Estimate of abundance of beaked whales in the Alboran Sea

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ABSTRACT

Links between atypical mass strandings of beaked whales and military manoeuvres have been demonstrated in several parts of the Mediterranean, including the Alboran Sea. Here, information on distribution and abundance of Cuvier's beaked whales is presented for the Alboran Sea, which has been shown to be a high use area for this species. Such information is of great importance to allow the impacts of mass strandings, entanglements, etc to be put in a population context and to highlight the most important areas for this species that may be a focus for conservation action. The data used for these analyses come from two sources: data collected during the summers of 2008 and 2009 on board the vessel Alliance during the Sirena08 and Med09 surveys; and data collected during surveys carried out under the umbrella of the NGO Alnitak from 1992 to 2009. Detection functions were obtained using distance sampling methods and density surface modelling was undertaken for three different datasets: a) northern section of the Alboran Sea (1992-2009); b) deep waters of the Alboran Sea (2008-2009); and c) whole Alboran Sea (2008-2009). Uncorrected estimates of density (in animals/km^2) were 0.0069 (CV=17.9%), 0.019 (CV=28.1%) and 0.0077 (CV=39.7%), respectively. A preliminary correction for availability bias (0.306) was applied to these estimates, based on data from one animal tagged in the area in 2008, to generate more realistic estimates. Based on these results, and comparison with estimates from elsewhere, it is clear that the Alboran Sea supports one of the highest densities of Cuvier´s beaked whales in the world. Information on distribution and habitat use of Cuvier's beaked whales in the Mediterranean should be made available to relevant parties in efforts to prevent the use of high intensity noise in high use areas for this species.

INTRODUCTION

The relationship between atypical mass strandings and military maneuvers has been already proved in several parts of the Mediterranean, including the Alboran Sea. Therefore, information on their distribution and habitat use in the Mediterranean is of fundamental importance for preventing further events of injury and death, i.e., 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.

An abundance estimate of beaked whales has been obtained for the Alboran Sea, an area which has proven to be a hot spot for this species. This is of great importance to (a) put potential threats into context (impact of a given amount of deaths -mass strandings, entanglements, etc- on the population) and (b) highlight the most important areas for this species, susceptible for protection for the conservation of the species.

These analysis are integrated in the project “Beaked whales and pilot whales in the Alboran Sea (SW Mediterranean): research towards improved science-based mitigation strategies from man-made sound” funded by ONR and carried out in collaboration among Woods Hole Oceanographic Institution, Alnitak Marine Research Center and Alnilam Research and Conservation.

DATA SOURCES

The data used for these analysis come from two sources: (a) data collected during summers of 2008 and 2009 onboard the vessel *Alliance* during the Sirena08 and Med09 surveys, and (b) data collected during surveys carried out under the umbrella of the ngo Alnitak, on board 3 vesels: *Toftevaag* (2008-2009), *Thomas Donagh* (2009) and the Fisheries Patrol boat of the General Secretariat of Maritime Fisheries (2008-2009). Data on radial distance and angle were collected in all cases. Figures 1 and 2 show the tracks on effort and Figures 3, 4 and 5 the sightings during on effort tracks.

Sightings correspond in their majority to Cuvier’s beaked whales (*Ziphius cavirostris*), but there are also several sightings not identified to species, but assumed to be most probably Cuvier´s beaked whales.

Three data-sets were used for three modeling exercises: (a) Alliance 2008-2009: only data from the *Alliance* vessel and considering only the area comprising depths of 500m or more between the eastern side of the Strait of Gibraltar and the vertical line between Cabo de Gata and de North African coast (31,370 km^2); (b) All ships 2008-2009: all data from all vessels during 2008 and 2009 and considering the whole area from coast, including the Strait of Gibraltar and the Gulf of Vera (to the vertical line between Cabo de Palos and the North African coast) (79,532 km^2); and (c) All ships 1992-2009: all data from all vessels from 1992 to 2009 and considering the usual study area from coast up to around 25nmi from shore, including the Strait of Gibraltar and the Gulf of Vera (25,589 km^2).

ANALYTICAL METHODS

The study area (the whole Alboran Sea from the Strait of Gibraltar to Cabo de Palos-Spain, and Algeria) was divided into 7,843 grid cells, with a cell resolution of 2 minutes latitude by 2 minutes longitude each. The grid cells were characterized according to several spatial and environmental variables (Table 1).

All on effort transects were divided into small segments (average 2.8 km, maximum 4 km) with homogeneous type of effort along them. It was assumed that there would be little variability in physical and environmental features (like bottom physiography, sst, etc.) within these segments. Each segment was assigned to a grid cell based on the mid point of the segment and values of covariates for each grid cell were associated with the segment.

For model-based abundance estimation based on spatial modeling, the methodology described in Cañadas and Hammond (2006; 2008) was followed, in which five steps were taken: (1) the detection function was estimated from the distance data and any covariates that could affect detection probability; (2) the number of groups in each segment was estimated through the Horvitz-Thompson estimator (Horvitz & Thompson 1952; Borchers et al. 1998); (3) the abundance of groups was modeled as a function of spatial and environmental covariates; (4) the mean group size was calculated; (5) steps 3 and 4 were combined and extrapolated to the whole study area to obtain the final abundance of animals.

A detection function to estimate the probability of detection was fitted to all beaked whale sightings from the four vessels from 1992 to 2009 to be used in the models "All ships 2008-2009" and "All ships 1992-2009" using all data, and another detection function was fitted to data from the *Alliance* for 2008-2009 to be used in the model for this specific dataset. Only sightings realized when surveying at speeds of 11kts or less were considered to avoid bias created by data collected at very different speeds. Covariates considered for inclusion in the detection functions were of two types: effort related covariates (ship, observation platform height, position of observer, speed of vessel, sea state, swell height, sightability conditions) and animals related (cue, group size, logarithm of group sizes).

