Beaked Whales and Pilot Whales in the Alboran Sea (SW Mediterranean)

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LONG-TERM GOALS

There has been growing recognition that atypical mass strandings of beaked whales may coincide with naval exercises that use mid-frequency sonar, but the causal chain of events from sound exposure to stranding has not been elucidated. Even less is known about potential risks for other species of odontocete or for other signals. The primary genus proposed for study here, the pilot whale, has been documented to mass strand coincident with a sonar exercise, but the evidence linking strandings of delphinid odontocetes with sonar is weaker than that for ziphiid beaked whales. Preliminary studies indicate that the responses of delphinids to sonar and predators may differ from responses of beaked whales to the same stimuli, suggesting differential risk. The proposed research is part of a collaborative research program that will compare responses of beaked whales *vs* other odontocetes to playbacks of mid-frequency sonar sounds vs other sounds. The primary applied goal of the proposed research is to gain a better understanding of risks presented by sonar and other sounds to these species, to define safe exposures, and to improve science-based mitigation strategies.

OBJECTIVES

The primary goals of the research proposed here are:

1. To assist with a cruise to tag, observe baseline behavior, and conduct playback experiments with beaked whales and blackfish in the Mediterranean during 2009. This includes, in terms of my participation:

    a. Organizing a meeting with Spanish authorities.

    b. Organizing a scientific meeting at a Mediterranean level.

    c. Participation in MED09 on board the Alliance.

2. To contribute to further work tagging, observing baseline behavior, and conducting playback experiments with pilot whales during the summers of 2010 and 2011. This includes achieving the following objectives:

a. To estimate the proportion of time the animals spend underwater, and therefore estimate g(0) to be able to obtain an absolute estimate of abundance for the population.

b. To understand their feeding behavior.

c. To understand their acoustic behavior, both under "normal" circumstances (e.g. when resting, feeding, travelling) and how they behave and react under different circumstances, such as presence of other species, different sources of potential stress (e.g. playbacks, maritime traffic).

d. To gain insight into their social structure and dynamics, both under "normal" circumstances and under different circumstances, such as presence of other species, different sources of potential stress (e.g. playbacks, maritime traffic).

APPROACH

Goal 1 (2009) was addressed through the organization of meetings (objectives a and b) and participation of Ana Cañadas and a group of trained Spanish researchers onboard the *Alliance* during the MED09 survey (see report for 2009 under Grant Number: N000140910536).

Goal 2 (2010-2011) was addressed through ship-based surveys in the Alboran sea on board the Alnitak research vessel *Toftevaag* in 2010, and the rented motor vessel Marvel in 2011in search of long-finned pilot whales, beaked whales, and other species of cetaceans.

WORK COMPLETED

Ship-based surveys

Alnitak provided the research ship Toftevaag for the survey in 2010, and in 2011, a motor vessel was rented for the field work. Ana Cañadas participated as PI for the visual data collection in the field trip for both years.

As PI of this project Ana Cañadas was in charge of the protocol for visual data collection during the survey mode of these cruises. She was also in charge of the validation and organization of the visual data during the surveys, on a daily basis, in preparation for its further analysis. This included cleaning the data (sightings, effort and environmental) checking for errors, filling in missing but recoverable fields, assigning effort status to each sighting, and compiling and organizing all the data in an excel spreadsheet in a format more easily usable for analysis.

Tagging of pilot whales

The cruises was very successful. Sixteen pilot whales tagged in 2010, all with multiple animals tagged within a social group. We also conducted focal follows on two *Ziphius cavirostris* in sea conditions suitable for tagging in 2010, but were not able to tag this difficult species. In 2011, other 19 pilot whales were tagged, also with multiple tags (up to 6) within a social group, and with longer duration than in 2010 (see Annex I).

Playback exposures to pilot whales

Two playback exposures with killer whale and control playbacks were performed to two different groups of pilot whales during the 2011 cruise.

Analysis of Sirena08 and Med09 survey data in the Alboran Sea

The survey data from Sirena08 and Med09 was analyzed to estimate abundance and to provide information on distribution patterns through spatial modeling of Cuvier's beaked whales and long-finned pilot whales, the two target species of this project. Data was analyzed first with software DISTANCE to estimate the probability of detection in order to correct the survey data. In a second step, the corrected data was analyzed with spatial modeling using software R, providing maps of predicted density and habitat patterns.

To increase sample size, data collected from 2008 and 2009 under the umbrella of Alnitak was also added to the dataset for the spatial modeling. These data were collected thanks to the funding provided by **Fundación Biodiversidad** from Spain. The detection functions created for each species include also all data collected under the Alnitak umbrella.

Results of the modeling exercise of beaked whales in the Alboran Sea from these data will be presented at the Biennial Conference of the SMM in Tampa, Florida, in November 2011.

Meetings and collaboration with Spanish administration

A meeting was organized in January 2009 to present the results from Sirena08 cruise and the plans for Med09 cruise (see report 2009 under Grant Number: N000140910536).

During 2010 and 2011, meetings were organized during the field work inviting relevant persons from the Spanish Administration to the field site. The invited representant both years was Silvia Revenga, Jefa de Servicio de la Subd. Gral. de Recursos Marinos y Acuicultura de la Dirección General de Recursos Pesqueros y Acuicultura, Secretaría General del Mar

The methods, equipment and preliminary results were presented, and lengthy discussions were held about the usefulness of this kind of research. In both cases the feedback was extremely positive.

Additionally, a meeting was held at the General Directorate of Environment and Forestry Policy in Madrid on 25th March 2011 to present the preliminary results of the 2010 field work and the plans for 2011. The interest and feedback was extremely positive too, offering the collaboration of the Spanish administration for our efforts to conserve cetaceans in the Alboran Sea, and particularly in the issue of the impacts of man-made noise on deep divers. The participants at the meeting were:

- Silvia Revenga, General Secretariat of the Sea (Head of Service)
- Juan Carlos Jorquera, General Secretariat of the Sea (Head of Department)
- Juan José Areces, General Directorate of Environment and Forestry Policy (Head of Service)
- Isabel López, General Directorate of Environment and Forestry Policy (Technician)
- Marta García, General Directorate of Environment and Forestry Policy (General Director)
- Peter Tyack, Alessandro Bocconcelli (WHOI)
- Ana Cañadas, José Antonio Vázquez (Alnilam)

RESULTS

Ship-based surveys

In 2010, a total of 444 km were surveyed on effort between 18th August and 6th September 2010, producing 37 sightings of several species: short-beaked common dolphins, *Delphinus delphis* (n=3); long-finned pilot whale, *Globicephala melas* (n=7); striped dolphin, *Stenella coeruleoalba* (n=7); common bottlenose dolphin, *Tursiops truncatus* (n=4): Cuvier´s beaked whale, *Ziphus cavirostris* (n=4) and unidentified dolphins (n=2). Additionally, 6 more sightings were made while off effort or as secondary sightings while working on a focal follow: common dolphins (n=1), pilot whales (n=2), bottlenose dolphins (n=2) and Cuvier´s beaked whales (n=1). Photo-identification work was carried out during the sightings of pilot whales and Cuvier´s beaked whales to contribute to the existing catalogues.

In 2011, a total of 283 km were surveyed on effort between 18th August and 7th September 2011. The relatively small amount of effort is due to the usually short time required to find pilot whales in the area and the very large time spent on tracking them. A total of 52 sightings were recorded while on searching effort, of 4 species: short-beaked common dolphins (n=7); long-finned pilot whale (n=7); striped dolphin (n=17); common bottlenose dolphin (n=1); and unidentified dolphin (either striped or common dolphins) (n=20). Additionally, several sightings were made while off effort or as secondary sightings while working on a focal follow, including common, striped and Risso's dolphins, *Grampus griseus*, and more groups of pilot whales. Photo-identification work was carried out during the sightings of pilot whales to contribute to the existing catalogue.

The small amount of total effort and number of sightings on effort per species does not allow performing a separated analysis for these two cruises. Therefore, these data will be added to the existing data set to be analyzed jointly with previous data within the framework of the project covered by the ONR Grant N000141110196.

Photo-identification

Long-finned pilot whales

In 2010, long-finned pilot whales were encountered and photographed on 5 different occasions. Photographs of the dorsal fin and other distinguishing features (for example, pigmentation patterns and scars) of individual pilot whales were usually taken by 5 or 6 different photographers (Table 1 in Annex I), both from RV Toftevaag and from the tag boat. A total of 7,773 photos of long-finned pilot whales were taken during the cruise. In 2011, a total of 5,597 photographs of long-finned pilot whales were taken during the cruise. All these photographs will be analyzed and recognizable individuals entered into a catalogue. Recognizable individuals will be cross-referenced with an existing catalogue of pilot whales to determine whether they have previously been photographed in the Alborán Sea. These will be analyzed within the framework of the project covered by the ONR Grant N000141110196.

Cuvier's beaked whales

In 2010, Cuvier's beaked whales were encountered and photographed on 5 different occasions. Photographs of the dorsal fin, body coloration and scars were taken (Table 1 in Annex I). A total of 731 photographs were taken of Cuvier's beaked whales, which will constitute the basis for a catalogue for this species in the Alboran Sea.

Deployment of D-Tags on long-finned pilot whales in the Alboran Sea
Table 2 in Annex I lists the pilot whales tagged during the field effort in 2010 and 2011. The time indicates the duration of the focal follow. Annex II shows the diving profiles of the tagged animals in 2011.

Given that the 2011 field work finished less than 3 weeks before the deadline for submission of this report, there has not been time to analyze all the D-Tags data yet. This will be done in the near future and a full report submitted to ONR as complement to this and project N000140910528. Nevertheless, the surface and diving times from the 2010 D-Tag data has been used to estimate availability bias of pilot whales in the Alboran Sea, in order to correct the abundance estimates if necessary. This is described in Annex III.

Playback exposures on long-finned pilot whales in the Alboran Sea
Two playback exposures with killer whale and control playbacks were performed to two different groups of pilot whales during the 2011 cruise. Given that the 2011 field work finished less than 3 weeks before the deadline for submission of this report, there has not been time to analyze the results of the playback experiments. This will be done in the near future and a full report submitted to ONR as complement to this and project N000140910528.

Analysis of Sirena08 and Med09 survey data in the Alboran Sea
Abundance and habitat use in the Alboran Sea for Cuvier's beaked whales and long-finned pilot whales was obtained and the full methods and results are described in Annex III.

It is important to highlight here 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.

IMPACT/APPLICATIONS

The main impacts of this project are:

First abundance estimate and habitat modeling of Cuvier´s beaked in the Alboran Sea
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, with one of the highest densities in the world. 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.

Contribution to a proposal for a Marine Protected Area and associated Management Plan for Cuvier's beaked whales in the Alboran Sea
The results of the analysis of abundance and habitat modeling of Cuvier's Beaked whales, presented to the General Directorate of Biodiversity of the Spanish Ministry for the Environment, prompted the direct request from such Directorate to develop a proposal for the creation an MPA for Cuvier's

beaked whales in the Alborán Sea and to set the basis for an associated Management Plan for such MPA. This proposal is submitted on 30th September 2011.

Valuable information on long-finned pilot whales diving and foraging behavior

These cruises developed and tested methods to measure social behavior and communication in pilot whales, and collected significant amounts of baseline data for pilot whales, including extremely interesting data on synchronized behavior. The analysis of these data will be done under Grant N00014-09-1-0528 (Peter Tyack).

RELATED PROJECTS

INDEMARES (LIFE07NAT/E/00732)

This European Commission LIFE+ Nature project deals with the identification of marine areas of special interest for the conservation of biodiversity. In the context of this project, coordinated by *Fundación Biodiversidad* and with the partnership of the Environment Ministry General secretariat for the Sea (SGM), the National Scientific Council (CSIC) the Spanish Oceanographic Institute (IEO) and the NGOs SEO Birdlife, WWF Adena, OCEANA, SECAC, CEMMA and ALNITAK, the latter coordinates action A14 (MITIGA LAB) in the Alboran Sea dealing with the development of technological measures for mitigating risk for cetacean populations deriving from the sectors of transport, energy, tourism, fishing and defense. With regards to the defense sector, MITIGA LAB creates a bridge between this project and the Spanish administration as well as other key stakeholders.

