Understanding the Patterns and Causes of Variability in Distribution, Habitat Use, Abundance, Survival and Reproductive Rates of Three Species of Cetacean in the Alborán Sea, Western Mediterranean

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LONG-TERM GOALS

The question of how environmental variability affects populations of marine top predators is an important one because of their role within ecosystems and their potential to influence community structure and biodiversity (Heithaus *et al.* 2008). An understanding of the patterns of distribution and abundance and particularly the causes of that variation is critical to making informed assessments of the importance of anthropogenic activities to marine mammal populations.

This project aimed at quantifying changes in distribution, habitat use, abundance, survival and reproductive rates of three species of cetacean in the Alborán Sea (western Mediterranean) in relation to variation in the physical and biological environment and human activities, based on 18 years of data. The study species, bottlenose dolphin (*Tursiops truncatus*), common dolphin (*Delphinus delphis*) and long-finned pilot whale (*Globicephala melas*) occupy different oceanographic niches off southern Spain. The Alborán Sea is a highly productive and distinct ecosystem that plays an important role in the oceanography of the Mediterranean basin, and has experienced marked changes in climatic and oceanographic conditions.

We attempted to relate features of a species' biology to environmental change, particularly climate change, focusing on distribution, abundance and estimated reproductive and survival rates. The two last ones provide information on the mechanisms that cause distribution and abundance to change. Knowledge of these relationships will help us to predict the future impacts of environmental change in a way that studies of distribution and abundance alone cannot.

This project aimed at doing this using a two decades dataset on bottlenose and common dolphin and pilot whale in the Alborán Sea and the time series of environmental changes generated by NOAA OceanWatch. Once established, these relationships were attempted to be used in conjunction with some simulated scenarios of environmental change to predict the potential effects of further change on these species over the next 40 years. The existing dataset available for these species covers 18 years. Data on human activities (e.g. fisheries, maritime traffic) are also needed to explore how they interact with the environmental changes and with the species parameters changes.

OBJECTIVES

The primary goals of the research in this Grant were:

(1) Quantify relationships between measures of cetacean population ecology, dynamics and status (distribution, habitat use, abundance, survival and reproductive rates) and variation in the marine environment (physical and biological oceanography, prey distribution and relative abundance) for the three focal species over the last 18 years in the Alborán Sea;

(2) Test the hypothesis that environmental changes have had a greater effect on cetacean species that feed at lower trophic levels;

(3) Explore the relative contribution of environmental variation and anthropogenic activities on cetacean population changes;

(4) Quantify the effect of moving the Cabo de Gata TSS (the source of major noise pollution) on the distribution and abundance of the three focal species.

(5) Predict responses of the three focal species to future environmental change under a range of scenarios;

(6) Assess how well cetaceans can serve as indicators of environmental change in the marine environment and of "ocean health" generally.

APPROACH

To achieve the objectives of this project, the following steps were proposed:

(**Step 1**) existing data on the focal cetacean species (line transect sampling and photo-identification), human activities and environmental variables will be compiled and organized into appropriate strata at appropriate resolution and spatial and temporal scales;

(**Step 2**) some new data will be collected (summers 2010 and 2011) and, if sample sizes are large enough, they will be organized in the same way as the existing data to complete a 20 year dataset;

(**Step 3**) available information on changes in the marine environment over the last two decades (through collaboration with IEO and IMEDEA) will be organized to allow joint analysis with the cetacean and human activities data described above;

(**Step 4**) density surface modeling (spatial modeling) of line transect data will be used to relate changes in distribution, habitat use and abundance of the focal species to changes in the environment, including data on oceanography and human activities as explanatory covariates;

(**Step 5**) mark-recapture analysis of photo-identification data will be used to relate changes in survival and reproductive rate to changes in the environment again using oceanographic and human activities data as covariates;

(**Step 6**) models that are developed that relate changes in cetacean biological/ecological characteristics to changes in the environment will be combined with the output of environmental simulation models to predict impacts into the future.

WORK COMPLETED

Compilation and organization of existing data

1.1 Data on cetaceans

In 2012, existing survey data on the focal cetacean species from 1992 to 2010 and *in situ* data on human activities from 1998 to 2009 were compiled and organized into effort and sightings files, both in the format for Distance sampling analysis (to estimate the detection function) and for spatial modeling. In 2013 new available data from 2010 and 2011 were added and formatted.

1.2 Data on environmental variables

These were obtained and organized in 2012. In 2013, however, three new covariates were created in base to those: sea surface temperature with one month, two months, and three months lag in order to explore if the distribution of the animals has a delay with respect to the oceanographic covariates. SST was tested in the models in 5 different ways: (a) as actual SST on the day and position of each sighting; (b) the SST with a time lag of one, two or three months before the day of the sighting at its position; (c) average SST for each summer/year at each grid cell; (d) SST anomaly for each summer/year at each grid cell; and (e) average summer SST for the whole study period for each grid cell.

1.3 Data on fisheries

Data on both fish catches and on fishing activity on fishing grounds were collected. Fish catches data were collected through IDAPES (the Andalusian information system of marketing and fisheries production data dependent from the Directorate General of Fisheries and Aquaculture of the Junta de Andalucía). The fishing activity data on two fisheries (trawling and purse seining) was collected through the automated system VMS (Location System of Spanish Fishing Vessel), which allows competent authorities to obtain satellite information on the positions of all fishing vessels over 12 meters at regular intervals of about 2 hours. These data were provided to Alnilam by the Secretariat of the Sea. Details of the characteristics of these data are given in ANNEX I.

All these data on fish landings and fishing activity were cross-processed to get spatial correlated information. This included a filtering process for both fisheries and for VMS data following similar criteria as the IEO (Spanish Oceanographic Institute). Detail on this process and the filtering are given in ANNEX I.

Additionally, we have estimated the spatial distribution of biomass of several fish prey species, which have been identified among target fish species for the three cetaceans species considered in this study based on the available bibliography. See all details of this estimation in ANNEX I.

New data collection

Data was collected through line-transect surveys at sea during summers of 2010 and 2011 (under GRANT N00014-09-1-0536), and added to the existing data, yielding a 20 year time series of data for the three focal cetacean species in the Alborán Sea. These surveys in 2010 and 2011 continued using the protocols developed over previous years (Cañadas & Hammond 2006; 2008). Photo-identification data for estimating survival and reproductive rates were collected during the same surveys and similarly added to existing data to create a 20-year dataset.