The response variable used to formulate a spatial model of abundance of groups was the estimated number of groups ($\hat{N}$) in each segment, rather than the actual counts (Hedley et al. 1999). They were estimated through the Horvitz-Thompson estimator (Horvitz & Thompson 1952):

$$\hat{N}_i = \sum_{j=1}^{n_i} \frac{1}{\hat{p}_{ij}} \quad (1)$$

where n_i is the number of detected groups in the i^{th} segment, and $\hat{p}_{ij}$ is the estimated probability of the j^{th} detected group in segment i, obtained from the detection function.

The abundance of groups was modeled using a Generalized Additive Model (GAM) with a logarithmic link function. The data were over-dispersed so a quasi-Poisson error distribution was used, with variance proportional to the mean. The general structure of the model was:

$$\hat{N}_i = \exp\left[\ln(a_i) + \theta_0 + \sum_k f_k(z_{ik})\right] \quad (2)$$

where the offset a_i is the searched area in the i^{th} segment (calculated as the length of the segment multiplied by two times the truncation distance of the detection function), θ_0 is the intercept, f_k are smoothed functions of the explanatory covariates, and z_{ik} is the value of the k^{th} explanatory covariate in the i^{th} segment.

Models were fitted using package 'mgcv' version 1.6-2 for R (Wood 2001). Model selection was done manually using three diagnostic indicators: (a) the GCV (Generalised Cross Validation score, an approximation to AIC Wood 2000); (b) the percentage of deviance explained; and (c) the probability that each variable was included in the model by chance. The decision include/drop a term from the model was adopted following the criteria proposed by Wood (2001). In all models, a visual inspection of the residuals was also made, especially to look for trends.

Given that there was very little variation in group sizes and there was no evidence of spatial variation of group sizes, the mean group size was used, instead of modeling group sizes.

The predictions of abundance of groups, multiplied by the mean group size in each grid cell, were produced over all the grid cells of the study area, according to the values of the covariate coefficients retained in the final models. The point estimate of total abundance was obtained by summing the abundance estimate of all grid cells over the study area.

These estimates are uncorrected for availability and perception bias, the two components of the g(0), or probability of detecting the animals at distance zero from the transect line, and are therefore underestimated by an unknown magnitude. Estimates were then corrected for availability bias using Oedekoven (2009) estimate or 0.306 based on data from a single D-Tag deployed on a Cuvier´s beaked whale in the Alboran Sea during Sirena08.

Six hundred non-parametric bootstrap resamples of the whole modelling process were done for each dataset, using day as the resampling unit, to obtain the coefficient of variation and percentile based 95% confidence intervals. In each bootstrap replicate, the degree of smoothing of each model term was chosen by ‘mgcv’, thus incorporating some model selection uncertainty in the variance. The final CV for the estimates from each dataset was calculated using the delta method (Seber 1982), combining the CV of the detection function with the model bootstrap CV. These values were plotted as surface maps of abundance and of variability.

RESULTS

Detection function:

The fitted detection functions for beaked whales as a group included for both datasets are shown in Table 2. Figures 6 and 7 show the detection functions for both datasets.

Spatial modeling:

Table 3 shows the covariates retained by the best-fitting model for each dataset and the smoothed functions. Table 4 shows the final predicted estimate of abundance for each dataset for the Alboran Sea and subareas (to make them comparable), both uncorrected and corrected for availability bias.

Figure 8 shows the prediction of abundance of beaked whales for 2008-2009 (data from all ships). Figure 9 shows the prediction of abundance for 2008-2009 only for waters over 500m depth (data from the *Alliance*). Figure 10 shows the prediction of abundance for 1992-2009 (data from all ships) considering only the northern Alboran Sea.

DISCUSSION

It is important to highlight that effort in the area during 2008 and 2009 was very heterogeneous and there was a big area in the center of the western half of the Alboran Sea which was not surveyed at all. Therefore, all predictions produced by the models into this area should be taken with extreme caution and be considered as an exploratory exercise. Therefore, these results should be considered as a very useful preliminary exploration of the Alboran Sea, which should be confirmed more soundly after proper systematic surveys are realized in the area, ensuring equal coverage probability or at least a more homogeneous coverage of the area and with more information on diving times and behavior of this population to allow for a reliable g(0) estimation.

The estimate of availability bias used to correct estimates of abundance is based on one single D-Tag. The corrected estimates should be treated with caution because of this, even if this value is in agreement with other g(0) values estimated for beaked whales elsewhere (Barlow et al. 2006).

Data collected from the Alliance in the Alboran Sea on multiple focal follows of Cuvier's beaked whales with precise measures of diving times both during shallow and deep dives will be analyzed this year to get better estimates of surface and diving times. In addition, a new method is being developed to better estimate a correction for availability bias from these data (D. Borchers, pers. comm.). Therefore, with these advances, a more robust correction or availability bias will be available for the Alboran Sea in a short time.

The density estimates obtained through the modeling of these three datasets are very consistent when comparing similar areas. The highest density, obviously, corresponds to the area over 500m depth, which is the most suitable habitat for this species, being almost never found in shallower waters. The density for such area extracted from the prediction from the whole area model is very similar. In the same way the estimates extracted for the area "All ships 1992-2009" corresponding to the northern Alboran Sea from the predictions for "Alliance 2008-2009" and "All ships 2008-2009" are equally very similar. These strong similarities in the estimates from the three different models give some confidence in the performance of these models.

Based on the modelling of these data, the Alboran Sea presents one of the highest densities of Cuvier´s beaked whales in the world, together with the Southern Gulf of Biscay area (see document presented during this meeting SC/63/SM7), compared to published estimates elsewhere (Table 4). However, it is a relatively small area containing a high proportion of suitable habitat so the other estimates may also contain areas of high density. Nevertheless, this is clearly an important area for Cuvier's beaked whales and warrants further study.