GTCAT (Alborán, un caso práctico para la aplicación de la Estrategia Marina Europea)

This project was funded by Fundación Biodiversidad in Spain, focusing on the creation of a platform for the promotion and coordination of international and intersectorial cooperation for the Working Group on Cetaceans, sea turtles and seabirds of the "Initiative for the sustainable development of the Alboran Sea". Through this platform research, management, capacity building and outreach actions have been developed actively prompting international cooperation. This project was envisaged as a pilot experience for the development of innovative and exportable tools to face the logistic and economic challenge of the conservation of the marine biodiversity. As with the previous project, GTCAT created a bridge between this project and the Spanish administration as well as other key stakeholders. Data collected in both projects are complementary to give a wider context to such data and the results of their analysis.

ONR: Tagging and Playback Studies to Toothed Whales

Grant Number: N00014-09-1-0528 to Peter Tyack.

Annex I

Table 1: Photographers, cameras used and number of photographs taken during pilot whale and Cuvier's beaked whale encounters.

Photographer	Camera used	Number of photographs taken		
		Cuvier's beaked whales	Long-finned pilot whales	Long-finned pilot whales
		2010	2010	2011
Ana Cañadas	Canon EOS 30D	41	915	2873
Rebecca Jewell	Canon EOS 40D	298	2429	
Eletta Revelli	Canon EOS 30D	197	808	
Leigh Hickmott	Nikon D300	114	1182	708
Frants Jensen	Canon EOS 300D	42	537	
Nicholas MacFarlane	Nikon D300s	39	1902	49
Laela Sayigh	Nikon D300s			536
Danielle Waples	Nikon D300s			1329
Eleanor Caves	Nikon D60			102
TOTAL		**731**	**7773**	**5597**

Table 2. Pilot whales tagged, and beaked whale tagging attempts for the 2010 and 2011 cruise in the Alboran Sea.

Date	Species	Tag ID	Group size	Time (start-end)
19-Aug-10	*Globicephala melas*	A	36	local 10.10-19.40
19-Aug-10	*Globicephala melas*	B	36	local 10.10-19.40
22-Aug-10	*Globicephala melas*	A	49	local 12.31-21.00
22-Aug-10	*Globicephala melas*	B	49	local 12.31-21.00
26-Aug-10	*Globicephala melas*	A	21	local 12.10-21.00
26-Aug-10	*Globicephala melas*	B	21	local 12.10-21.00
02-sept-10	*Ziphius cavirostris*	Unknown	4	local 14.43-17.22
03-sept-10	*Globicephala melas*	A	11	local 15.40-20.30
03-sept-10	*Globicephala melas*	B	11	local 15.40-20.30
03-sept-10	*Globicephala melas*	C	11	local 15.40-20.30
03-sept-10	*Globicephala melas*	D	11	local 15.40-20.30
05-sept-10	*Ziphius cavirostris*	Unknown	3	local 10.10-11.00
05-sept-10	*Globicephala melas*	A	14	local 14.25-20.30
05-sept-10	*Globicephala melas*	B	14	local 14.25-20.30
05-sept-10	*Globicephala melas*	C	14	local 14.25-20.30
05-sept-10	*Globicephala melas*	D	14	local 14.25-20.30
05-sept-10	*Globicephala melas*	E	14	local 14.25-20.30
05-sept-10	*Globicephala melas*	F	14	local 14.25-20.30

Table 2. Pilot whales tagged, and beaked whale tagging attempts for the 2010 and 2011 cruise in the Alboran Sea (continued)

18-Aug-11	*Globicephala melas*	A	13	local 10.16-14.25
18-Aug-11	*Globicephala melas*	B	13	local 10.59-15.13
23-Aug-11	*Globicephala melas*	A	11	local 09.09-18.19
23-Aug-11	*Globicephala melas*	B	11	local 09.28-18.32
23-Aug-11	*Globicephala melas*	C	11	local 10.16-16.50
23-Aug-11	*Globicephala melas*	D	11	local 12.37-05.01 (24-Aug-11)
29-Aug-11	*Globicephala melas*	A	14	local 11.01-16.22
29-Aug-11	*Globicephala melas*	B	14	local 11.14-16.37
29-Aug-11	*Globicephala melas*	C	14	local 17.14-09.09 (30-Aug-11)
29-Aug-11	*Globicephala melas*	D	14	local 18.07-03.45 (30-Aug-11)
29-Aug-11	*Globicephala melas*	E	14	local 19.34-04.05 (30-Aug-11)
29-Aug-11	*Globicephala melas*	F	14	local 20.03-20.07
05-Sept-11	*Globicephala melas*	A	10	local 09.20-15.10
05-Sept-11	*Globicephala melas*	B	10	local 09.34-00.12 (06-Sep-11)
05-Sept-11	*Globicephala melas*	C	10	local 09.48-00.25 (06-Sep-11)
05-Sept-11	*Globicephala melas*	D	10	local 14.05-00.29 (06-Sep-11)
05-Sept-11	*Globicephala melas*	E	10	local 17.15-23.46
07-Sept-11	*Globicephala melas*	A	7	local 10.57-18.23
07-Sept-11	*Globicephala melas*	B	7	local 11.05-18.23

Annex II

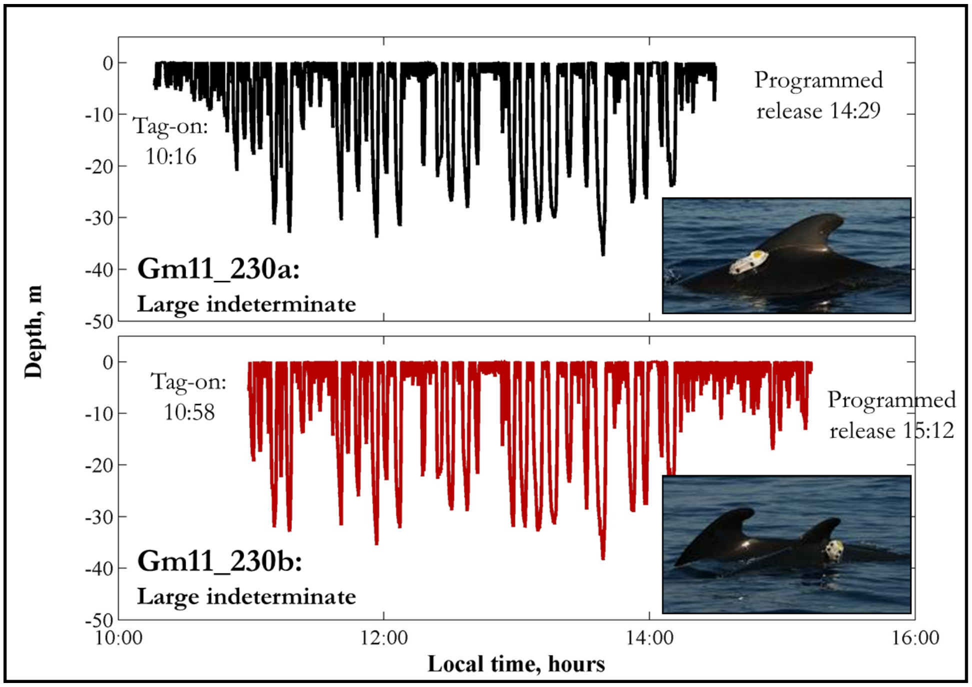

Fig.1. 18-Aug-2011 - 2 tag deployments on long-finned pilot whales

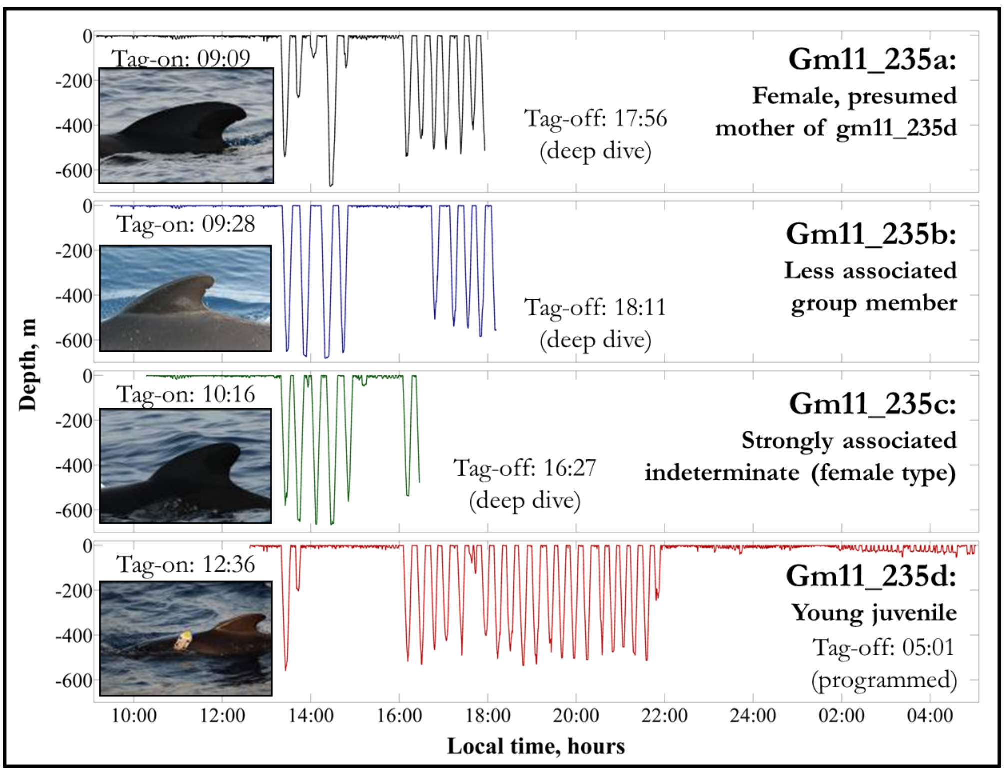

Fig.2. 23-Aug-2011 - 4 Long-finned pilot whale tag deployments

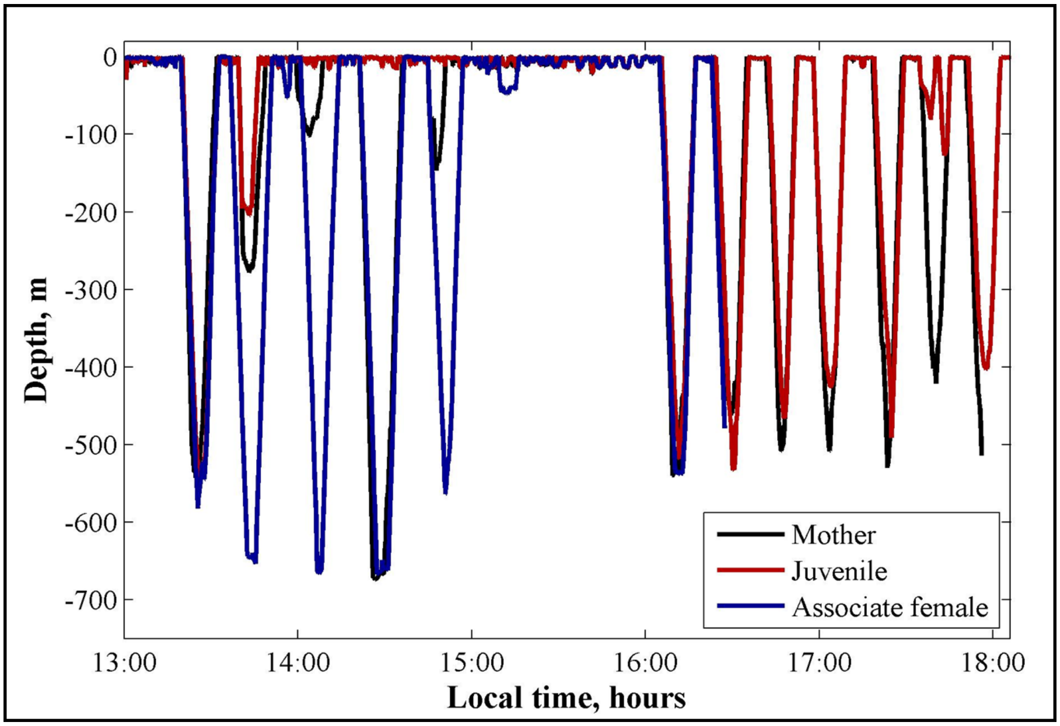

Fig.3. 23-Aug-2011 - Extract of synchronized depth profiles from trio. Young juvenile was left at surface during several dives, with no other group members near. However, given the depth of its own foraging dives, it seems it was fully capable of foraging at the same depths as the mother and associated female.

