterranean	Ship-based	2008-2009	5,647	212
ISPRA	Italy	Adriatic Sea	Aerial survey	2010	10,368	4

Table 2. Covariates selected in the model, their estimated degrees of freedom (approximately number of knots in the smoothed function - 1), their p-value (probability that their inclusion in the model is by chance), and the % of deviance explained by the model.

Covariates	Estimated degrees of freedom	P value	% Deviance explained
Depth	4.89	<0.0001	
Sst	4.97	<0.0001	57.8%
Latitude	4.99	<0.0001	

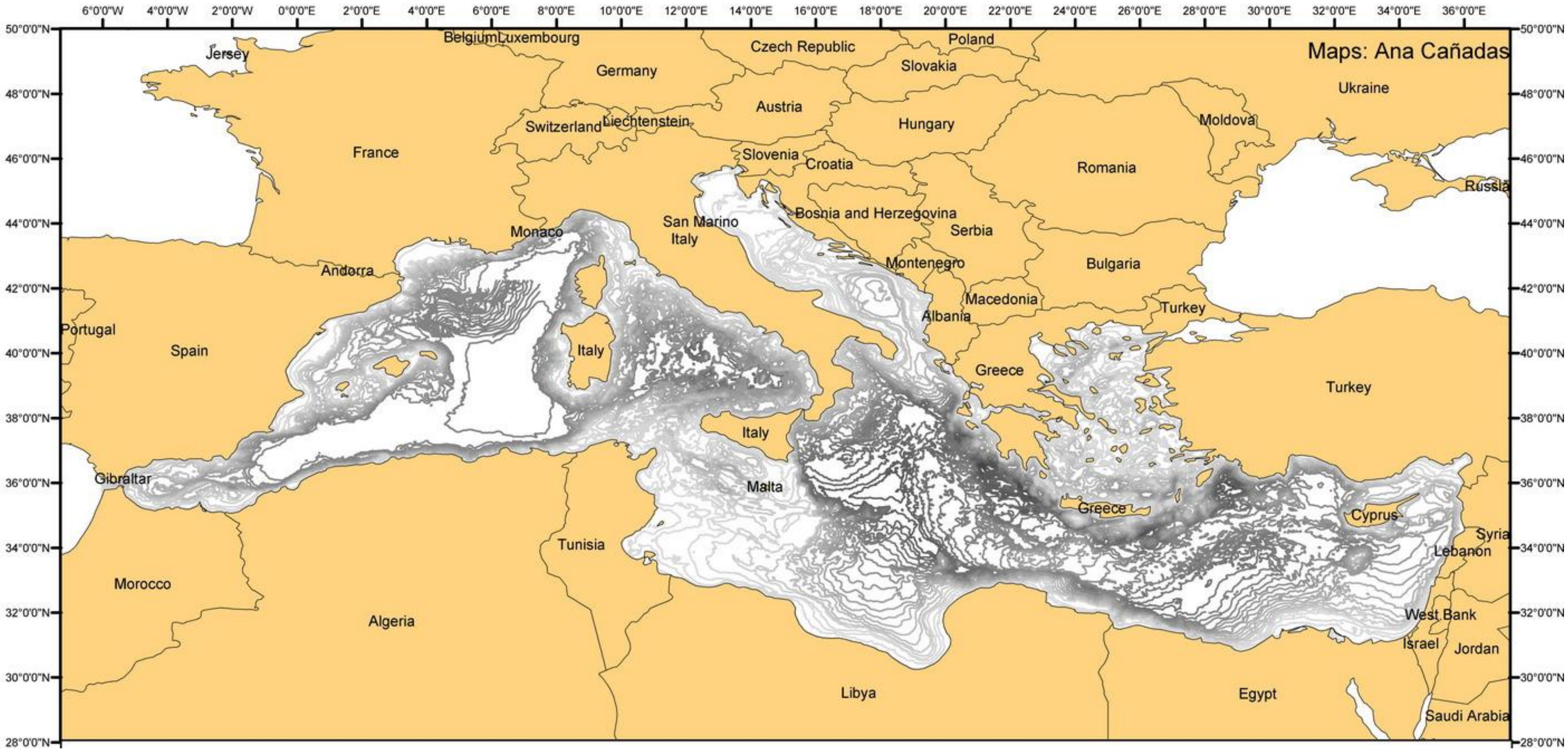

Figure 1. Bathymetry of the Mediterranean Sea

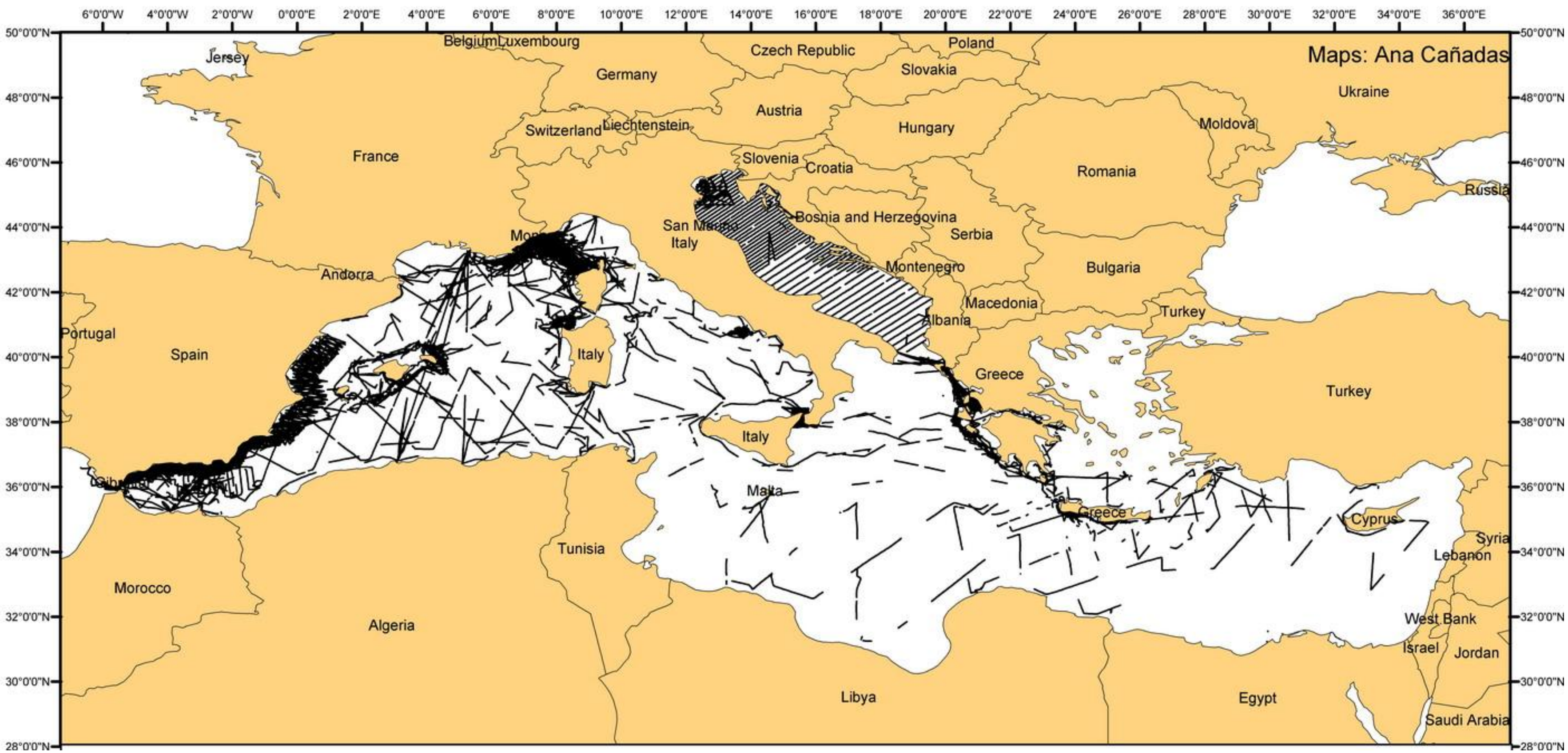

Figure 2a. Searching effort (track lines) from 1990 to 2010