ACKNOWLEDGEMENTS

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Table 1. Variables associated to the grid cells and used in the models

Name	Description	Source
lat	latitude	GPS data
lon	longitude	GPS data
depth	depth	2-Minute Gridded Global Relief Data (ETOPO2v2). National Geophysical Data Center (NGDC). NOAA Satellite and Information Service.
logdepth	logarithm of depth	Derived from ETOPO2 data
cvdepth	coefficient of variation of depth	Derived from ETOPO2 data
sddepth	standard deviation of depth	Derived from ETOPO2 data
slope	slope (meters per km)	Derived from ETOPO2 data: $\frac{\left(\frac{depth_{max} - depth_{min}}{distance\ in\ km_{(depth_{max} - depth_{min})}}\right)}{10}$
ci	contour index	Derived from ETOPO2 data: $\frac{(depth_{max} - depth_{min})}{depth_{max}} * 100$
distcoast	distance from coast	Calculated with the extension Spatial Analyst from ArcGis 9.2., using bathymetric data from GEBCO.
dist200	distance from the 200 m isobath	Calculated with the extension Spatial Analyst from ArcGis 9.2., using bathymetric data from GEBCO.
dist1000	distance from the 1000 m isobath	Calculated with the extension Spatial Analyst from ArcGis 9.2., using bathymetric data from GEBCO.
chlavsum	average summer chlorophyll concentration	Sensor Sea-viewing Wide Field-of-view (SeaWiFS) of satelite Orbview-2. Resolution: 0.1 º. Program NOAA CoastWatch.
chldssum	standard deviation of summer chlorophyll concentration	Derived from the sensor Sea-viewing Wide Field-of-view (SeaWiFS) of satelite Orbview-2. Resolution: 0.1 º. Program NOAA CoastWatch.
sstavsum	average summer sst	Sensor: Moderate Resolution

		Imaging Spectroradiometer (MODIS) on Aqua, Advanced Very High Resolution Radiometer (AVHRR) on POES, Imager on GOES, Advanced Microwave Scanning Radiometer (AMSR-E) on Aqua. Resolution: 0.1º. Program: NOAA CoastWatch.
sstdssum	standard deviation of summer sst	Derived from sensor: Moderate Resolution Imaging Spectroradiometer (MODIS) on Aqua, Advanced Very High Resolution Radiometer (AVHRR) on POES, Imager on GOES, Advanced Microwave Scanning Radiometer (AMSR-E) on Aqua. Resolution: 0.1º. Program: NOAA CoastWatch.
sshsum	average summer sea surface height anomaly	Altimetry sensors in several airspace vessels (JASON-1, TOPEX/POSEIDON, ENVISAT, GFO, ERS 1/2, GEOSAT). Resolution: 0.25 º. Program NOAA CoastWatch
prpravsum	average summer primary productivity	Measurement of primary productivity based on the following satellite measurements: Chlorophyll-a concentration and photosynthetically available radiation (PAR) measurements from the SeaWiFS sensor aboard the GeoEye spacecraft, SST measurements from the NOAA Pathfinder Project and from the Reynolds Optimally-Interpolated SST (OISST) v2 product from NOAA's National Climatic Data Center (NCDC). Resolution: 0.1 º. Program NOAA CoastWatch
disttraf	distance from main shipping lines	Calculated with the extension Spatial Analyst from ArcGis 9.2., using bathymetric data from GEBCO.

Table 2. Detection functions for the two datasets

Dataset	Model	Covariates	Average probability of detection (CV)	Truncation distance (m)	Number of observations within truncation distance
Alliance 2008-2009	Half-normal	Null model (only perp. distance)	0.35 (0.101)	7,000	94
All ships 1992-2009	Hazard-rate	Platform height, sea state	0.36 (0.083)	3,800	150

Table 3. Best models selected for the spatial modeling for all species. Covariates into brackets mean an interaction

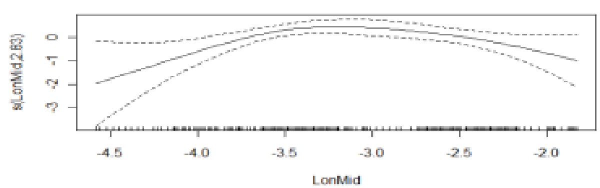
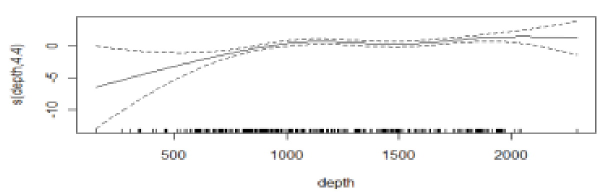
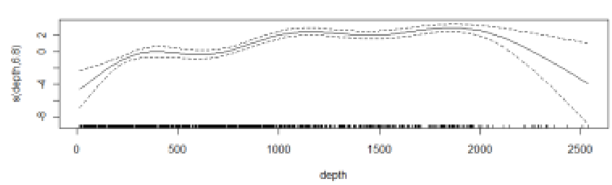
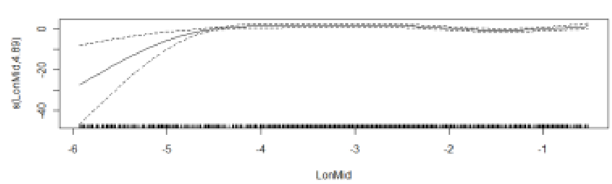
Dataset	Deviance explained	Covariates (degrees of freedom)	Smoothed functions
Alliance 2008-2009	13.0 %	- Depth (4.40) - Longitude (2.83)	 
All ships 2008-2009	24.6 %	- Depth (6.80) - Longitude (1.89)	 