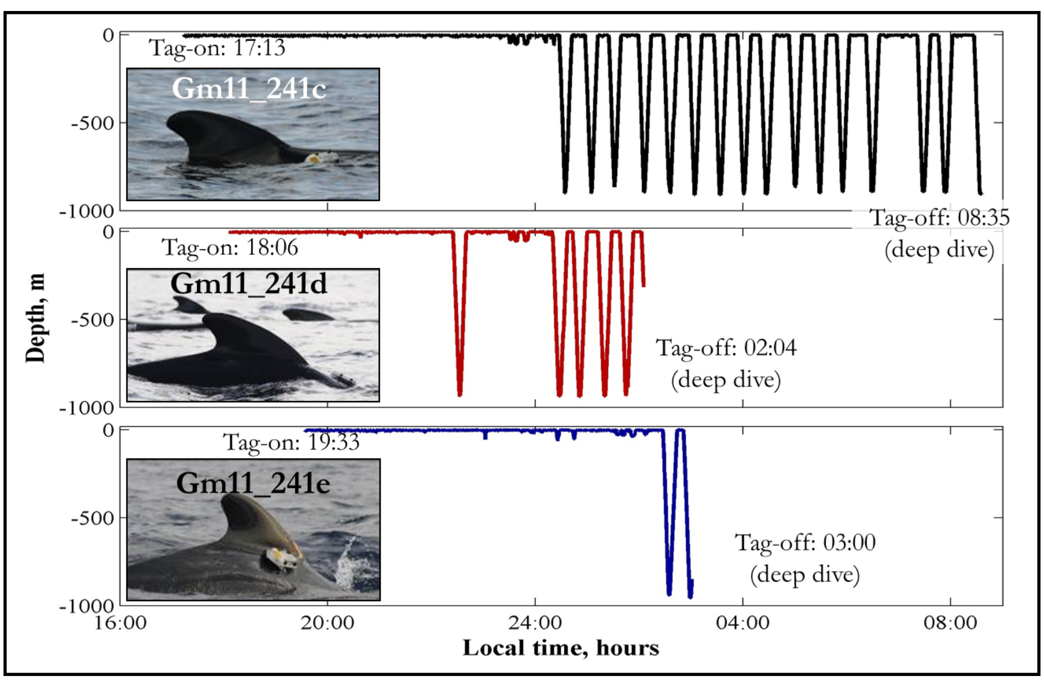

Fig.4. 29-Aug-2011 - 4 Long-finned pilot whale tag deployments. Gm11_241f: Attachment for 117s, dislodged during breaching. Playback experiments. Data still to be analyzed.

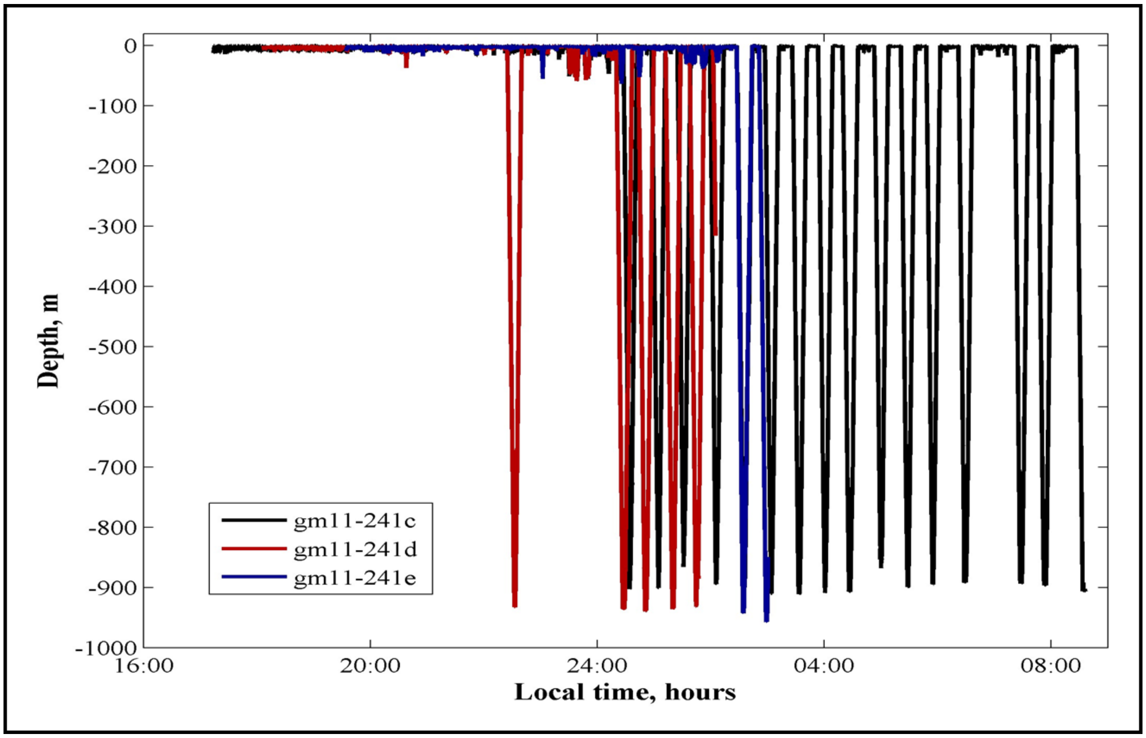

Fig.5. 29-Aug-2011 – Deep overnight dives. Evidence for bottom foraging at >900m of depth

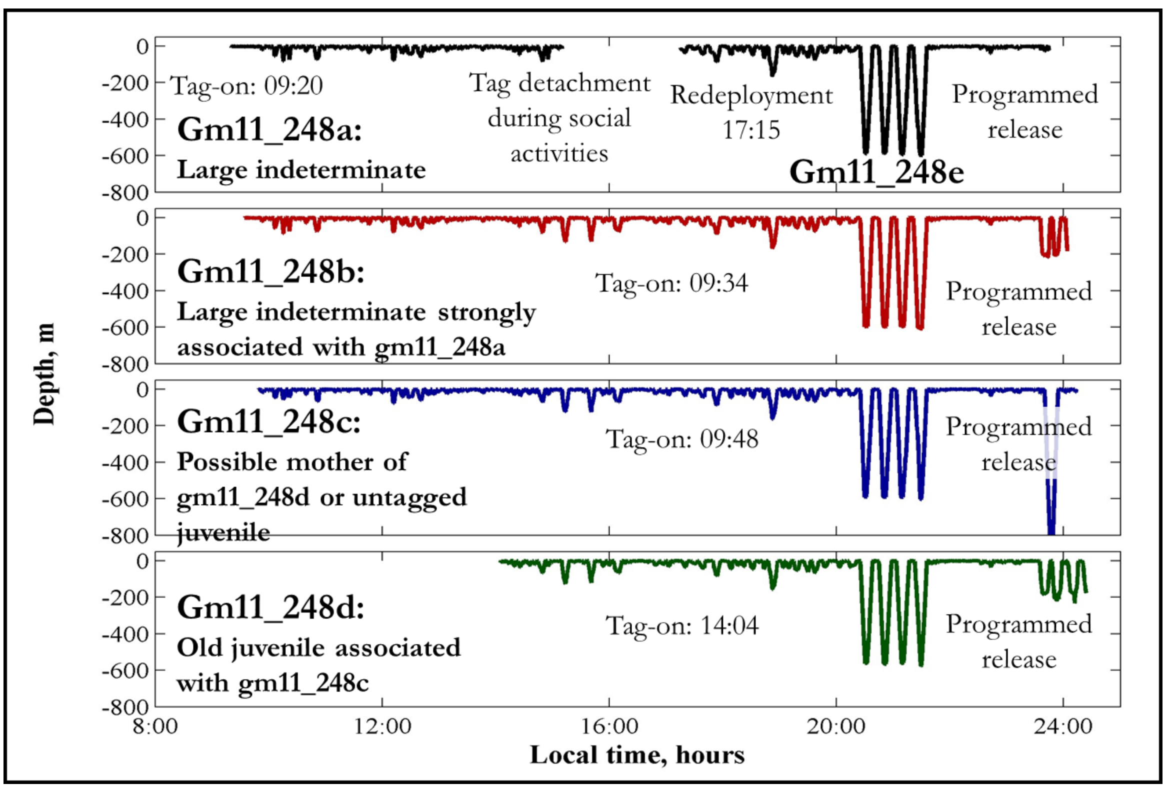

Fig.6. 05-Sep-2011 – 4 Long-finned pilot whale tag deployments within a group of 5 animals.

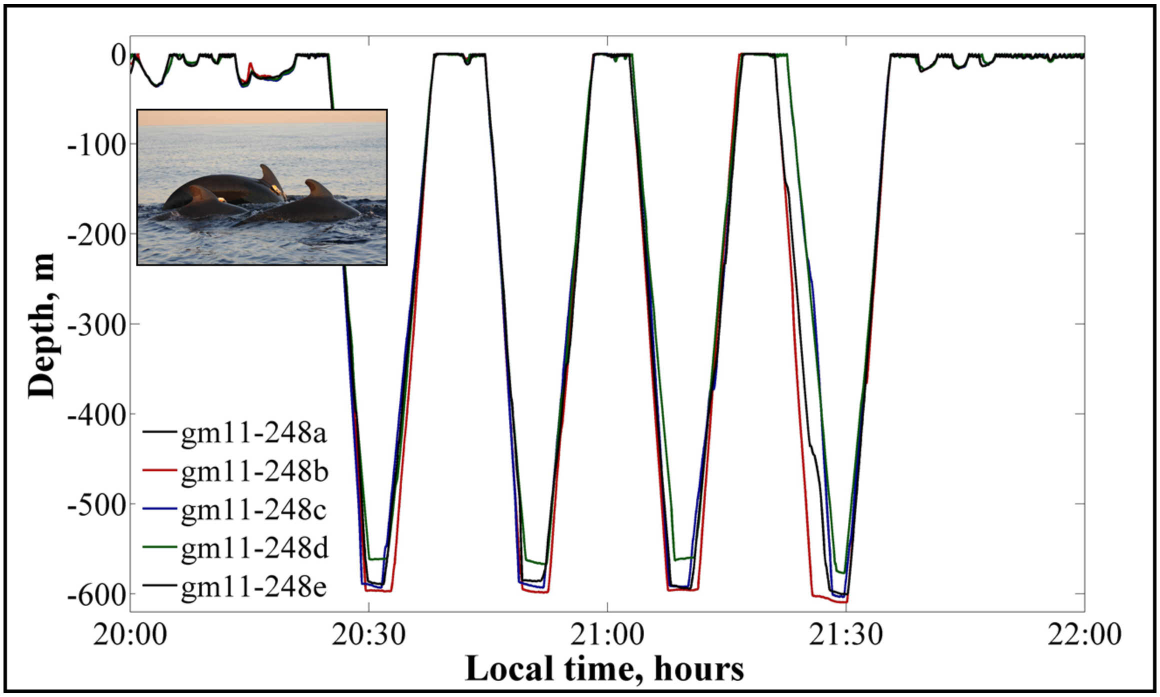

Fig.7. 05-Sep-2011 – Temporally synchronized bottom foraging. Different foraging (and bottom) depths between animals indicate that while dives are temporally synchronized they are not foraging at the same place, but separating out. "e" tag is the same animal as tag "a", so same color coding (and therefore only one present at a time).