Information on changes in the marine environment

Data on sea surface temperature (SST) climatology has been organized both for the whole year and for the summer months. The two plots below (Figures 1 and 2) show this climatology, each year anomaly and the obvious trend of increase. Anomaly at a given year is the difference between the SST of that year and the mean SST of the whole period considered (1985-2012 here).

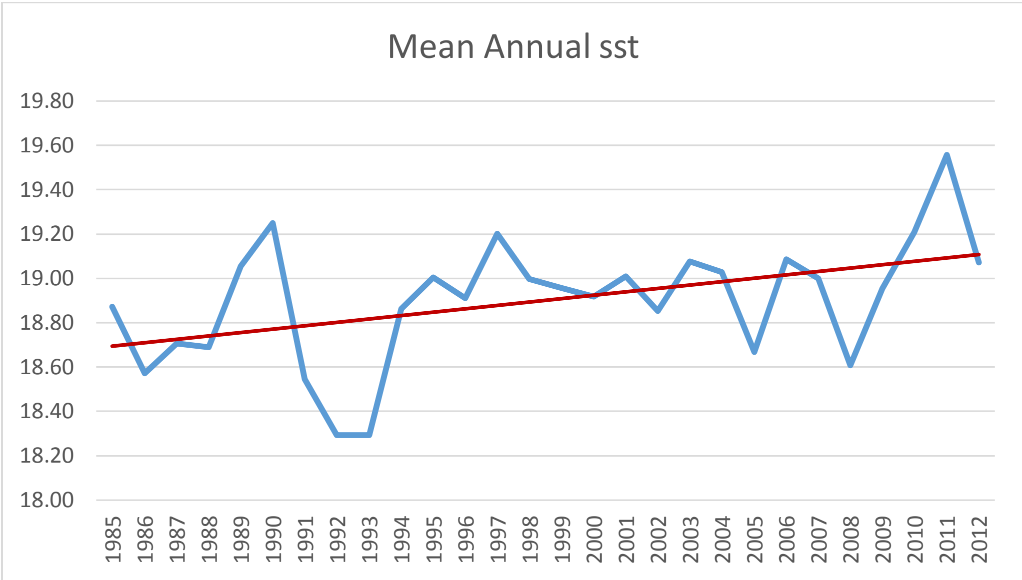


Figure 1. Climatology of annual sea surface temperature in the Alboran Sea

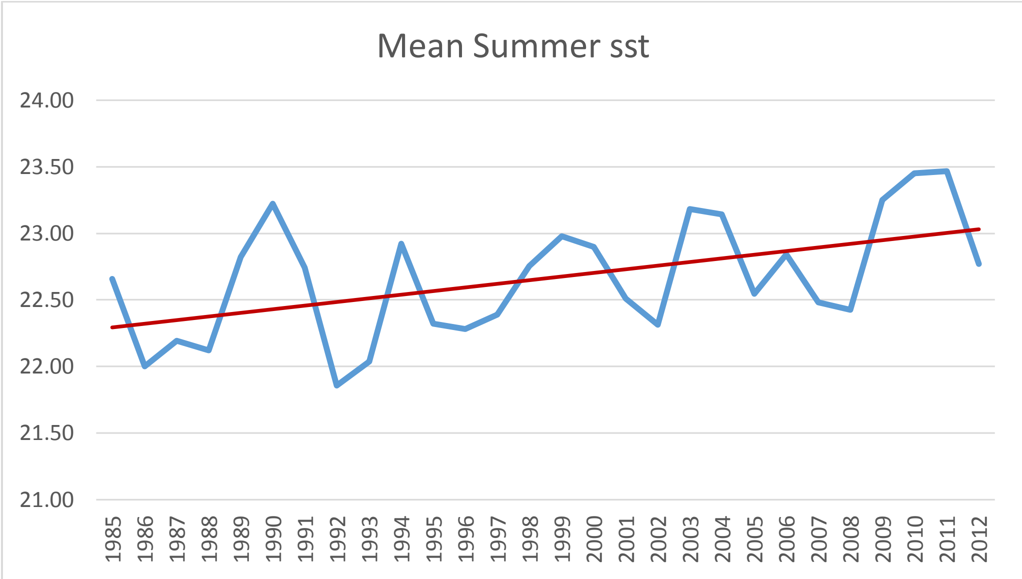


Figure 2. Climatology of annual summer sea surface temperature in the Alboran Sea

Following these plots, effort and sightings data has been arranged to group consecutive years with similar climatology (either above or below mean) in order to do the spatial modelling and investigate if this factor has an influence in the distribution of the animals.

The previous plots were done using the overall SST for the whole Alboran Sea. Additionally, an individual climatology was created for each grid cell of the study area as not the whole Alboran Sea changes in the same way its SST with time. Some areas change more or less they SST over the time due to the different oceanographic characteristics of each particular area. This was used later on during Step 6.

The different degree of change can be observed in the plots of SST for summers 1992 to 2011 (Figure 3 below and Figures 1 to 20 in large size, in ANNEX II). The areas more to the west change generally less than the areas more to the east. The mean SST for the period 1985-2012 for the three subareas (Western Alboran, Eastern Alboran and Gulf of Vera), as well as the mean anomaly and slope of the regression line fitted to the mean SST are given in Table 1. Furthermore, the warmer the waters get, it seems that the stronger the difference become between west and east, probably due to the cooling effect of the Alboran Western gyre (see Figures 3 to 5, and Figures 21 to 23 in ANNEX II).