Table 4. Uncorrected (for availability and perception bias) and corrected (for availability bias) estimates of abundance and measures of uncertainty for beaked whales in the Alboran Sea from spatial modeling

Dataset	Sub-area	Area	Uncorrected Density (animals / km^2)	Uncorrected estimate of abundance (95% CI)	Corrected Density (animals / km^2)	Corrected estimate of abundance (95% CI)	Coefficient of Variation
Alliance 2008-2009	Total	Alboran Sea over 500m depth (31,370 km^2)	0.0190	596 (349 – 776)	0.0621	1948 (1140 - 2536)	28.1%
	All ships 1992-2009	Northern Alboran Sea (25,589 km^2)	0.0066	170 (132 – 360)	0.0217	556 (431 - 1177)	41.4%
All ships 1992-2009	Total	Northern Alboran Sea (25,589 km^2)	0.0069	162 (110 – 199)	0.0207	529 (360 - 650)	17.9%
All ships 2008-2009	Total	Alboran Sea all depths + Gulf of Vera (79,532 km^2)	0.0077	610 (418 – 1056)	0.0251	1994 (1366 - 3451)	39.7%
	Alliance 2008-2009	Alboran Sea over 500m depth (31,370 km^2)	0.0170	537 (357 – 821)	0.0560	1755 (1167 - 2683)	35.5%
	All ships 1992-2009	Northern Alboran Sea (25,589 km^2)	0.0067	172 (133 – 278)	0.0220	562 (435 - 909)	23.8%

Table 5. Estimates of abundance and correction for g(0) for Cuvier´s beaked whales in other parts of the world (extracted from Barlow et al. 2006, see references there)

Region	**Years**	**Surface area (km^2)**	**Overall Density (animals / km^2)**	**Overall estimate of abundance**	**g(0)**	**Corrected for g(0)**	**CV (%)**
NORTH PACIFIC							
Eastern Tropical Pacific ship surveys	1986-1990	19,148,000	0.0001	20,000		N	27.0
California ship surveys	1991	815,000	0.0020	1,621	0.84	Y	82.0
Eastern North Pacific ship surveys	1986-1996	25,000,000	0.0036	90,725	0.23	Y	-
US West Coast ship surveys	1996 & 2002	1,142,500	0.0016	1,884	0.23	Y	68.0
Hawaii ship surveys	2002	2,452,916	0.0062	15,242	0.23	Y	143.0
NORTH ATLANTIC							
US NE coast CETAP summer aerial surveys	1978-1982	278,350	0.0001	25		N	94.0
Gulf of Mexico ship surveys	1991-1994	398,960	0.0001	30		N	50.0
Gulf of Mexico ship surveys	1996-2001	380,432	0.0002	95		N	47.0
Gulf of Mexico aerial surveys	1992-1994	85,815	0.0001	11		N	71.0
Gulf of Mexico aerial surveys	1996-1998	70,470	0.0003	22		N	83.0

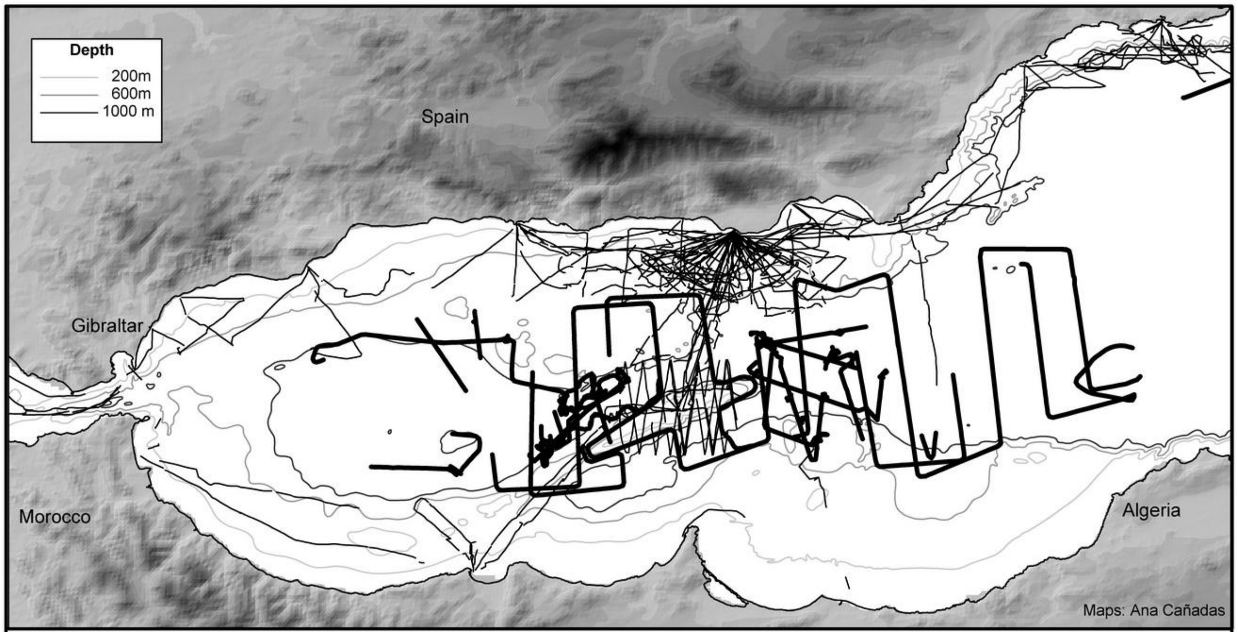


Figure 1. Searching effort in 2008 and 2009 by the *Alliance* (thick line) and by *Toftevaag*, *Thomas Donagh* and Fisheries Patrol boat (thin line).