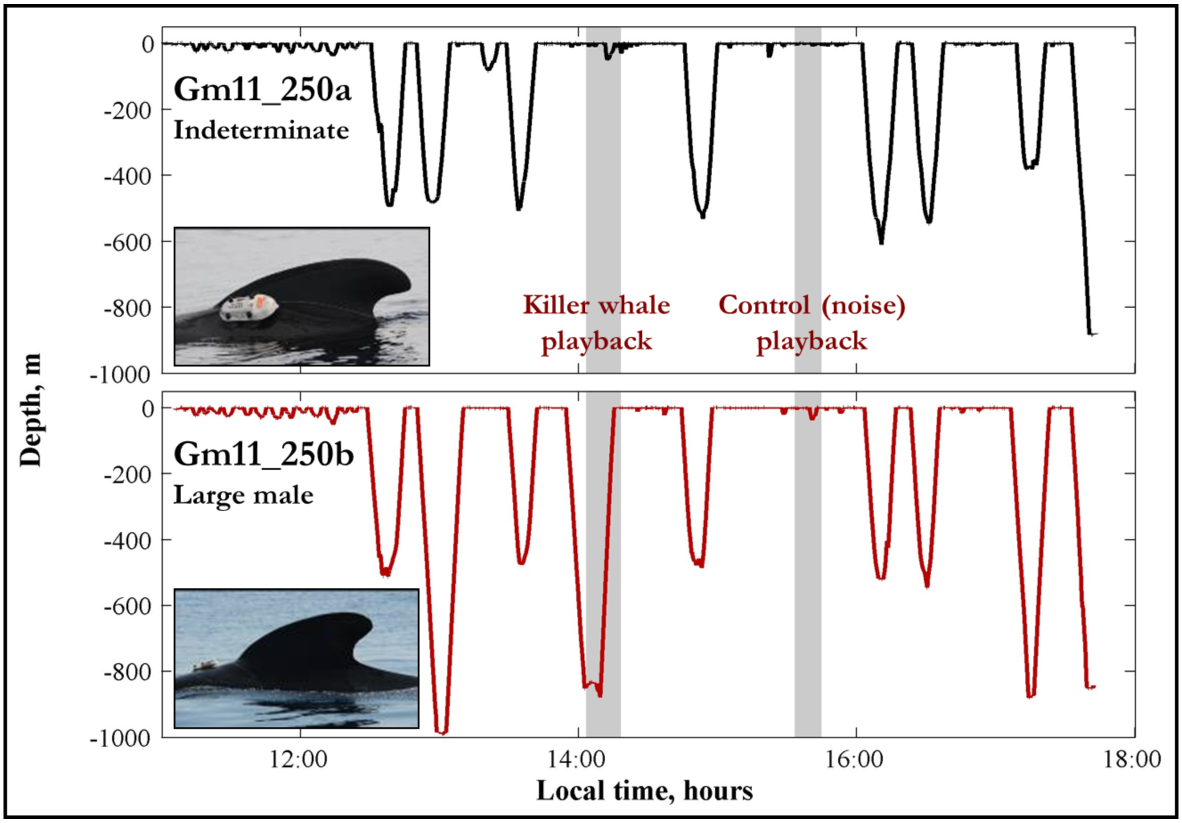

Fig.8. 07-Sep-2011 – Two tags placed within group of 4 animals. Playbacks exposures. No obvious reaction by remaining group members at the surface, though data still have to be analyzed.

Annex III

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, 5 and 6 the sightings during on effort tracks for Cuvier's beaked whales and long-finned pilot whales.

Two species were analized for this project: Cuvier's beaked whales and long-finned pilot whales. Sightings of beaked whales 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. Long-finned pilot whales were positevely identified to species level.

The two data-sets were used for two modeling exercises: (a) 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 (b) 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, the Island of Alboran and the Gulf of Vera (25,589 km^2).

DATA ORGANIZATION

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.

ANALYTICAL METHODS

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 group size was modeled as a function of spatial and environmental covariates, or mean group size was calculated, depending on the species; (5) steps 3 and 4 were combined and extrapolated to the whole study area to obtain the final abundance of animals.

Detection functions

A detection function to estimate the probability of detection was fitted to each species 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 for Cuvier's beaked whales. 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).

Spatial models

The response variable used to formulate a spatial model of abundance of groups was the count of groups (*N*) in each segment (Hedley et al. 1999).

The abundance of groups was modeled using a Generalized Additive Model (GAM) with a logarithmic link function. A Tweedie error distribution was used. Tweedie distributions are a special case of an *exponential dispersion model* which will have mean μ and variance $\varphi\mu^p$, where $\varphi > 0$ is a dispersion parameter, and p, called the index parameter, (uniquely) determines the distribution in the Tweedie family. Special cases include: $p = 0$, which is the normal distribution, $p = 1$ with $\varphi = 1$, which is the Poisson distribution, $p = 2$, which is the gamma distribution, and p = 3, which is the inverse Gaussian distribution. Tweedie distributions exist for all real values of p except for $0 < p < 1$. Apart from the four special cases identified above, their probability density function have no closed form. The parameter p chosen for the Tweedie distribution, through inspection of GCV (Generalised Cross Validation score, an approximation to AIC, Wood 2000), was 1.1, very close to a Poisson distribution but with some over-dispersion.
The general structure of the model was:

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

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 effective strip width –*esw*- 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; (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 for both species, the mean group sizes were 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.

Availability bias

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.

There are methods to estimate the g(0), either during the surveys (using double platform configuration to do a mark-recapture analysis) or, less desirable, during analysis when double platform observation was not realized. Double platform was not used during the present surveys. In the cases of common, striped and bottlenose dolphins, there are estimates of g(0) for surveys from large vessels in the NE Atlantic (e.g. CODA, SCANS-II) which in these three species is around 0.5 to 0.55. A correction made with this g(0) would yield an abundance estimate more or less double of what is presented here.

Nevertheless, even if it could be assumed that sightings from the Alliance could have a similar g(0) than from those surveys in the NE Atlantic due to similarities in the vessel size and height and the use of BigEyes binoculars in both, many of the sightings used in these analysis were made from much smaller vessels, where we cannot assume a similar g(0). Therefore, a correction cannot be made in this way.

Another way of minimizing the bias produced by animals missed on the trackline is by estimating the availability bias from information on diving times, speed of the vessel and height of the observation platform.

The probability of being available can be estimated as follows (Laake *et al*. 1997):

$$\hat{a} = \frac{E[s]}{E[s]+E[d]} + \frac{E[d](1-e^{-w/E[d]})}{E[s]+E[d]} \tag{3}$$

where *E[s]* is the expected length of each period of availability, *E[d]* is the expected length of each period of unavailability and w is the time an animal is within detectable range and *w* is the time an animal is within detectable range (based on vessel's speed and expected maximum radial distance for detection).

For estimating availability bias of long-finned pilot whales in the Alboran Sea within our study, the DTAG data from 14 pilot whales tagged in 2010 within the framework of this project were used. Table 4 shows the data used to estimate the availability bias for this species. A total of 652 dive events and 646 surface events were used for the calculations. Two approaches were explored: (a) using the mean and CV of all surface and dive events of all animals together (all events having the same weight); and (b) using the mean and CV of the means of the surface and dive events of the 14 animals (all animals having the same weight).

For estimating availability bias of Cuvier's beaked in the Alboran Sea within our study, the focal follow data from 57 groups of this species during Sirena08 and Med09 survey cruises were used. Table 5 shows the data used to estimate the availability bias for this species. A total of 166 dive events and 153 surface events were used for the calculations. As in some groups of animals only surface events could be recorded, the approach used was to use the mean and CV of all the events from all animals together. Nevertheless, four different calculations were done using (a) all the focal follow data with a *w* estimated from the Alliance (average speed of 5kt and maximum expected radial distance of detection of 9km); (b) all the focal follow data with a *w* estimated from the other ships (average speed of 5.5kt and maximum expected radial distance of detection of 4km); (c) DTAG data from one single animal tagged during Sirena08 with a *w* estimated from the Alliance; and (d) DTAG data from one single animal tagged during Sirena08 with a *w* estimated from the other ships.

<u>Estimation of uncertainty</u>
Four 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 and the CV of the group sizes; and subsequently, this CV with the CV from the availability bias from equation 3.

RESULTS

Detection function:
The fitted detection functions for all species are shown in Table 2. Figures 7 and 8 show the detection functions.

Spatial modeling:
Table 3 shows the covariates retained by the best-fitting model for each dataset and the smoothed functions for each species. Table 6 shows the final predicted estimate of abundance for each dataset for the Alboran Sea and subarea (to make them comparable), both uncorrected and corrected for availability bias when correction was possible.

Figures 9 and 10 show the predictions of abundance for each species for 2008-2009 (data from all ships). Figures 11 and 12 show the prediction of abundance for 1992-2009 (data from all ships) considering only the northern Alboran Sea.

Correction for availability bias for Cuvier's beaked whales:
Equation 3 for estimating availability bias was: $\hat{a}$ = 0.899 (CV=7.3%) for approach (a), $\hat{a}$ = 0.621 (CV=10.4%) for approach (b), $\hat{a}$ = 0.843 (CV=17.4%) for approach (c), and $\hat{a}$ = 0.550 (CV=26.2%) for approach (d). The lowest values for (b) and (d) are due mainly to the much shorter maximum expected radial distance of detection of the other ships in comparison with the Alliance, giving a *w* = 24min while *w* was 58min for the Alliance. On the other hand, the values from the DTAG are smaller than from the focal follow because the focal follow is underestimating the mean dive time. This occurs because during the focal follow, while the shallow dives are usually recorded in their totality with no problems, only very few deep dives are recorded as their long duration makes the detection of the surfacing after it very difficult, so the length of these deep dives cannot be recorded. Nevertheless the mean dive time from focal follow (26.3min) is very similar to that from the DTAG (33min).

Being the availability bias very similar between focal follow and DTAG data, the focal follow approaches were selected as they are based on multiple animals, and therefore give us more confidence on the means than the DTAG based on one single animal. Corrections were therefore made for the 2008-2009 estimate of abundance for the whole Alboran Sea using the Alliance correction (approach a), and the 1992-2009 estimate for the northern Alboran Sea was corrected using the other ships availability bias (approach b) (Table 7).

Correction for availability bias for long-finned pilot whales:
Equation 3 for estimating availability bias gave the same result using both approaches described in methods: $\hat{a}$ = 1. Both approaches were done using a *w* estimated from the vessel Alliance and from all the other ships, and the results were identical too. This means that there is no availability bias for long-finned pilot whales in our study. This is so because *w*, the time an animal is within detectable range is 30 minutes (at an average speed of 5.5kt and an expected maximum radial distance to detection – obtained from recorded data from the surveys – of 5km), while the mean dive time for both approaches are less than 4min. Furthermore, the maximum surface time recorded was 86min and the maximum dive recorded was 21min (less than *w*). Therefore, no correction is needed for our estimates of abundance of long-finned pilot whales in the Alboran Sea from the survey cruises used in these estimates.

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.

Cuvier's beaked whales:

The density estimates obtained through the modeling of these two datasets are very consistent when comparing the similar areas (see Table 7). The estimates extracted for the area "All ships 1992-2009" corresponding to the northern Alboran Sea from the predictions for "All ships 2008-2009" are very similar. These strong similarities in the estimates from the two 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, compared to published estimates elsewhere (Table 8). However, it is a relatively small area containing a high proportion of suitable habitat so the other estimates may also contain suitable areas of high density. Nevertheless, this is clearly an important area for Cuvier's beaked whales and warrants further study.

Figure 9 shows that the highest predicted density of Cuvier's beaked whales are in the eastern half of the deep waters of the Alboran Sea, especially around the island of Alboran. As mentioned before, more survey effort is needed in the western half of the basin to verify that such area is truly a low density one. There is, nevertheless, a zero prediction for the areas around the Strait of Gibraltar, reinforcing the hypothesis that Cuvier's beaked whales in the Mediterranean are isolated from those in the Atlantic.

Long-finned pilot whale

Also in the case of long-finned pilot whales the results obtained through the modeling of the two datasets are very consistent when comparing the similar areas (see Table 7).

Figure 10 shows that the highest predicted density of long-finned pilot whales occur in two discrete areas: the Strait of Gibraltar and the deep waters of the northern section of the eastern half of the basin. Again, more survey effort is needed in the western half of the basin to verify that such area is truly a low density one.

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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.