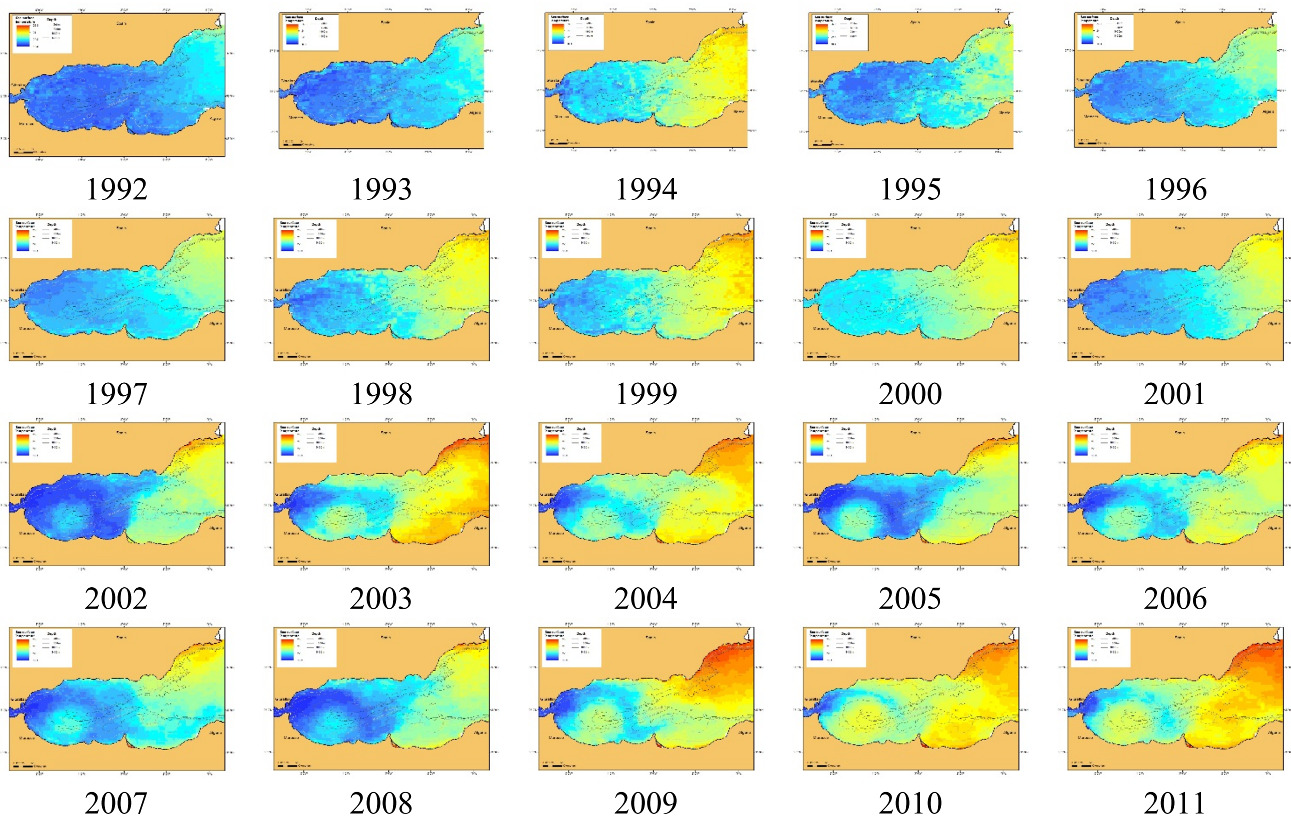


Figure 3. Sea surface temperature 1992-2011

Furthermore, the westernmost area of the Alboran Sea, closer to the Strait of Gibraltar has a negative slope in the regression line for the anomaly, i.e., this area gets relatively cooler over the years, in contrast with the relatively warmer trend in the rest of the area. This can be observed in Figure 3 where the westernmost area gets cooler (darker blue) especially during the second decade with respect to the fist one. It can also be clearly observed in Figure 4, plotting the overall anomaly over those years for each grid cell. The dark blue color in the map corresponds to the grid cells with a negative anomaly (i.e. decrease in SST over time). It is also obvious the important effect of the permanent Western Alboran gyre, which has much lower increase in SST that the rest of the areas. The effect of the second (not permanent) Eastern Alboran gyre can also be observed.