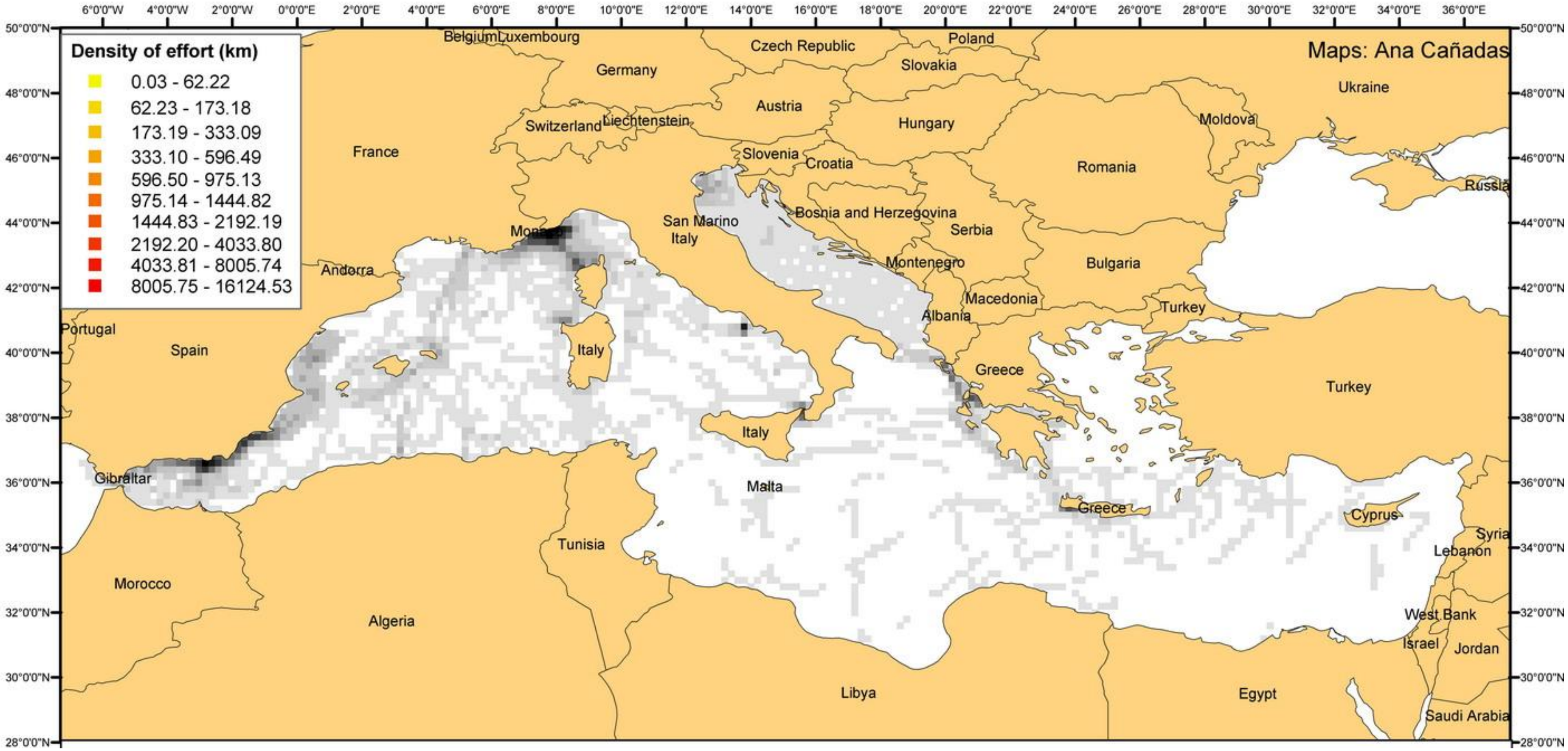

Figure 2b. Searching effort (density, in km) from 1990 to 2010

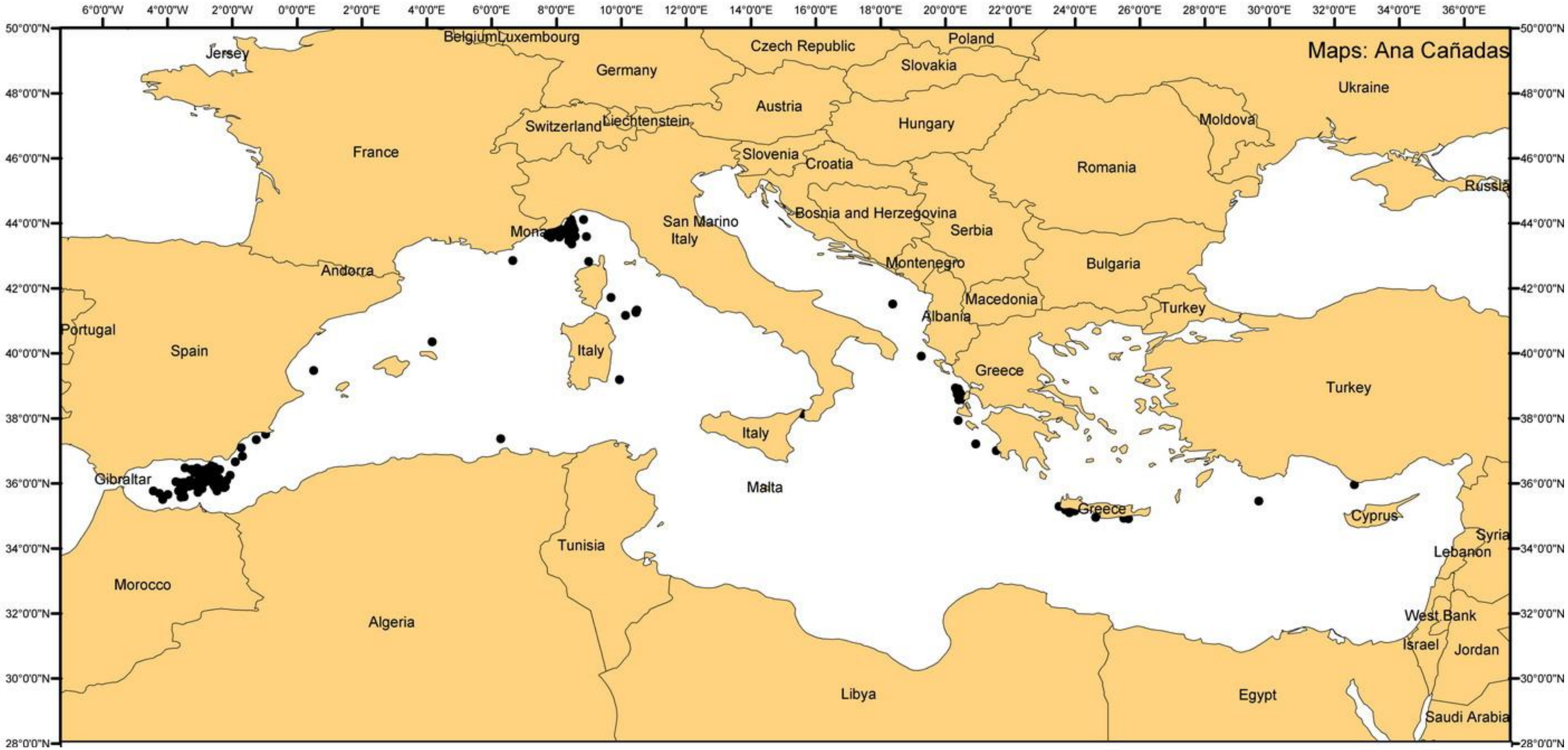

Figure 3. Sightings of beaked whales from 1990 to 2010

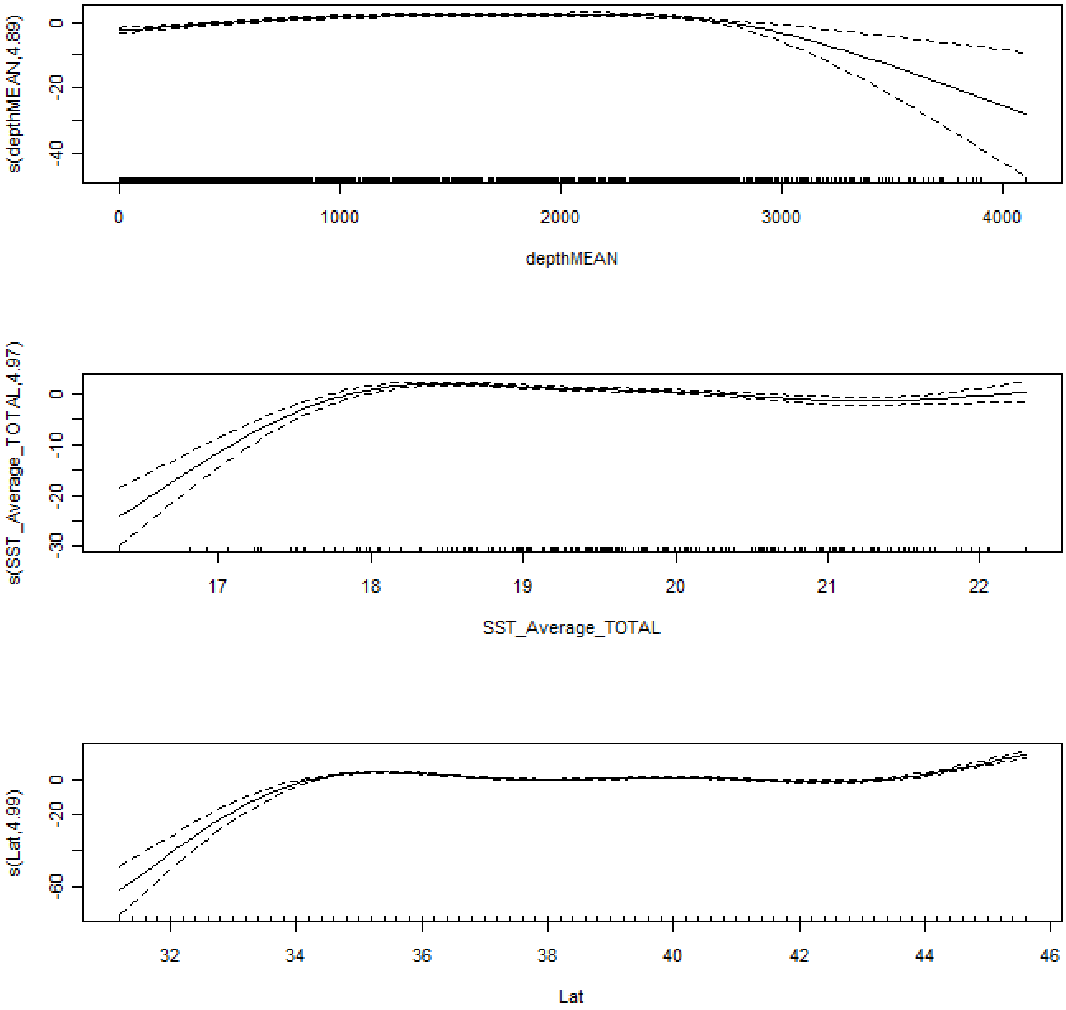

Figure 4. Smoothed functions of the covariates selected in the final model: depth, average sea surface temperature, and latitude.. The ticks on the x axis show the distribution of the sample data used in the model (the grid cells) for each covariate. The dashed lines represent ±1 se. The y-axis represents an index of relative density. When the fitted line of the smooth function is greater than 0, the covariate has a positive effect and *vice versa*.