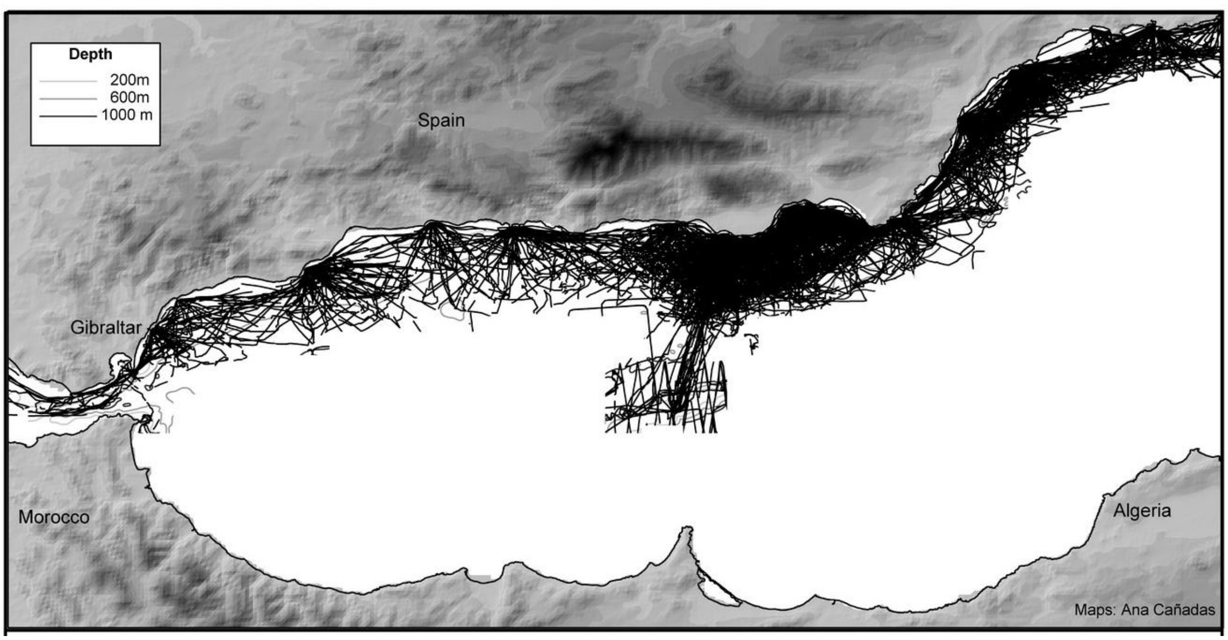


Figure 2. Searching effort from 1992 to 2009 by all ships in the northern Alboran Sea.

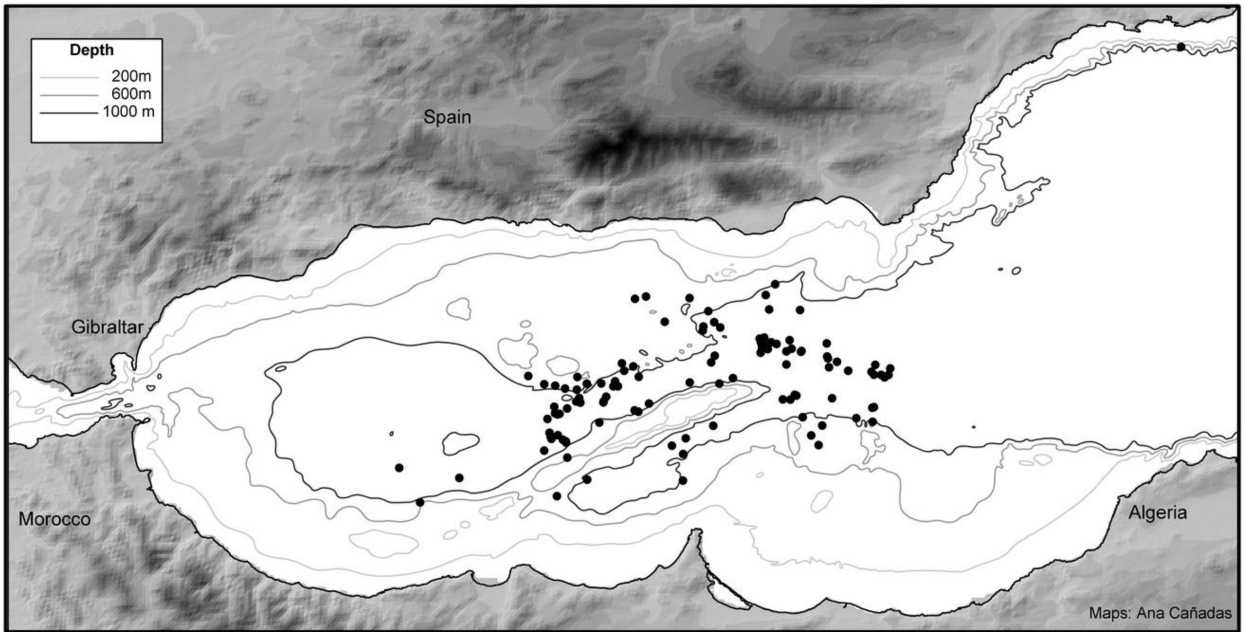


Figure 3. Sightings of beaked whales in 2008 and 2009 by all ships.