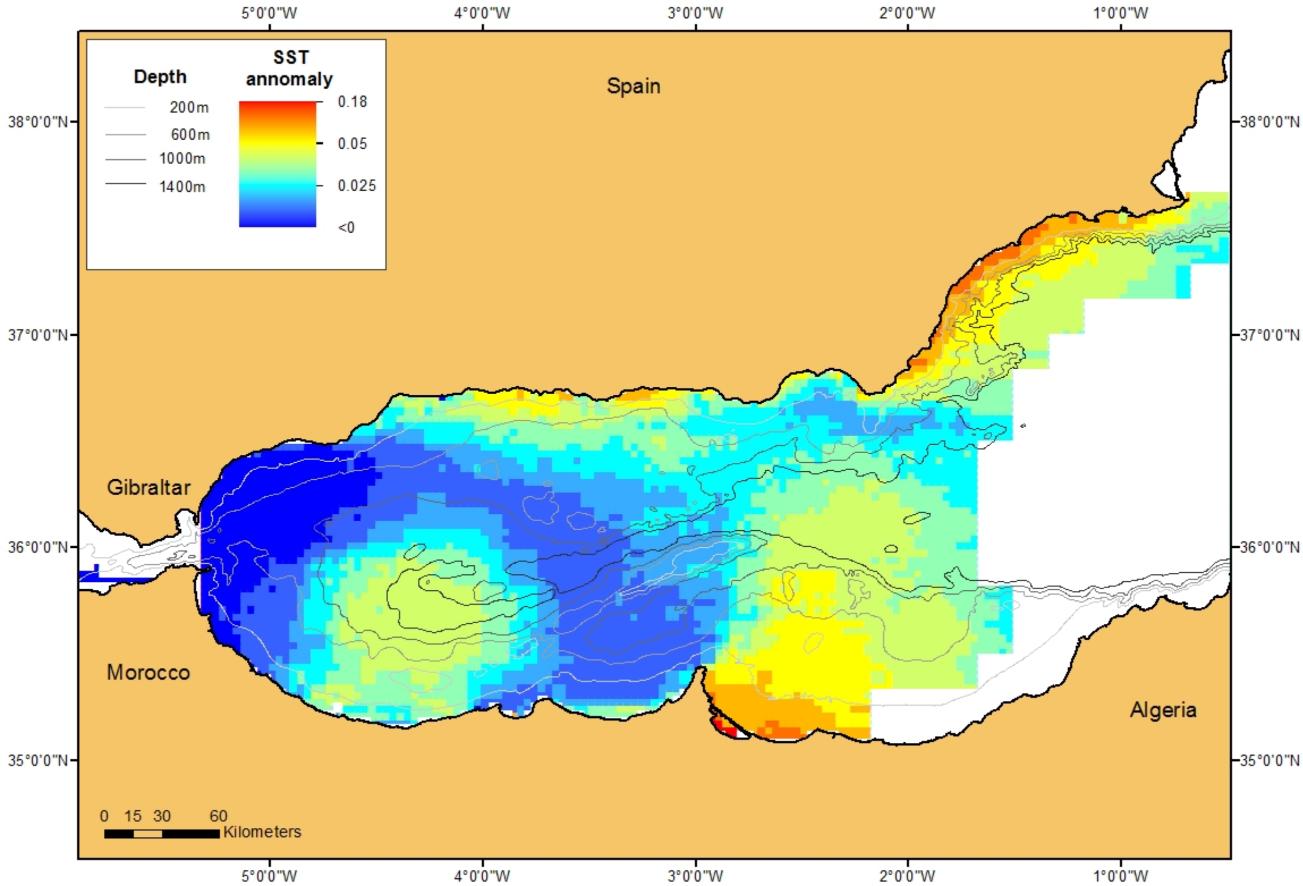


Figure 4. SST anomaly calculated for each grid cell.

Table 1. Mean SST and anomaly and slope of the regression line fitted to the mean SST (ºC) for the period 1985 to 2012 in the three subareas.

Subarea	Western Alboran	Eastern Alboran	Gulf of Vera
Mean SST	21.96	22.51	23.57
Mean anomaly	0.29	0.76	1.26
Slope	0.0108	0.0280	0.0465

Density surface modeling

4.1 Methodology for density surface modelling

4.1.1. Data organization

The study area was divided into grid cells, with a cell resolution of 2 minutes latitude by 2 minutes longitude. Each grid cell was characterized by geographical and environmental covariates. Data used for this project was filtered for summer (defined as June to September), to have a more homogeneous cover over time. Data were organized at five spatial levels, and were used depending on the species and the detail considered, and for comparison: Western Alborán, Eastern Alboran, Gulf of Vera, Alboran (W Alboran + E Alboran) and Global area (all sub-areas together). Figure 5 shows these sub-areas and some features mentioned over the report.

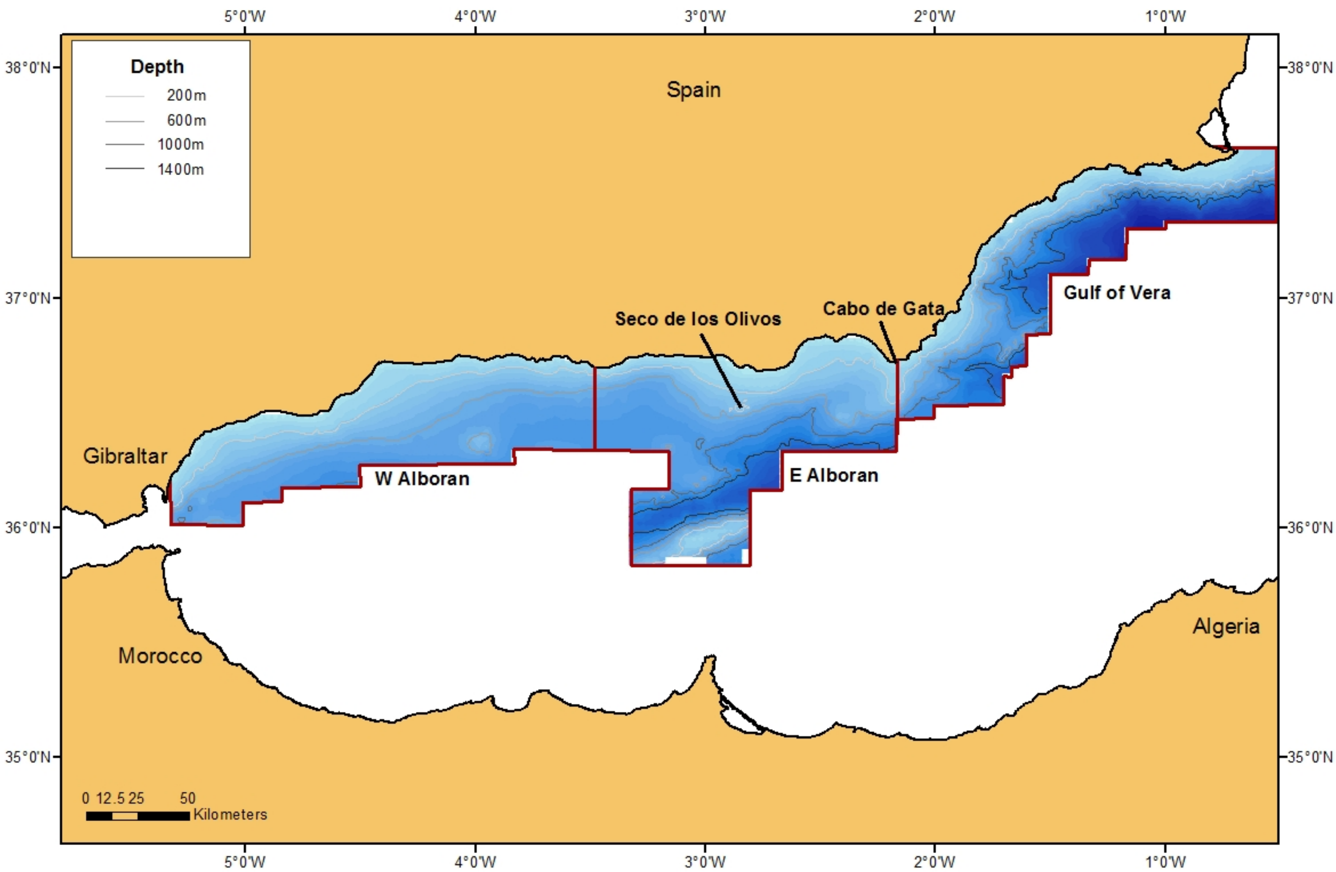


Figure 5. Study area and sub-areas

All on effort transects were divided into small segments (average 2.7 km) of homogeneous effort type. It was assumed that there would be little variability in physical and environmental features within 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.