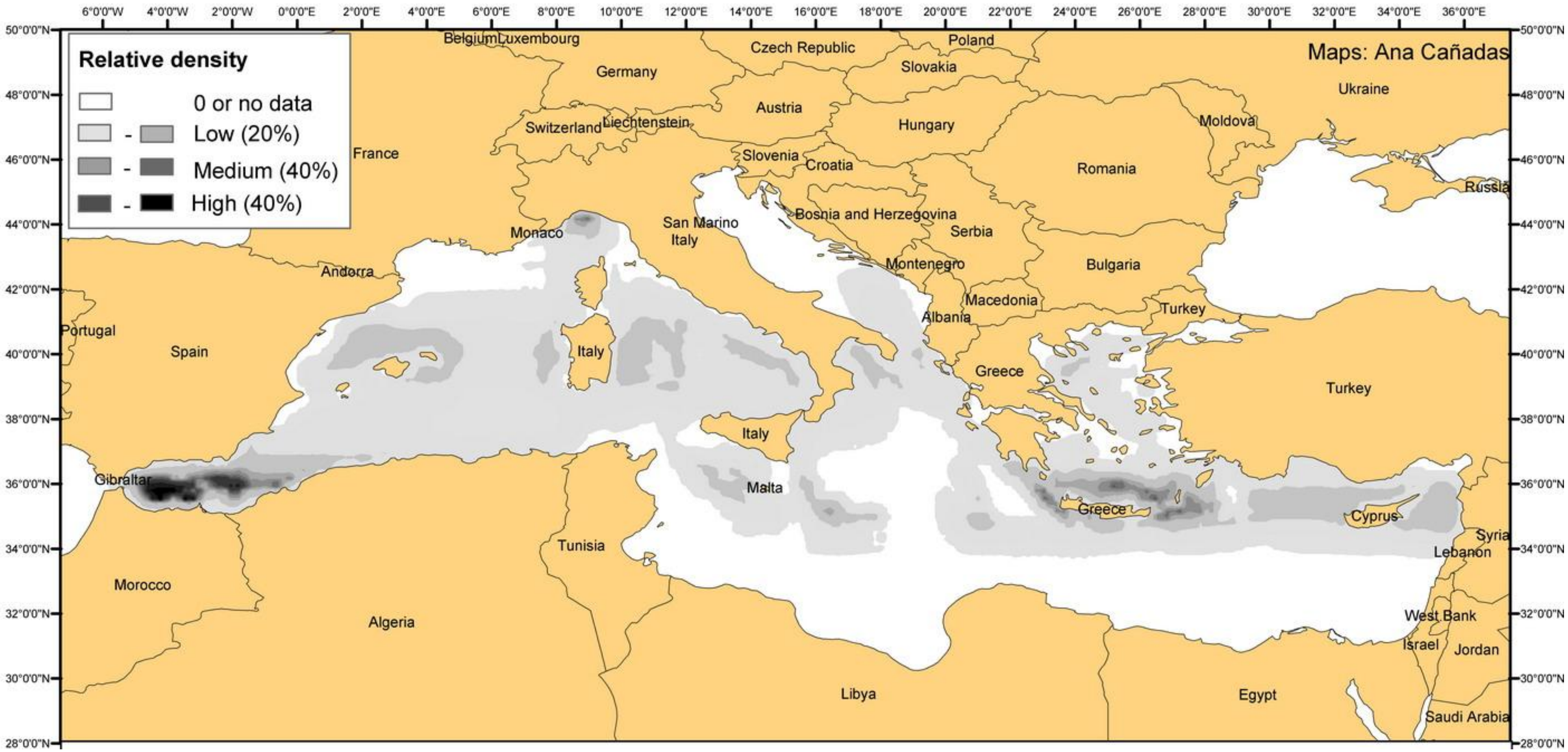

Figure 5. Predicted relative density of beaked whales