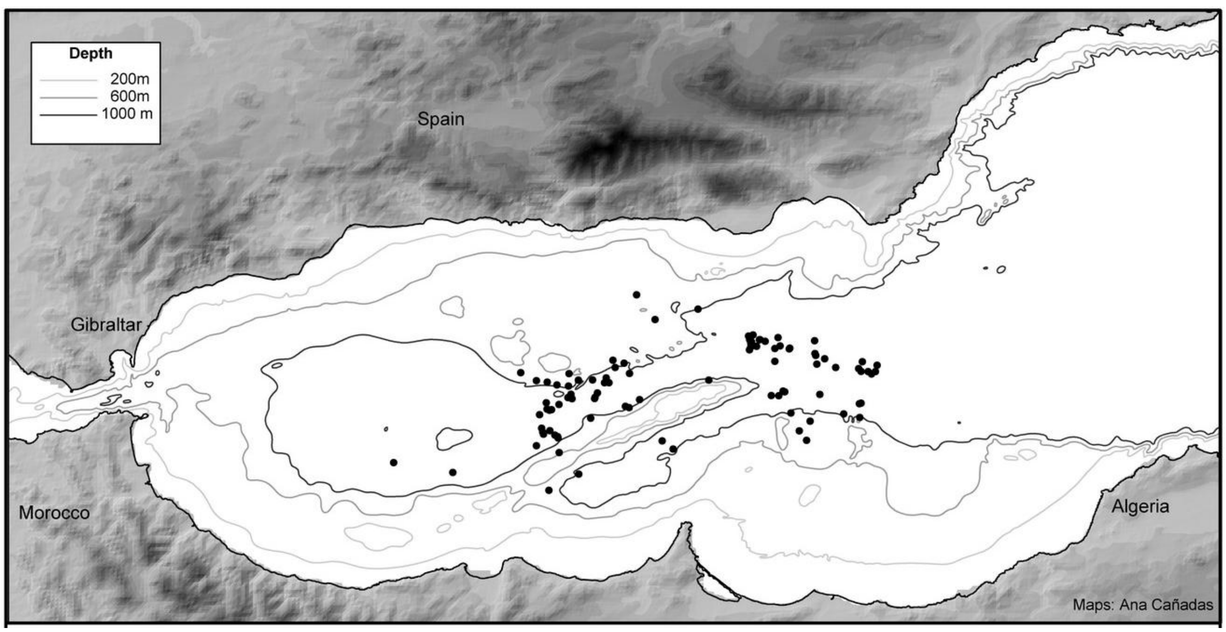


Figure 4. Sightings of beaked whales in 2008 and 2009 by the *Alliance*.

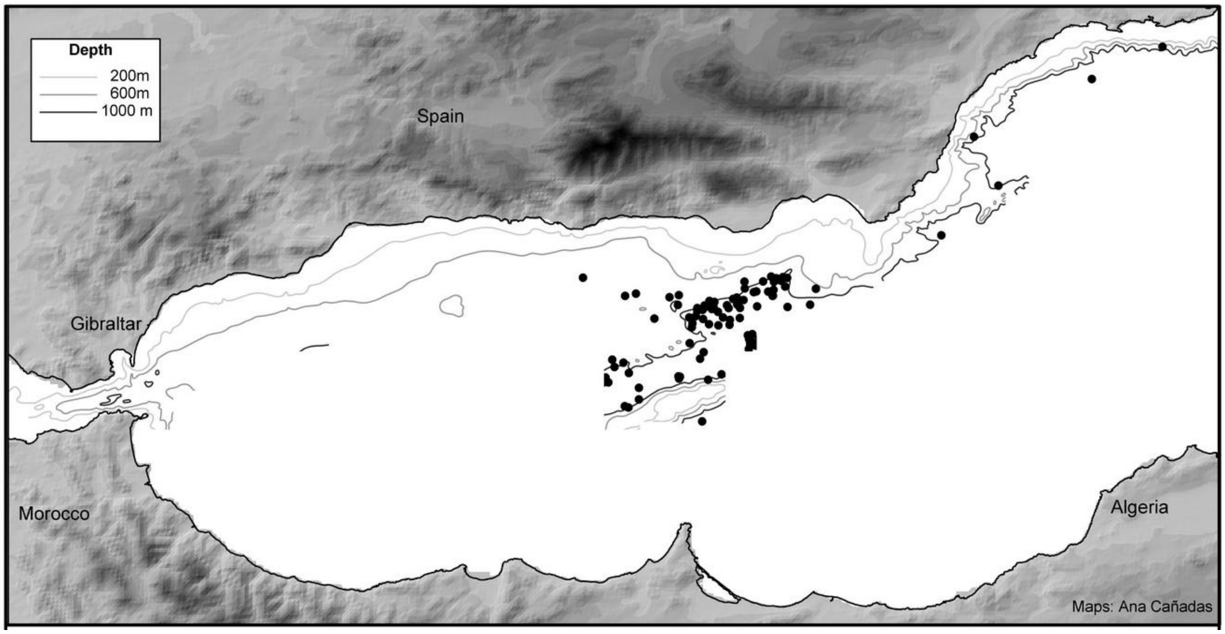


Figure 5. Sightings of beaked whales from 1992 to 2009 by all ships in the northern Alboran Sea.