4.1.2. Spatial modelling of abundance

For model-based abundance estimation, four steps were followed, with some modifications from Cañadas and Hammond (2006): (1) a detection function was estimated from the line transect data and any covariates that could affect detection probability; (2) abundance of groups was modelled as a function of geographical and environmental covariates; (3) groups size was modelled as a function of detection probabilities and covariates; (4) abundance of animals was estimated in each grid cell as the product of model predictions from steps 2 and 3. When the model of group size was not significant, the mean group size (stratified by sub-area) was used instead.

Estimation of detection function.

The software DISTANCE 6.0 release 2 was used to estimate the detection function, using the multiple covariate distance sampling (MCDS) method (Marques 2001; Thomas et al. 2005).

Modelling abundance of groups and group size.
The abundance of groups was modelled using a Generalized Additive Model (GAM) with a logarithmic link function. Over-dispersion in the data was explore and estimated after trying several error distribution. A Poisson error distribution was finally used, as it fitted best the data with overdispersion always around 1, and using the effective searched area of each segment as an offset. The response variable was the number of groups encountered in each segment of effort.

Models were fitted using package 'mgcv' version 1.7-26 for R (Wood 2011). Manual selection of the models was done using three indicators, as described in Cañadas and Hammond (2006): (a) the GCV (General Cross Validation score; Wood 2001); (b) the percentage of deviance explained; and (c) the probability that each variable is included in the model by chance.

Group size was also modelled using a GAM with a logarithmic link function. The response variable was the number of individuals counted in each group and, given the large overdispersion due to the wide range of group sizes, a quasi-Poisson error distribution was used, with the variance proportional to the square mean. Manual selection of the models was done following the same criteria described for the models of abundance of groups.

Estimation of abundance.
Abundance of groups and of group size were predicted from the final models in all grid cells of the study area, The estimated abundance of animals for each grid cell was calculated as the product of its predicted abundance of groups and its predicted group size. The point estimate of total abundance was obtained by summing the abundance estimates in all grid cells over the study area.

Estimation of variance.
The whole analytical process was applied to four hundred non-parametric bootstrap resamples, using day as the resampling unit, to obtain the coefficient of variation and percentile based 95% confidence intervals. For each model in each bootstrap resample, the degree of smoothing of each model term was chosen by the 'mgcv' package, thus incorporating some model selection uncertainty in the variance. The delta method (Seber 1982) was used to combine the CV from the bootstrap with the CV from the detection function (and from the mean group size when this was used instead of modelled group size), giving a final CV.

4.2 Long-finned pilot whales
Density surface modelling of line transect data has been done for long-finned pilot whales with environmental and anthropogenic explanatory covariates looking at potential inter-annual variation.

4.2.1 Anthropogenic covariates
Maritime traffic
The most relevant anthropogenic covariate tested is the main lines of maritime traffic, in the form of distance to the main corridor, one to the marine traffic corridor before the displacement of the Traffic Separation Scheme (TSS) off Cabo de Gata 20 nm to the south, and another one to the corridor after its displacement. The use of this covariate in the density surface modelling of pilot whales did not show any effect on their distribution. Probably these animals, being resident in the area, are habituated to the high level of presence of large ships and their noise. However, the risk of collision exists as does the potentially negative effects of the noise produced by this intense marine traffic. Therefore, comparing the traffic lines before and after the displacement of the TSS with the distribution of the animals, it is

undeniable that it has been a very positive measure as it avoids now the main density areas of pilot whales.

Figures 1 to 4 in ANNEX III show the traffic lines before and after the displacement of the TSS, together with the sightings of this species and the density prediction for both periods.

Fisheries
No effect at all was observed when trying to model pilot whale density with fisheries covariates. This makes sense considering that pilot whales are teutophagic, i.e. they feed on deep cephalopods, which are not targeted by the main fisheries and certainly not by the ones explored here.

<u>4.2.2 Environmental covariates</u>
In terms of oceanographic covariates, no effect at all could be observed of the sea surface temperature (SST), chlorophyll concentration or primary productivity on the density of long-finned pilot whales. None of these covariates explained any variability (less than 1%), neither considering the whole dataset, nor stratifying by areas or by groups of years. This makes sense considering that pilot whales are teutophagic, i.e. they feed on deep cephalopods, which do not depend on SST for their distribution, or at least in a direct way.

What seems to have had an effect on the population is the morbillivirus epizootia affecting long-finned pilot whales in the Strait of Gibraltar and the Alboran Sea in 2006-2007. There has been a reduction in abundance from before to after the epizootia, although not significantly different when modelling the whole study area. Recalling the information on the existence of three clans of pilot whales in the area (see Step 5 below), it was stated, based on the occurrence of the strandings, that the epizootia affected mainly the clan of the Strait of Gibraltar, and in a much lesser extent those further to the East. In order to avoid confounding effects, only the area of Alboran, excluding the Strait of Gibraltar and the Gulf of Vera, was modeled before and after the epizootia. The abundance estimates were 2088 animals (CV=13.7%) from 1992 to 2005 (Figure 6) and 1878 (CV=14.4%) from 2006 to 2011 (Figure 7). It seems that this reduction is due mainly to a reduced group size rather than to a reduction of number of groups (mean group size 1992-2005: 28.5, CV=8.4%; mean group size 1992-2005: 23.1, CV=8.9%). From photo-identification work, the population of the Strait of Gibraltar has undergone a much more drastic decline, from around 350 individuals prior the epizootia to around 40 nowadays (R. de Stephanis, pers. comm).

Figures 5 to 8 in ANNEX III show the same surface density maps but including effort tracks and sightings first, and group sizes second, to show how data support these results.