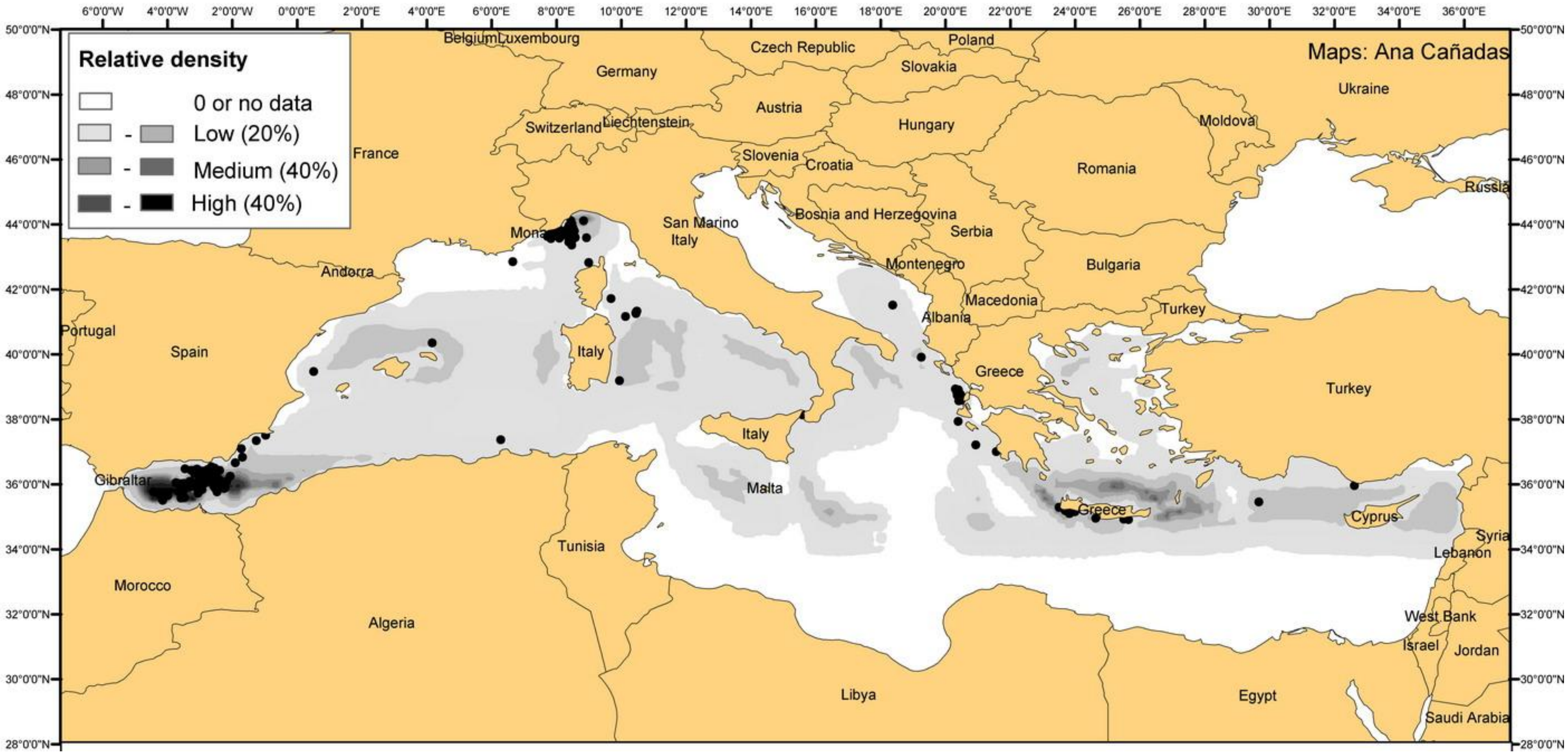

Figure 6. Predicted relative density and sightings of beaked whales