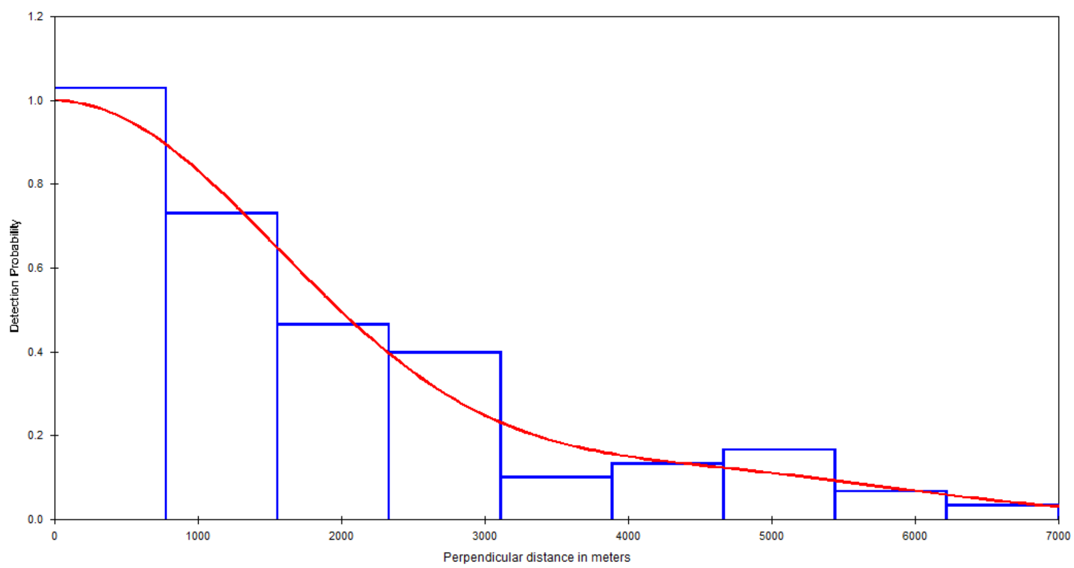


Figure 6. Perpendicular distance distribution (histograms), and fitted detection functions (line) for the *Alliance* 2008-2009 dataset.

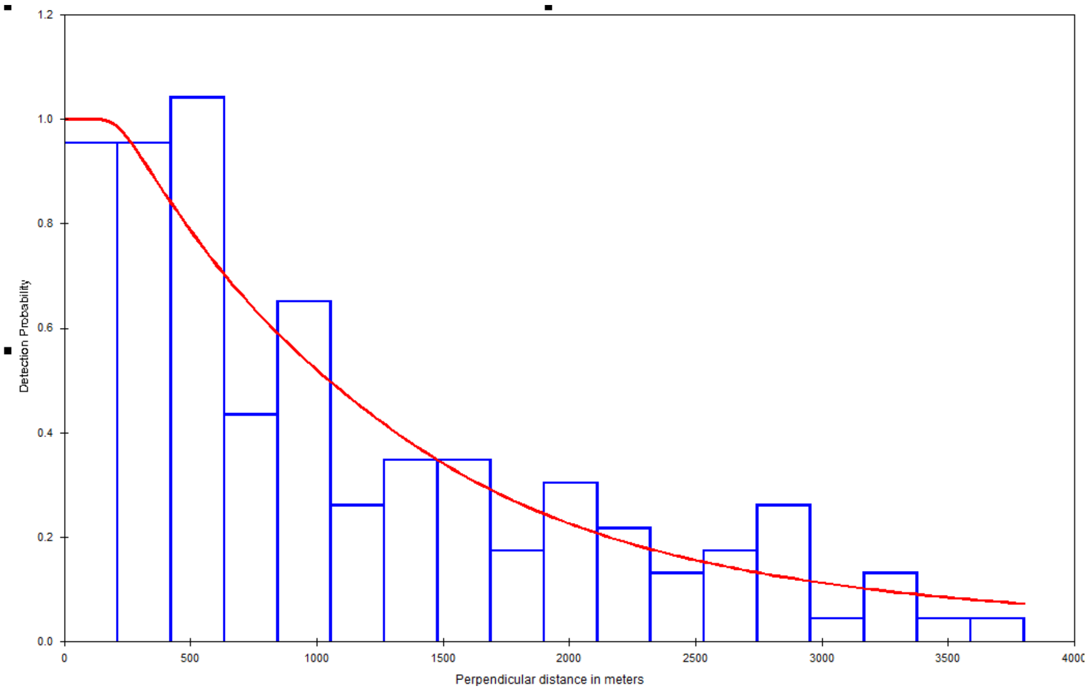


Figure 7. Perpendicular distance distribution, pooled over all covariates (histogram), and fitted detection functions, conditional to the observed covariates (line) for the All ships 1992-2009 dataset.

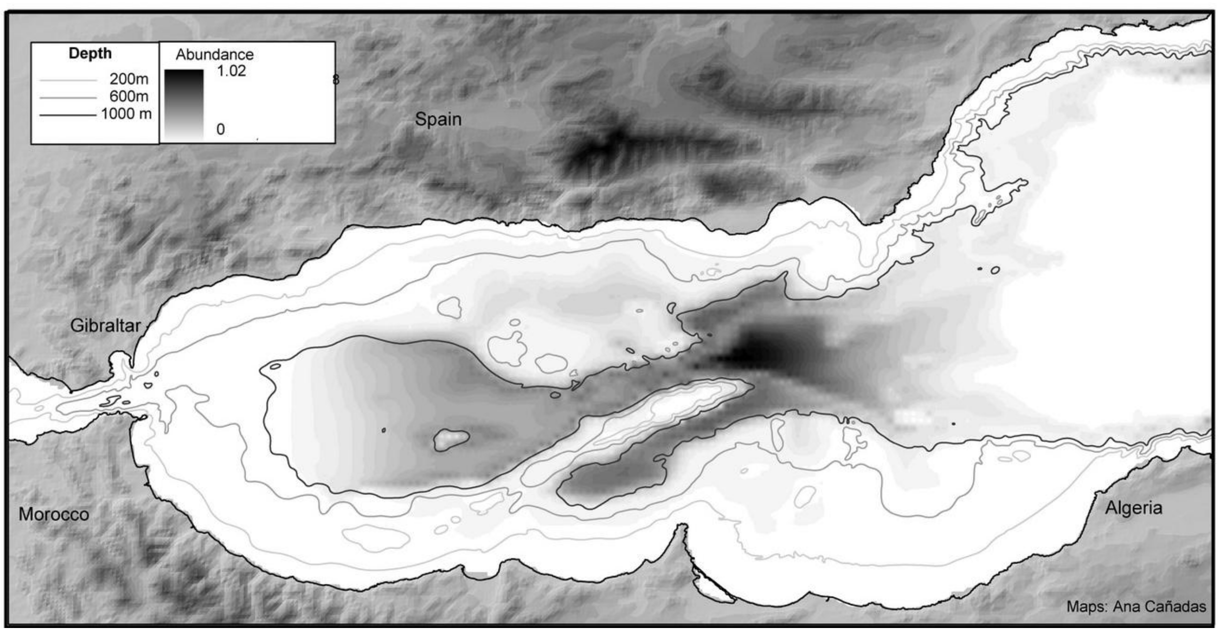


Figure 8. Prediction of abundance of beaked whales for 2008-2009 (from all ships).