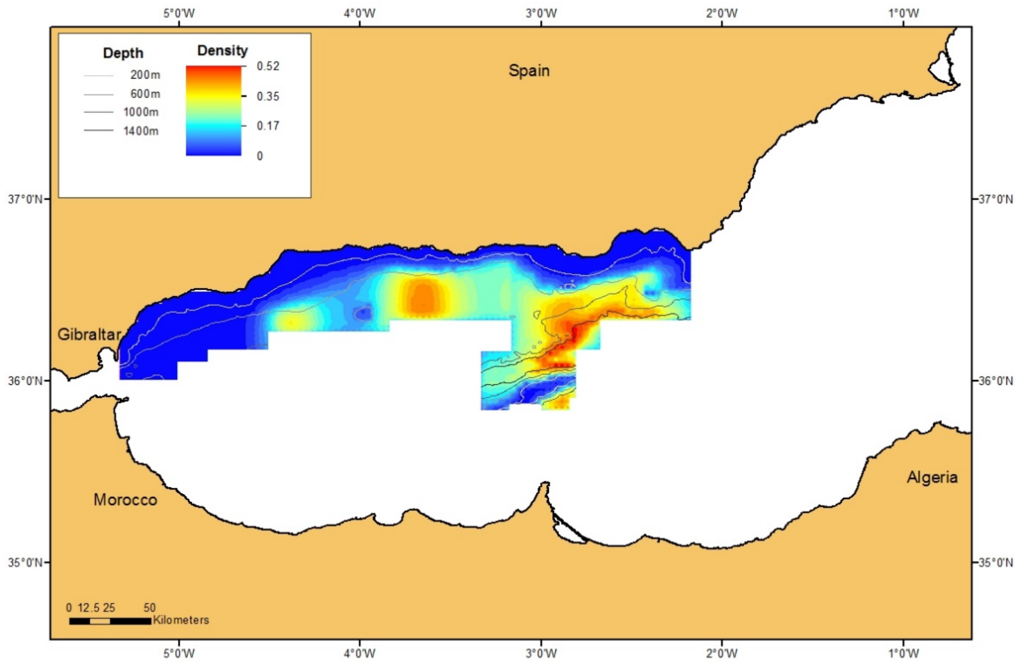


Figure 6. Prediction of density of pilot whales for the period 1992 to 2005 (before the epizootia)

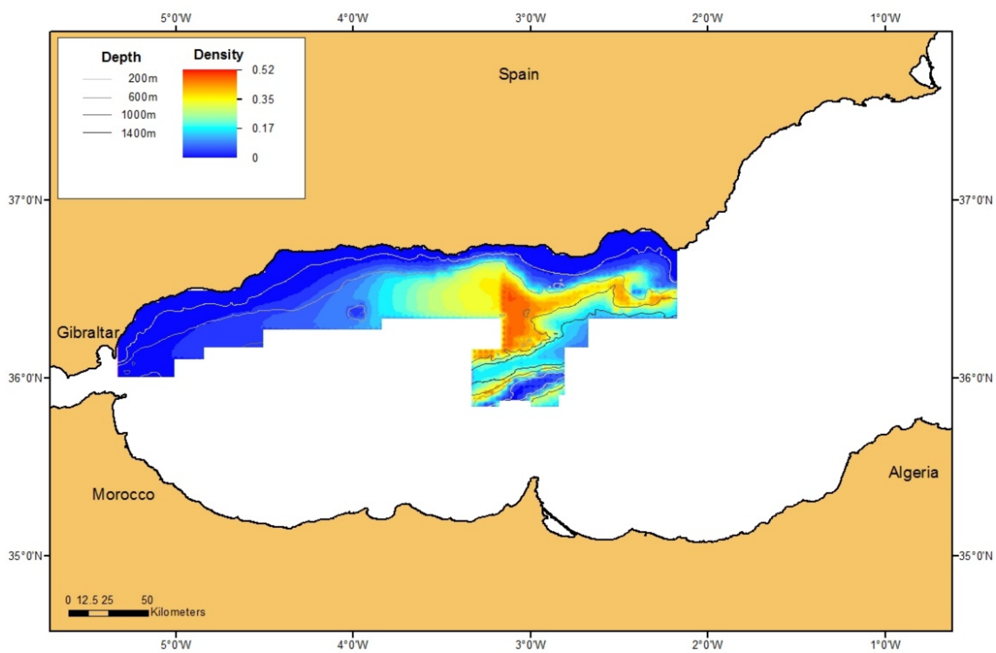


Figure 7. Prediction of density of pilot whales for the period 2006 to 2011 (during and after the epizootia)

4.3 Bottlenose dolphins

Density surface modelling of line transect data has been done for bottlenose dolphins with environmental and anthropogenic explanatory covariates looking at potential inter-annual variation.

4.3.1 Anthropogenic covariates

Maritime traffic

One of the anthropogenic covariates tested is the main lines of maritime traffic, in the form of distance to the main corridor, one to the marine traffic corridor before the displacement of the Traffic Separation Scheme (TSS) off Cabo de Gata 20 nm to the south, and another one to the corridor after its displacement. The use of this covariate in the density surface modelling of bottlenose dolphins did not show any effect on their distribution. Probably these animals, being resident in the area, are habituated to the high level of presence of large ships and their noise. However, the risk of the potentially negative effects of the noise produced by this intense marine traffic exists. Therefore, comparing the traffic lines before and after the displacement of the TSS with the distribution of the animals, it is undeniable that it has been a very positive measure as it gets further now from the main density areas of bottlenose dolphins.

Figures 1 and 2 in ANNEX IV show the traffic lines before and after the displacement of the TSS, together with the sightings of this species and the density prediction for both periods.

Fisheries

In terms of fisheries covariates, we explored the effect of the trawling variables obtained in Step 2, both in terms of fishing effort and fish biomass. We used trawling fisheries because bottlenose dolphins are known to feed on demersal prey, which is the specific target of the bottom trawlers. Additionally we explored the effect of the encounter rate of trawlers and of sport fishing boats (Fig. 4 and 5 in ANNEX IV respectively). These were obtained from our own data collected since 1998, in the form of number of boats detected (trawlers or sport fishing boats) actually fishing in a radius of 1.5nmi from the research ship on each sampling station (every 3nmi of transect, see Fig. 3 in ANNEX IV). All of them were significant when modelled individually although they explained little deviance, between 2.9 and 4.3%. And in any case, they lost their effect when including the environmental covariates (point 4.2.2), so they were not retained in the final density models. Most probably the significance in the individual models just mentioned, is due more to a "coincidence" of habitats (fisheries and dolphins) than to an issue of cause-effect. Furthermore, the relationships density-fishery (encounter rate trawlers and sport fishing boats) are not linear, which makes their interpretation harder (Fig. 4 and 5 in ANNEX IV). Figures 6 and 7 in ANNEX IV shows the surface maps of encounter rates of these two fisheries. Both are rather coastal and therefore coincide to a large extent with the distribution of the bottlenose dolphins in the area, especially around the Seco de los Olivos underwater Sea mound, an important area both for fisheries and for dolphins (see point 4.2.2), as can be seen in Figures 8 and 9 where sightings of this species are plotted over the previous maps.