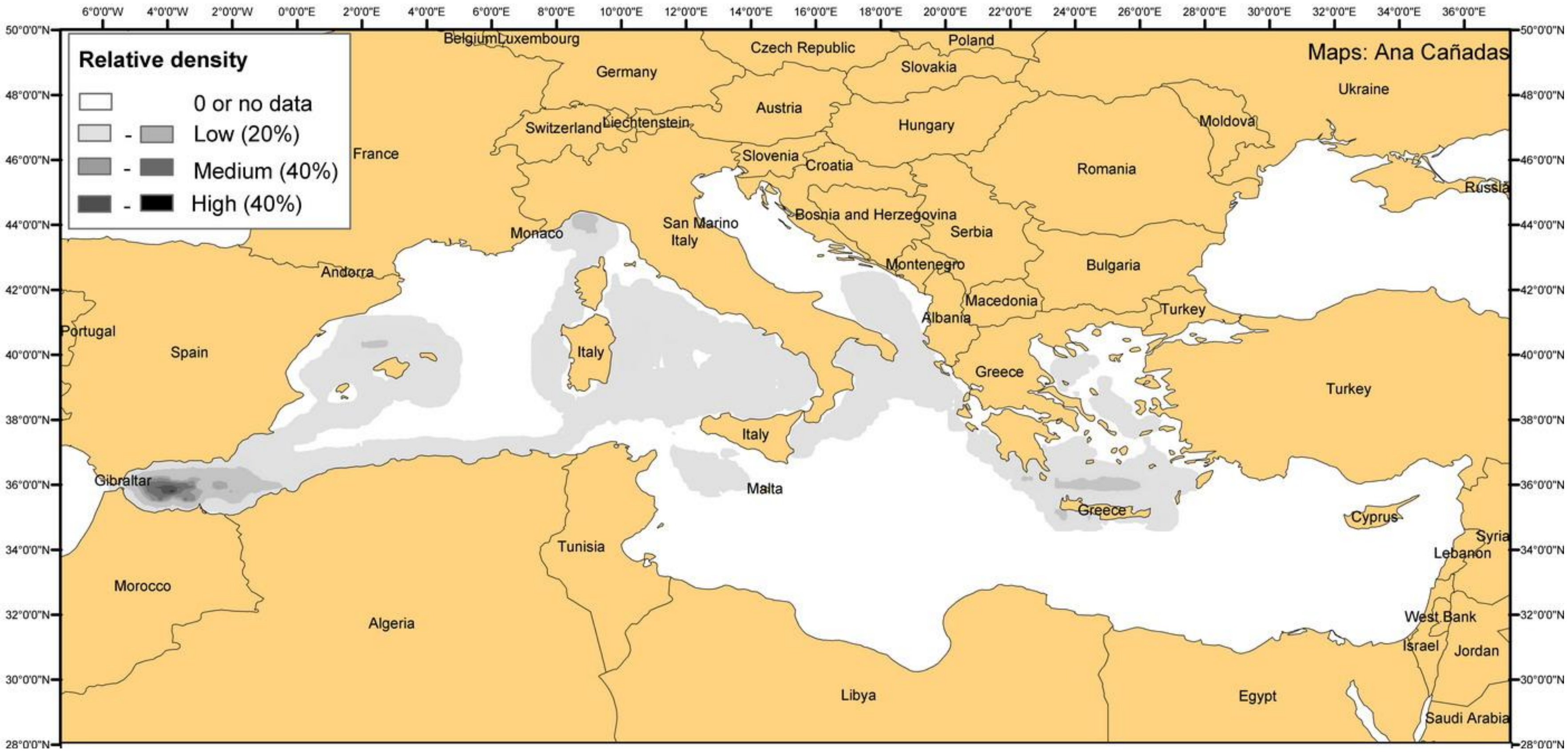

Figure 7. Lower 95% CI of the relative index of density