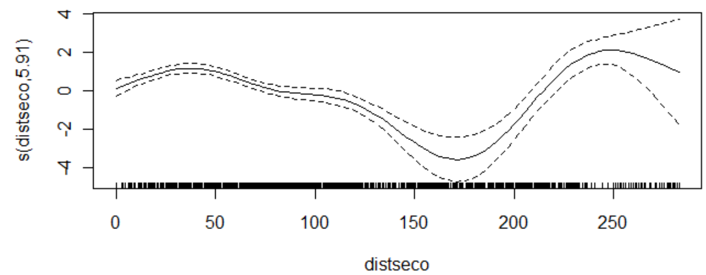
Table 1. Variables associated to the grid cells and used in the models (continued)

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 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. Best models selected for the detection functions for both species

Species	Model	Covariates	Average probability of detection (CV)	Truncation distance (m)	Number of observations within truncation distance
Dataset Alliance 2008-2009					
Beaked whales	Half-normal	Null model (only perp. distance)	0.35 (0.101)	7,000	94
Dataset All ships 1992-2009					
Globicephala melas	Hazard-rate	Platform height, sea state	0.19 (0.049)	4,000	612
Beaked whales	Hazard-rate	Platform height	0.35 (0.082)	3,800	154

Table 3a. Dataset All ships 2008-2009. Best models selected for the spatial modeling of groups for both species.

<table>
<tr><th>Species</th><th>Deviance explained</th><th>Covariates (degrees of freedom)</th><th>Smoothed functions</th></tr>
<tr><td>Long-finned pilot whales</td><td>22.9%</td><td>- Distseco (5.91)
- Depth (4.92)</td><td>

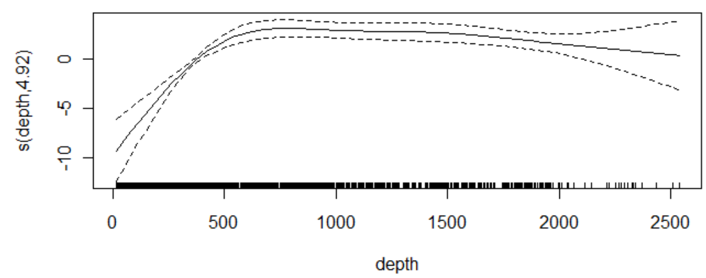
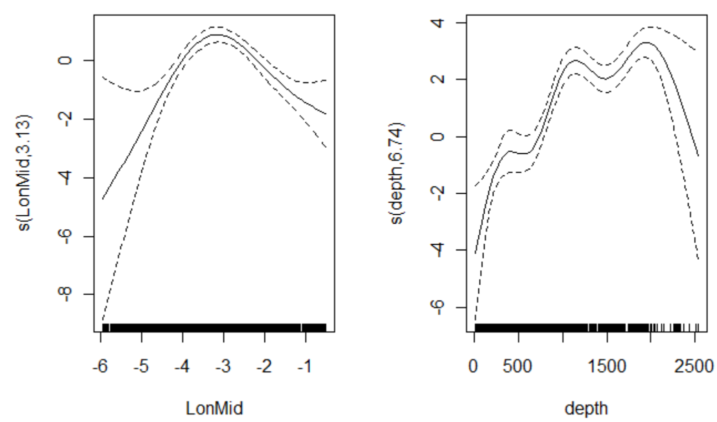

</td></tr>
<tr><td>Beaked whales</td><td>26.8%</td><td>- Depth (6.74)
- Longitude (3.13)</td><td>
</td></tr>
</table>

Table 3b. Dataset All ships 1992-2009. Best models selected for the spatial modeling for groups for both species. Covariates in braquets mean an interaction.

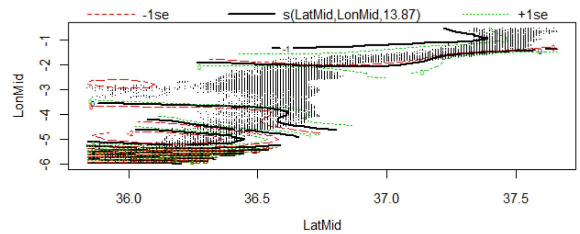
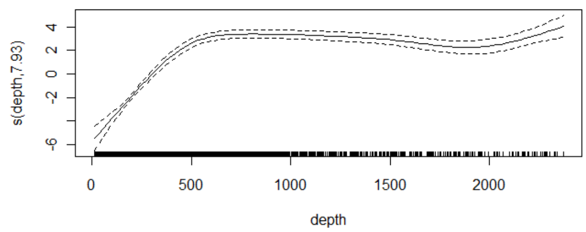
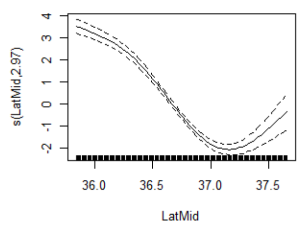
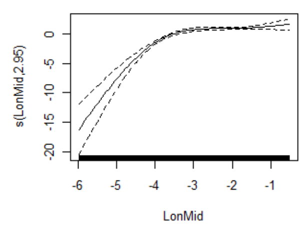
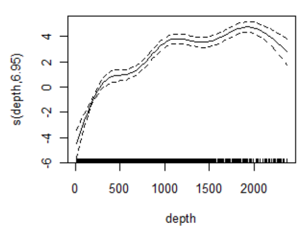
Species	Deviance explained	Covariates (degrees of freedom)	Smoothed functions
Long-finned pilot whales	25.3%	- (Latitude, Longitude) (13.87) - Depth (7.93)	 
Beaked whales	44.6 %	- Latitude (2.97) - Longitude (2.95) - Depth (6.95)	  

Table 4. Data used to estimate availability bias of long-finned pilot whales, from DTAG data from 2010

	Dive time (sec)			Surface time (sec)			Proportion at surface
Animal	**Count**	**Mean**	**CV**	**Count**	**Mean**	**SD**	
gm10_231a	52	226.0	0.184	52	199.6	205.9	**0.4690**
gm10_231b	56	257.4	0.162	55	215.8	201.1	**0.4515**
gm10_234a	74	317.5	0.092	74	334.2	652.6	**0.5128**
gm10_234b	95	198.5	0.141	95	281.9	579.4	**0.5868**
gm10_238a	54	158.1	0.111	54	389.1	517.1	**0.7110**
gm10_238b	84	285.2	0.113	84	292.3	321.5	**0.5061**
gm10_246a	41	164.1	0.138	40	335.4	672.8	**0.6660**
gm10_246b	30	129.8	0.094	29	158.5	205.2	**0.5414**
gm10_246c	22	141.8	0.134	21	139.2	222.8	**0.4839**
gm10_246d	4	142.6	0.246	3	263.3	261.8	**0.5807**
gm10_248b	56	160.8	0.179	56	347.9	319.5	**0.6839**
gm10_248c	58	219.0	0.189	58	278.9	232.4	**0.5601**
gm10_248e	18	112.0	0.067	17	451.4	394.1	**0.7919**
gm10_248f	8	122.1	0.139	8	628.3	431.5	**0.8373**
Total	**652**	**218.6**	**0.046**	**646**	**299.5**	**449.5**	**0.5749**
Mean		**188.2**			**308.3**		**0.5987**
SD		**64.1**			**126.4**		**0.1214**
Cuenta		**14.0**			**14.0**		**14.0**
SE		**17.1**			**33.8**		**0.03**
CV		**0.0911**			**0.1096**		**0.0542**

Table 5. Data used to estimate availability bias of Cuvier's beaked whales, from focal follow data from 2008 and 2009.

	Surface time (min)	**Dive time (min)**
mean	2.03	26.33
min	0.20	5.80
max	7.00	47.55
sd	1.216	16.950
count	153	166
se	0.10	1.32
sum	5.53	44.12
Proportion	0.112	
CV	0.048	0.050

Table 6. Estimates of abundance and measures of uncertainty for long-finned pilot whales in the Alboran Sea from spatial modeling (no correction needed as availability bias = 1)

Dataset	Sub-area	Area	Density (animals / km^2)	Estimate of abundance (95% CI)	Coefficient of Variation
All ships 1992-2009	Total	Northern Alboran Sea (25,589 km^2)	0.1220	2,888 (2,565 – 3,270)	11.6%
All ships 2008-2009	Total	Alboran Sea + Gulf of Vera (79,532 km^2)	0.049	3,868 (2,762 – 5,170)	17.9%
	All ships 1992-2009	Northern Alboran Sea (25,589 km^2)	0.0904	2,314 (1,937 – 2,764)	17.9%

Table 7. 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)	Coefficient of Variation	Corrected Density (animals / km^2)	Corrected estimate of abundance (95% CI)	Coefficient of Variation
All ships 1992-2009	Total	Northern Alboran Sea (25,589 km^2)	0.0037	86 (57 – 106)	17.6%	0.0038	96 (81-114)	20.4%
All ships 2008-2009	All ships 1992-2009	Northern Alboran Sea (25,589 km^2)	0.0039	99 (60 – 162)	52.7%	0.0043	110 (67 – 180)	53.2%
	Total	Alboran Sea + Gulf of Vera (79,532 km^2)	0.0046	369 (226 – 623)	52.7%	0.0052	410 (250 – 673)	53.2%

Table 8. 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

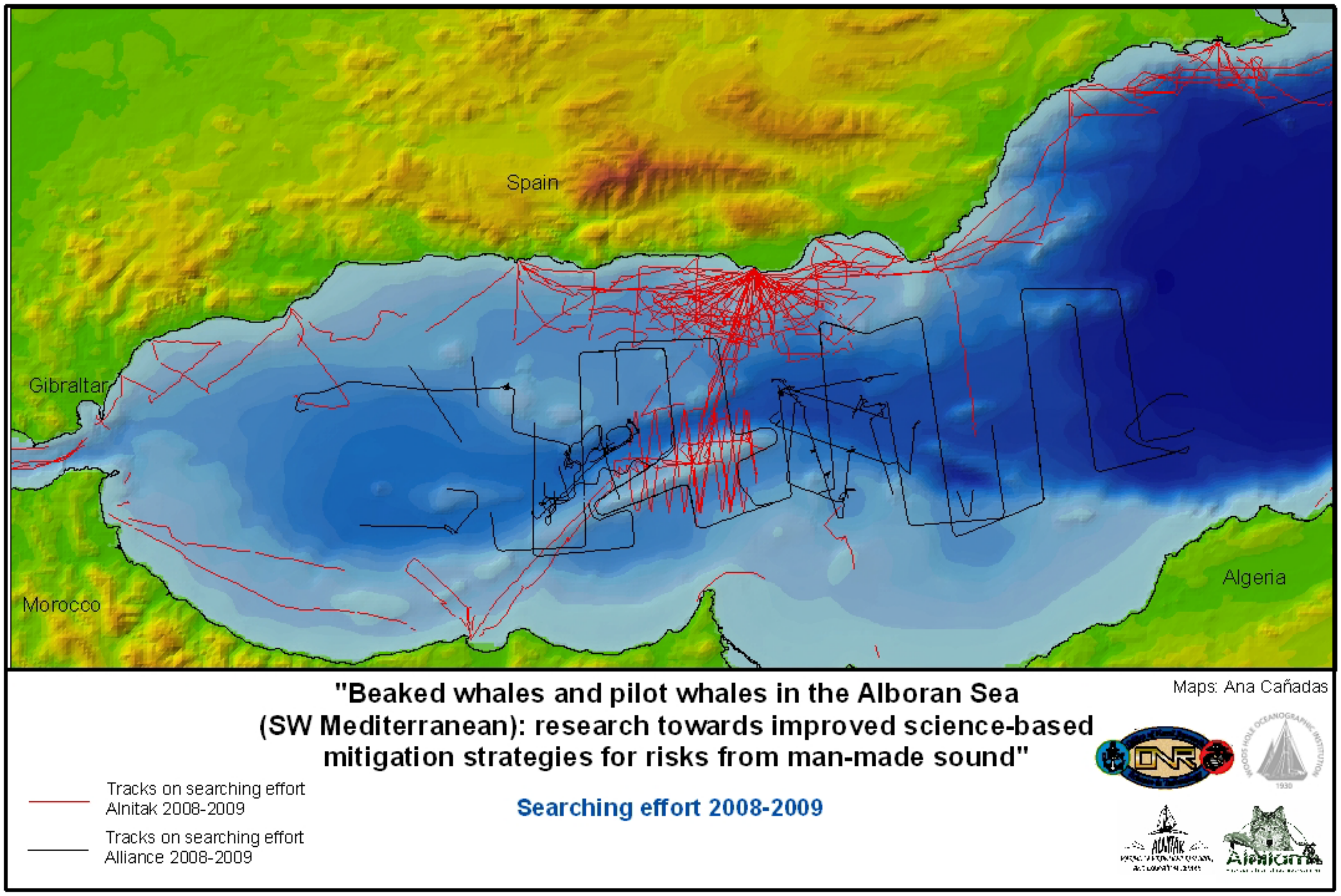


Figure 1. Searching effort in 2008 and 2009 by all ships.