4.3.2 Environmental covariates

In terms of oceanographic covariates, no effect could be observed of the sea surface temperature (SST), chlorophyll concentration or primary productivity on the density of bottlenose dolphin. SST was tested in 5 different ways: (a) as actual SST on the day and position of each sighting; (b) the SST with a time lag of one, two or three months before the day of the sighting at its position; and (c) SST climatology for each year. None of these covariates explained any variability (2% or less), neither considering the whole dataset, nor stratifying by areas or by groups of years. Bottlenose dolphins feed primarily on demersal fish, therefore it is not strange that SST does not affect much this species (at least in the range observed in a relatively small area such as the Alboran Sea) as demersal fish do not depend on SST for their distribution, or at least in a direct way. In fact, the covariates that explained more deviance and were more significant, were depth, distance from the Seco de los Olivos Sea Mound and bottom physiography (a factor with 4 levels: plain, escarpment, canyon and mound), especially when combined together. According to the models, they have a preference for depths between 100 and 500m, sea mounds and closer to the Seco de los Olivos in particular. The Seco de los Olivos is an underwater mountain located in the north-eastern section of the Alboran Sea, between 200 and 600 m and rising up to 72 m depth. This is an important area of upwelling induced by the topography, which has been highlighted for having the highest concentrations of ichthyoplankton of the northern half of the Alboran Sea (Rubín et al. 1992).

Following the results from Cañadas and Hammond 2005, we refitted the models with the updated method (point 4.1) and the new available data and differentiating by groups of years according to field observations of the probable arrival and departure of immigrant groups. These groups were: 1995-1996, 1997-2000, 2001-2004, 2005-2006, 2007-2011. In all groups the habitat use was very similar, but only varied the abundance. The density scale in the density surface maps is the same so the difference in density can be perceived. Figures 10 to 19 in ANNEX IV show the density surface maps, alone and with the effort tracks and sightings over them to visually assess how well the data supports the model predictions. In each group of years, only the corresponding surveyed area is modelled and predicted. The final results on abundance match the field observations of the arrival of immigrant groups in 1997 and 2005 and their subsequent gradual leaving during 2000-2001 and 2006-2007 respectively. Figure 8 below shows the fluctuations in abundance in the subarea of Almeria. This was chosen for comparison purposes as it is the only sub-area heavily surveyed every year.

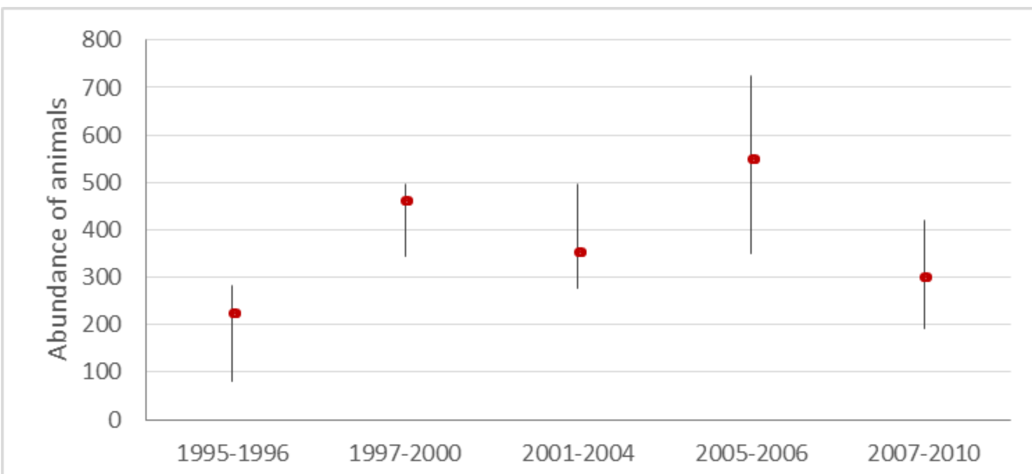


Figure 8. Abundance estimates for bottlenose dolphins during different groups of years. Red dots correspond to the point estimate and bars to the lower and upper 95% Confidence Intervals.

However, the increase in abundance during 1997-2000 seems to be due both to an increase of encounter rate of groups and an increase of group sizes, whereas in 2005-2006 it is due only to an increase in group sizes (Figures 9 and 10).

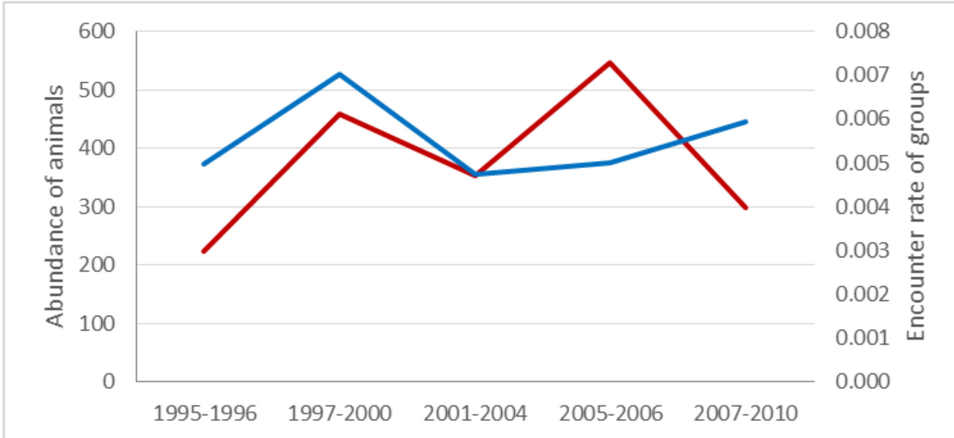


Figure 9. Abundance estimates for bottlenose dolphins during different groups of years in red. Blue line is the encounter rates of groups.