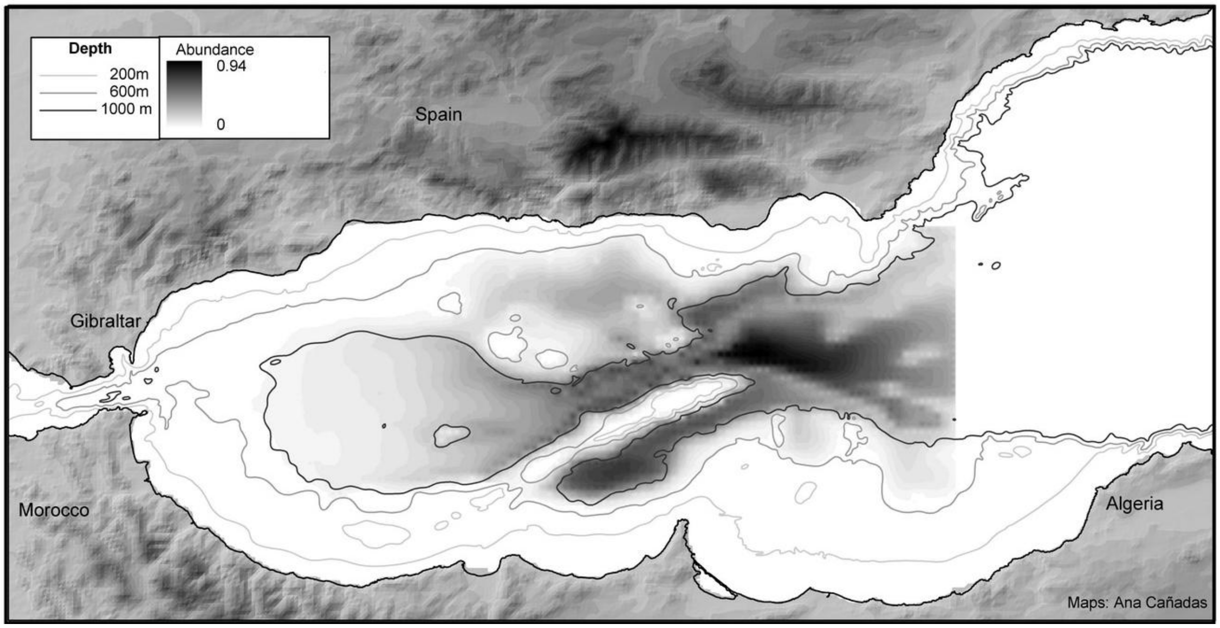


Figure 9. Prediction of abundance of beaked whales for 2008-2009 (from the *Alliance*).

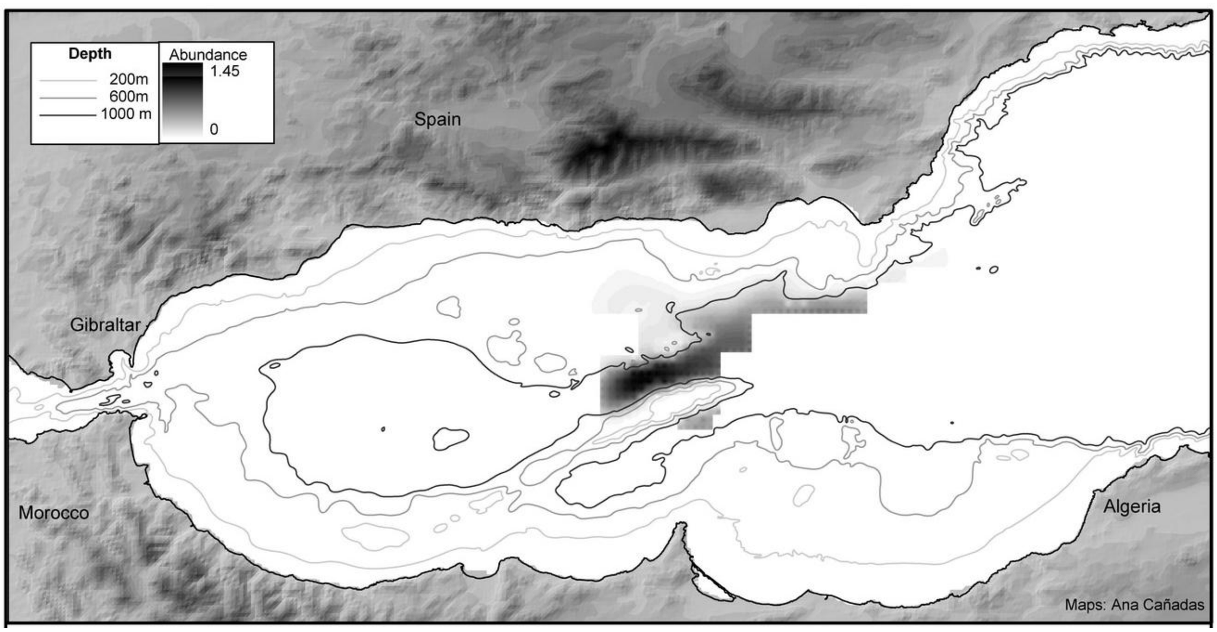


Figure 10. Prediction of abundance of beaked whales for 1992-2009 (from all ships).