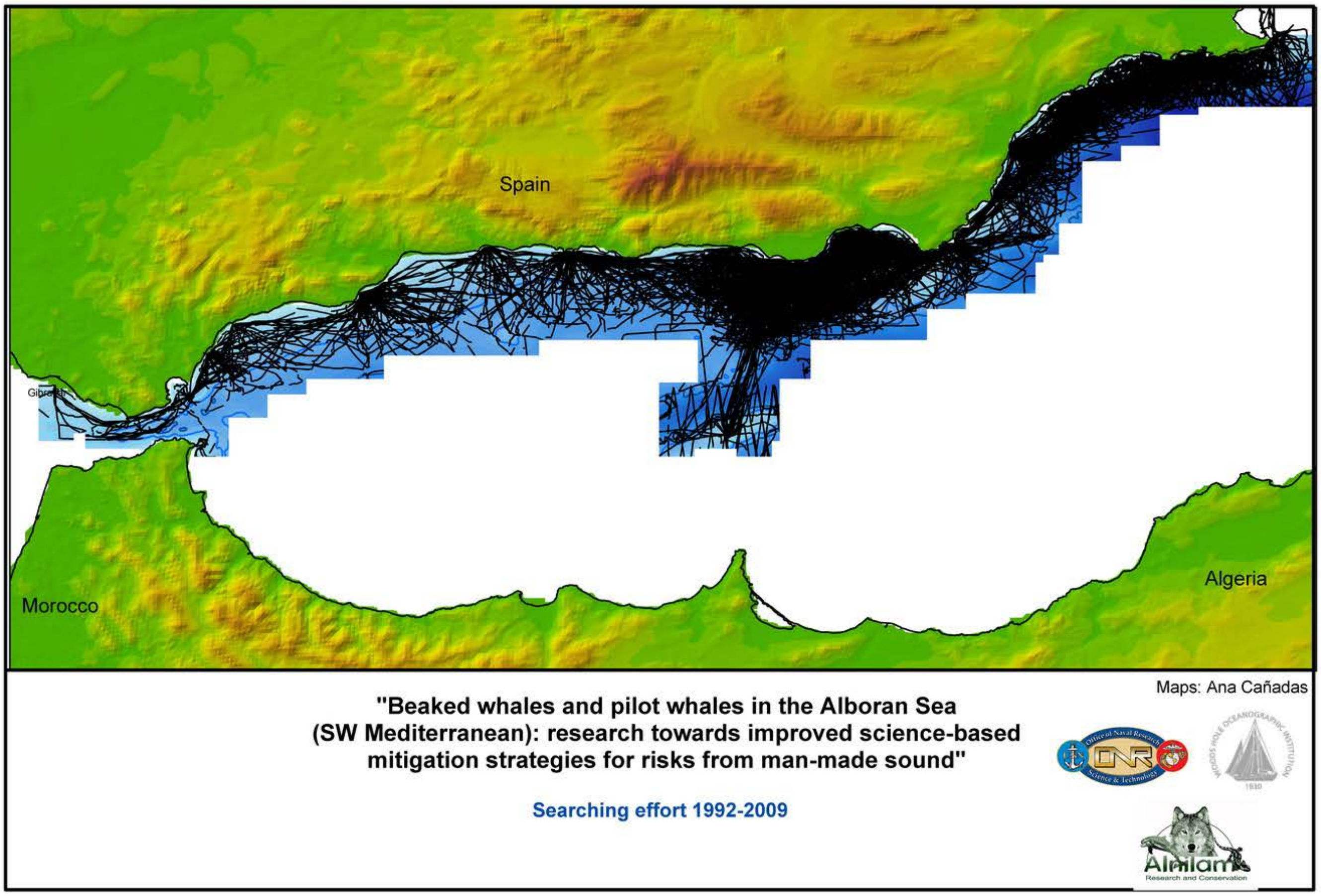


Figure 2. Searching effort from 1992 to 2009 by all ships.

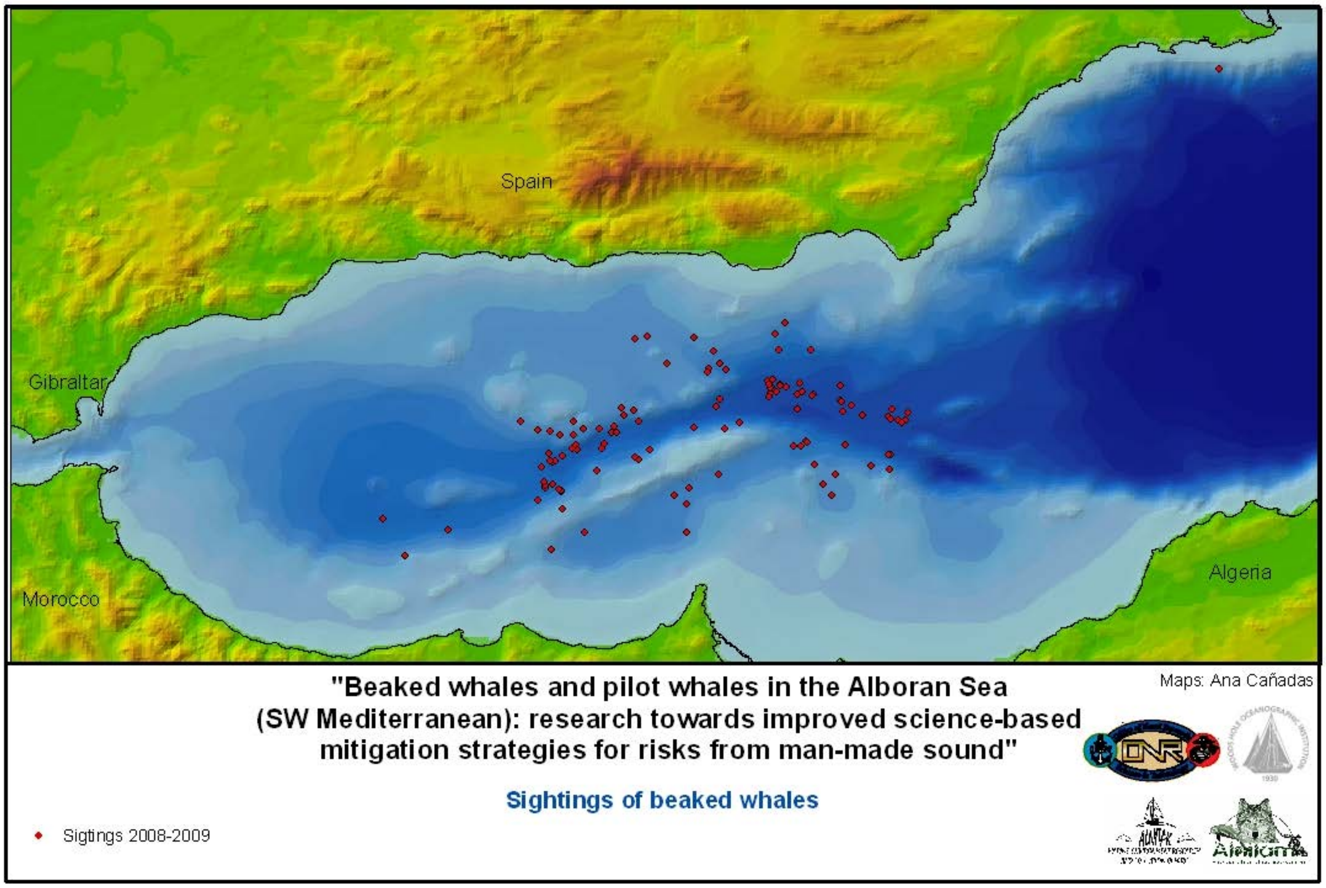


Figure 3. Sightings of beaked whales in 2008 and 2009 by all ships.

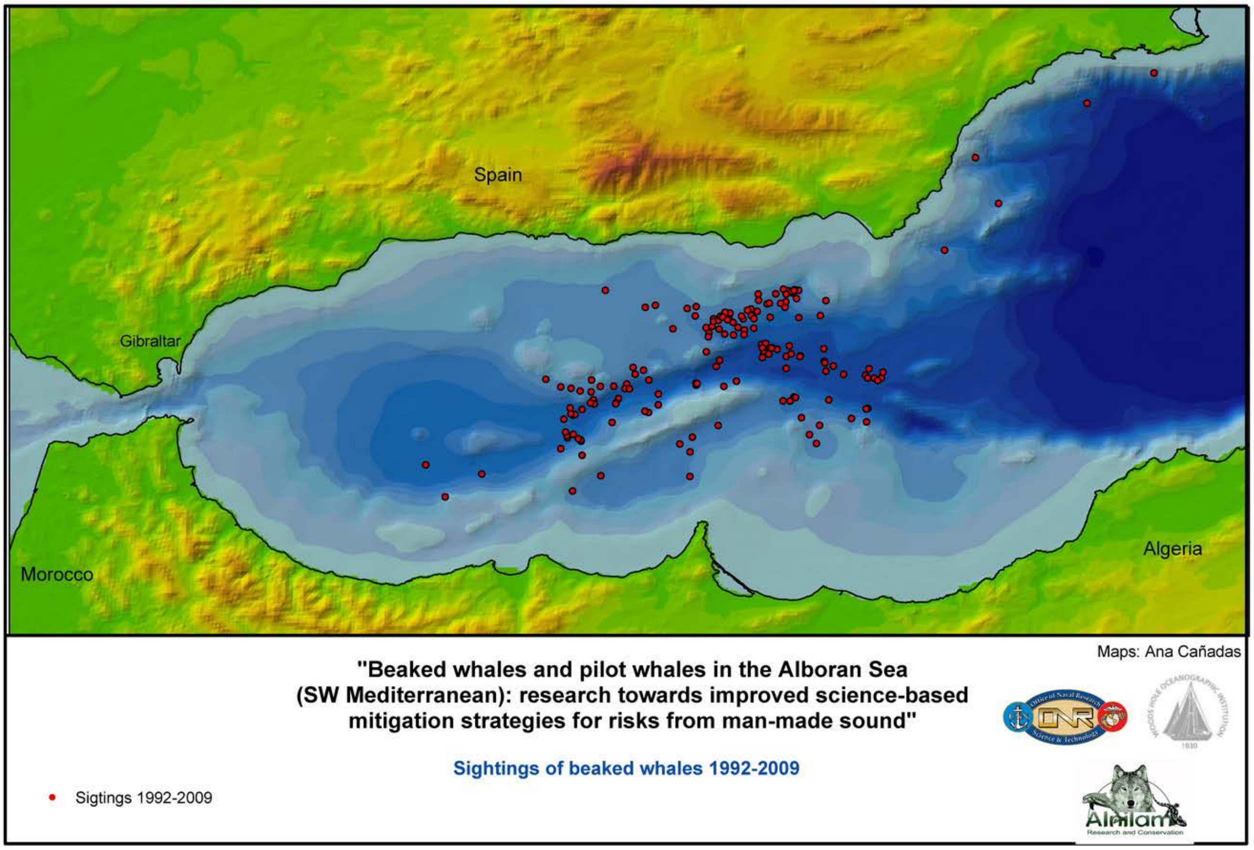


Figure 4. Sightings of beaked whales from 1992 to 2009 by all ships.