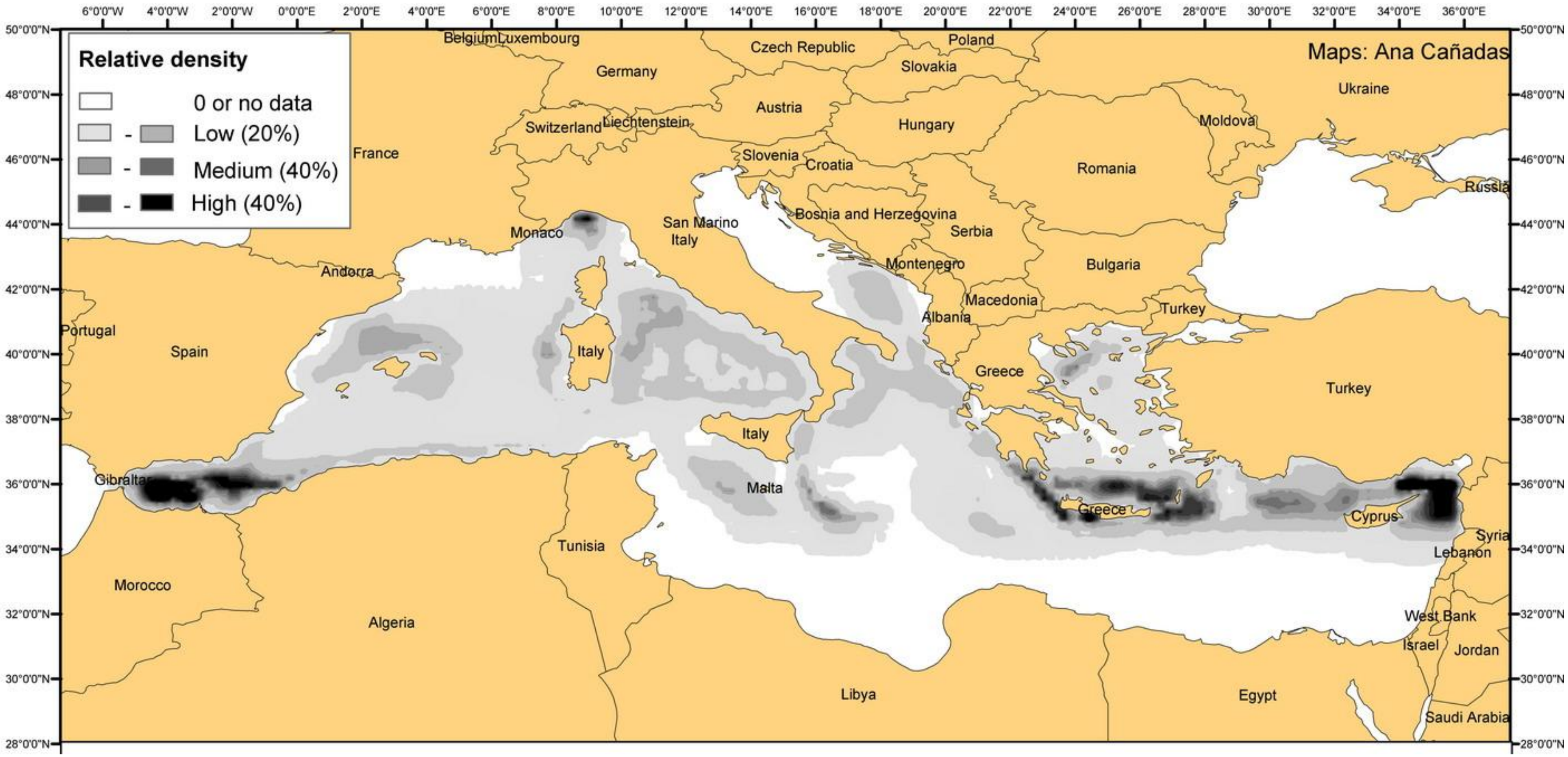

Figure 8. Upper 95% CI of the relative index of density