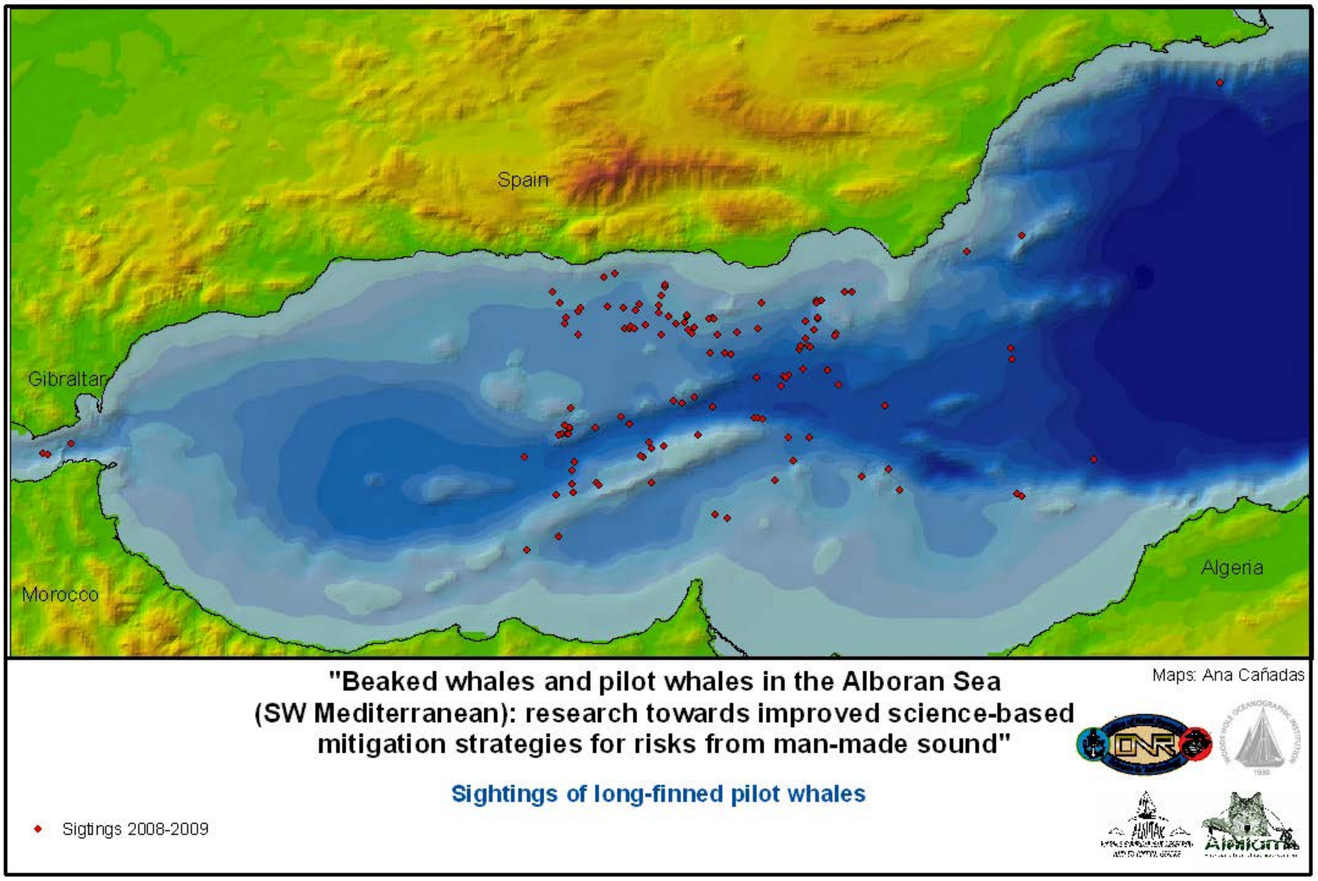


Figure 5. Sightings of long-finned pilot whales in 2008 and 2009 by all ships.

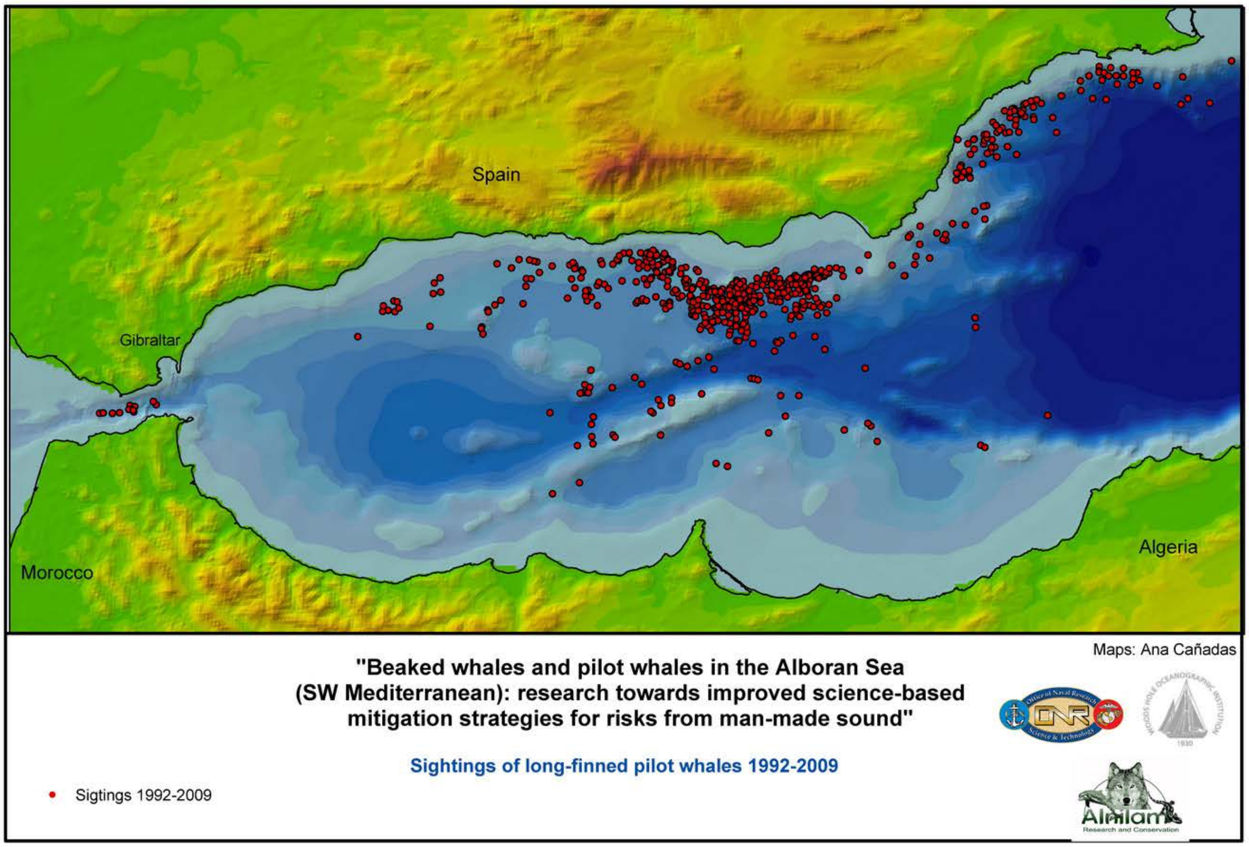


Figure 6. Sightings of long-finned pilot whales from 1992 to 2009 by all ships.

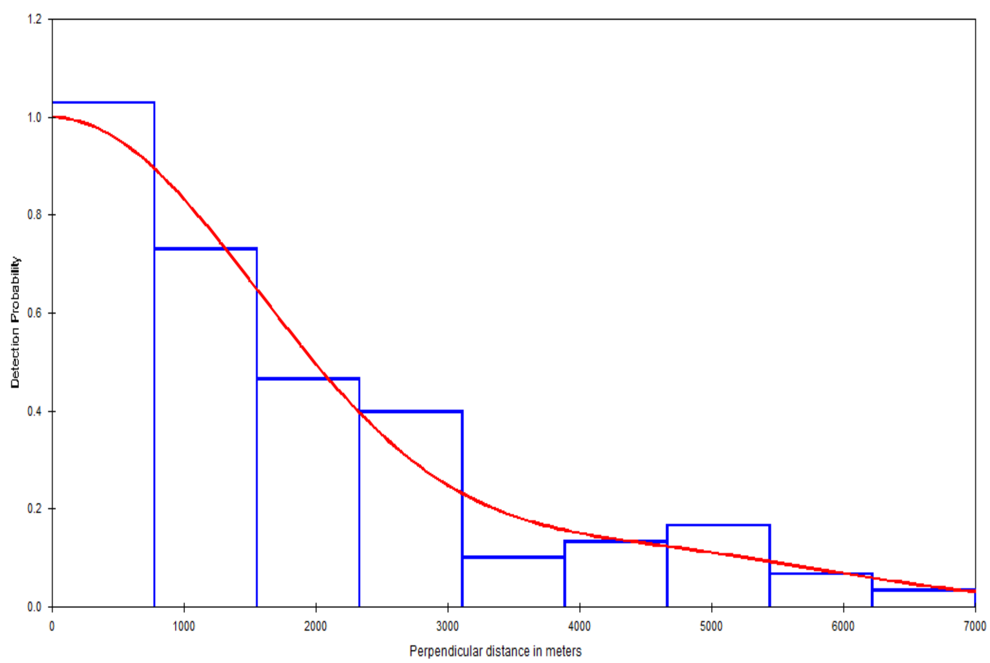


Figure 7. Perpendicular distance distribution (histograms), and fitted detection functions (lines) for the Alliance 2008-2009 dataset for Cuvier's beaked whales.

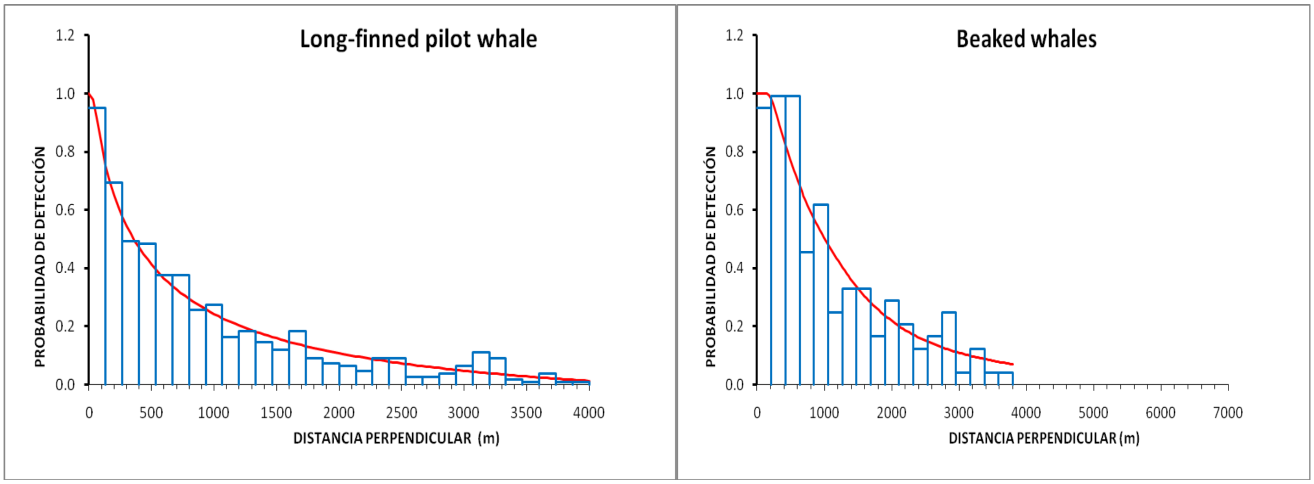


Figure 8. Perpendicular distance distribution, pooled over all covariates (histogram), and fitted detection functions, conditional to the observed covariates (line) for the All ships 1992-2009 dataset.

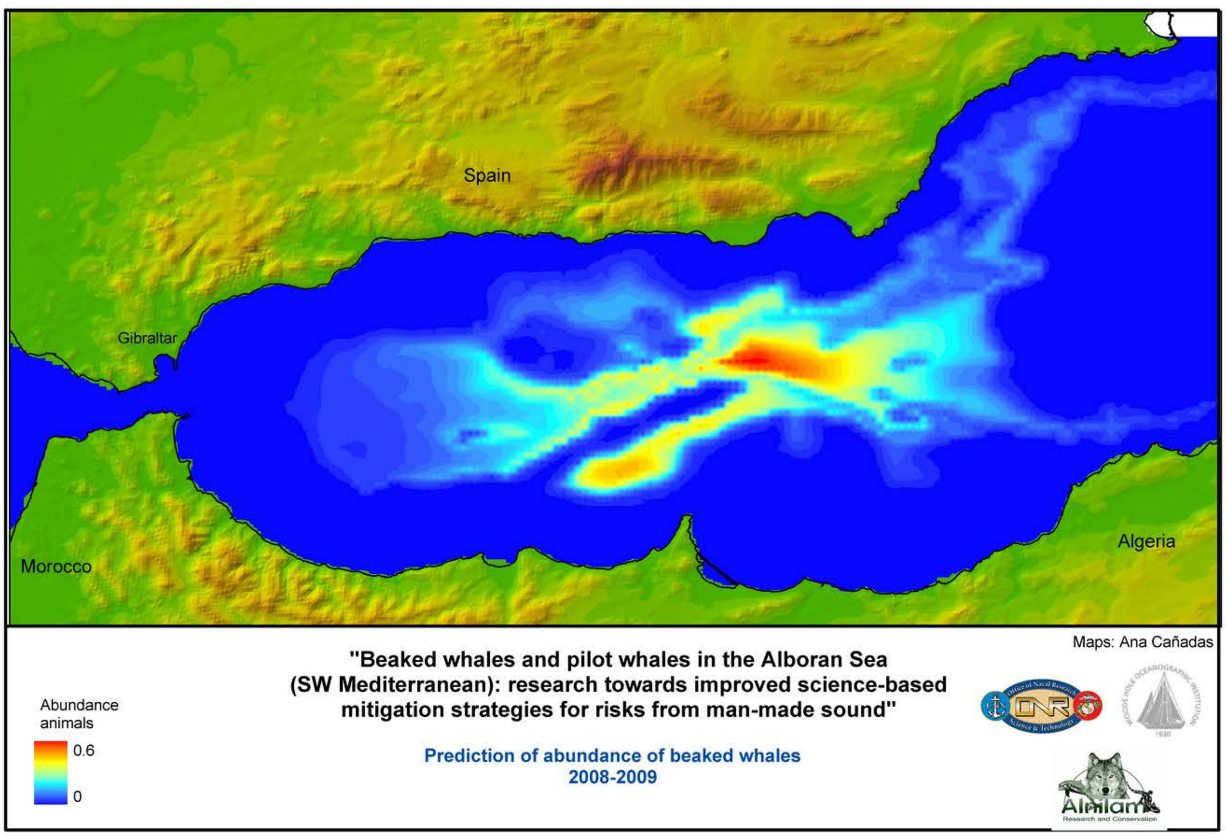


Figure 9. Prediction of abundance of beaked whales for 2008-2009

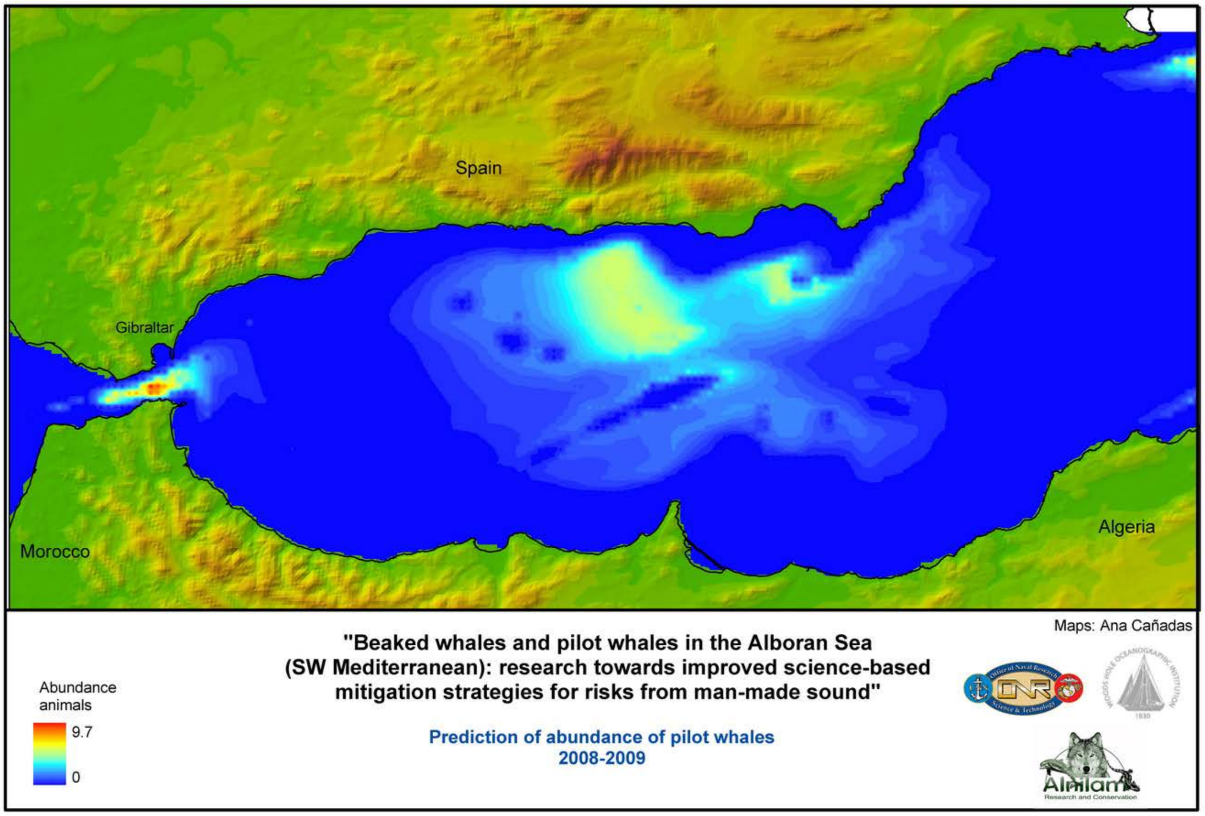


Figure 10. Prediction of abundance of long-finned pilot whale for 2008-2009.

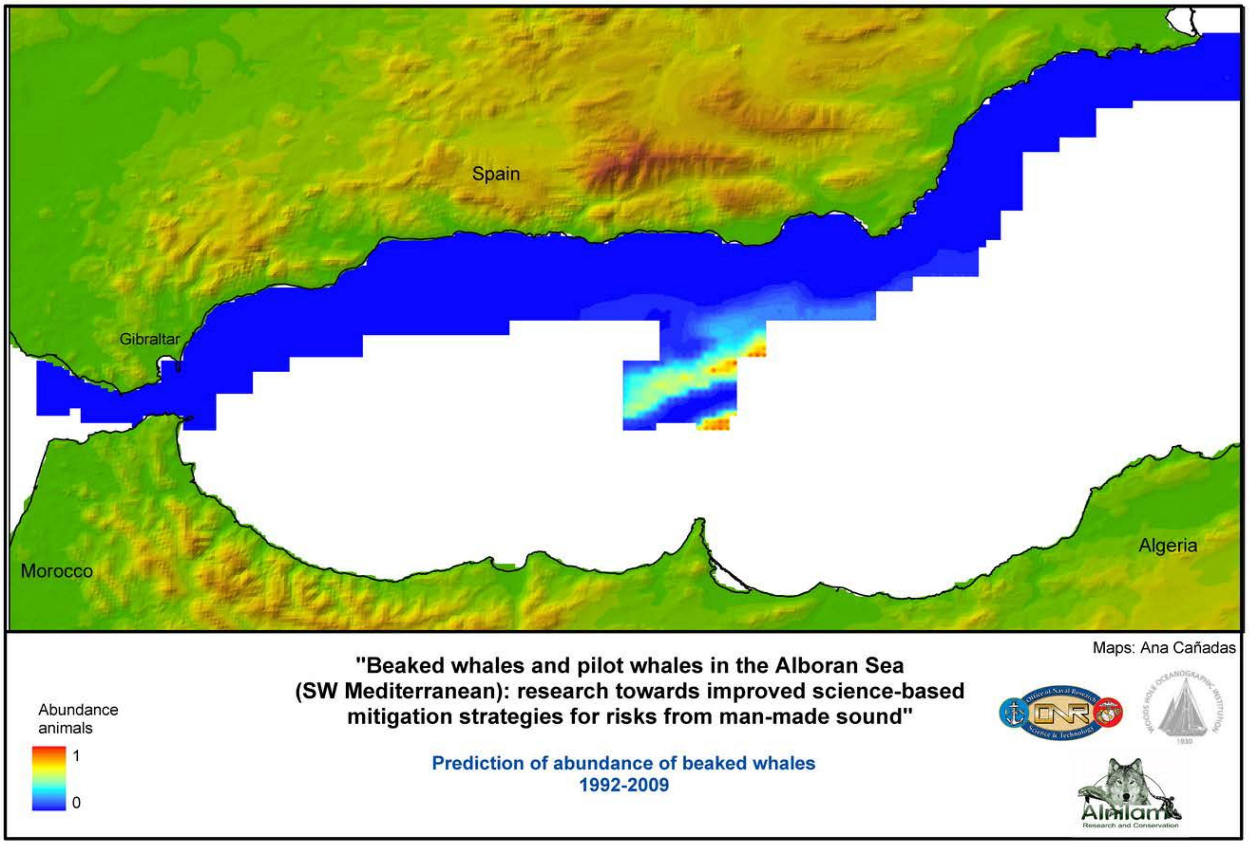


Figure 9. Prediction of abundance of beaked whales for 1992-2009

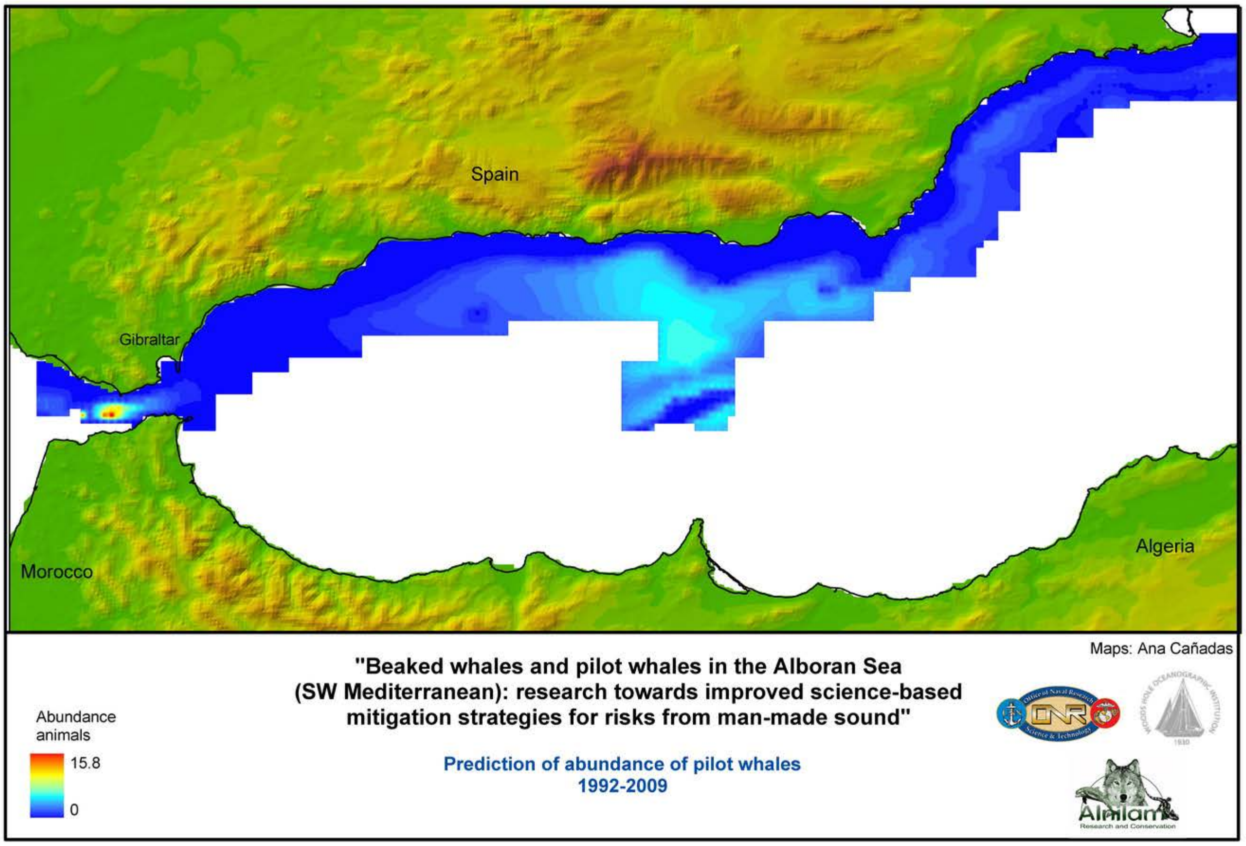


Figure 10. Prediction of abundance of long-finned pilot whale for 1992-2009.