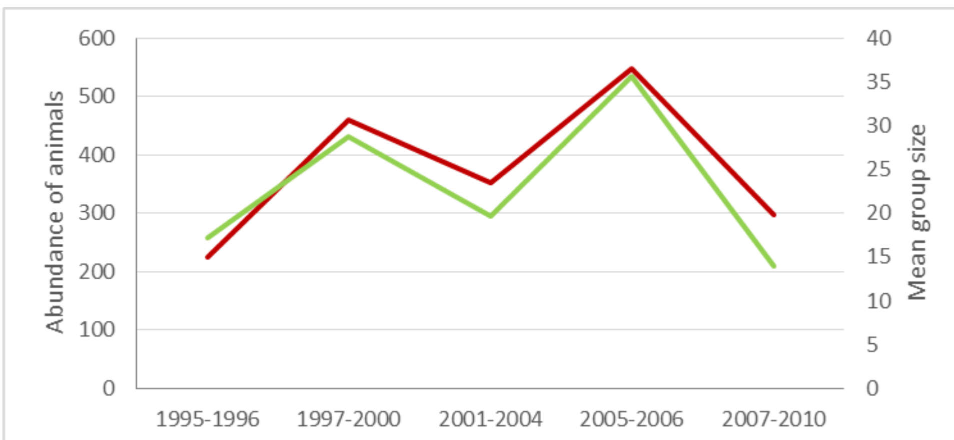


Figure 10. Abundance estimates for bottlenose dolphins during different groups of years in red. Green line is the mean group sizes.

No relationship was found between these fluctuations in abundance, encounter rates of groups and group sizes and the sea surface temperature or any other environmental covariate. To visualize this lack of relationship, Figures 20 and 21 in ANNEX IV show the climatology anomalies for summers 1992-2009 and encounter rates of groups and group sizes respectively.

4.4 Common dolphins

Density surface modelling of line transect data has been done for common dolphins with environmental and anthropogenic explanatory covariates looking at potential inter-annual variation.

4.4.1 Anthropogenic covariates

Maritime traffic

One of the anthropogenic covariates tested is the main lines of maritime traffic, in the form of distance to the main corridor, one to the marine traffic corridor before the displacement of the Traffic Separation Scheme (TSS) off Cabo de Gata 20 nm to the south, and another one to the corridor after its displacement. The use of this covariate in the density surface modelling of common dolphins did not show any effect on their distribution. Probably these animals, being resident in the area, are habituated to the high level of presence of large ships and their noise. However, the potentially negative effects of the noise produced by this intense marine traffic exists. Therefore, comparing the traffic lines before and after the displacement of the TSS with the distribution of the animals, it is undeniable that it has been a very positive measure as it gets further now from the main density areas of common dolphins.

Figures 1 and 2 in ANNEX V show the traffic lines before and after the displacement of the TSS, together with the sightings of this species and the density prediction.

Fisheries

In terms of fisheries covariates, we explored the effect of the fisheries variables obtained in Step 2, both in terms of fishing effort and fish biomass. Additionally we explored the effect of the encounter rate of trawlers and of sport fishing boats as in the case of bottlenose dolphins (see above). None of them were significant and they explained virtually no deviance (less than 1%) in the models of abundance of groups. Interestingly enough, purse seine fisheries effort or biomass (in total of particularly for sardines or for anchovies, two of the main prey species of common dolphins) had no effect on density of groups of common dolphins of on group sizes.

However, encounter rate of trawlers, trawling effort and biomass of trawling prey were significant and explained between 6 and 8.5% of the deviance when modelling group sizes individually, although the relationships were not linear and difficult to interpret. Probably, as in the case of bottlenose dolphins, the significance in the individual models just mentioned, is due more to a "coincidence" of habitats (fisheries and dolphins) than to an issue of cause-effect, especially considering that trawling targets demersal fish species and common dolphins target mainly epipelagic fish as prey.

4.4.2 Environmental covariates

For common dolphins, the environmental covariates with most effect both on the density of groups and on the group sizes is depth and sea surface temperature. In terms of depth they have a preference for waters between 100 and 500 m although they are present in deeper waters too. In terms of SST, the pattern is different for density of groups and for group sizes. In the model of density of groups, density increases almost lineally towards cooler temperatures (Figure 3 in ANNEX V), while in the model of group sizes the preference is for larger group sizes at medium temperatures (22.5 to 24ºC, Figure 4 in ANNEX V). Figures 5 to 7 in ANNEX V show the surface maps of density of groups, group sizes and density of animals (combination of the previous two), respectively. It is clear in these maps that there is a strong pattern of higher density of groups towards the west where the water is cooler and decreases progressively towards the east where the water becomes warmer. However, group sizes are larger in the eastern part of the Alboran Sea with medium sea surface temperature and are in average smaller towards the west with cooler waters. As result, the density of animals is higher in the two areas; at the westernmost end of the Alboran Sea where there are more but smaller groups, and to the easternmost end of the Alboran Sea (not including the Gulf of Vera) where there are less groups but larger. It is probable that they exploit the resources in these areas, both rich on epipelagic fish, with different strategies. But these are unknown.

Two sets of models were created. First, models for individual years were run and predictions of surface density were extracted according to the summer SST of the year modeled (yearly models). In the second set, a global model was run with all years pooled together, using a covariate composed by the average summer SST of each year according to the year in which the on effort segment of track was run (general model). Then predictions were yielded for each year separately according to the particular summer SST of each year. The difference between the two sets of models is that the yearly models use only information from each particular year to generate predictions for each year, while the general models use the information from all years to generate predictions for each particular year according to the particular SST of such year. Both in the global models and the yearly models the density scale is the same for all years within each set, for purpose of comparison. For most years the predictions from both sets of models are very similar, highlighting almost the same areas as high density. The years with more discrepancy were 1992 to 1994. In 1992 there were very few sightings, so we could argue that the standalone model for that year is not very reliable. During 1993 and 1994 only the Gulf of Vera was surveyed. This area has very different oceanographic characteristics than the Alboran Sea, and maybe common dolphins use this area in a slightly different way than the Alboran Sea, so using the general model for the whole area to draw predictions only for this subarea may not be the best way. For these years the yearly models are probably more accurate.

In summary, we believe that the predictions drawn from the general model are more useful and they capture the common dolphin distribution of density adequately.

Relationship between density of animals and SST

Looking at the relationship between density of animals and SST anomaly, the general pattern is increased density at lower SST and vice versa. This can be observed both spatially and temporally, and the combination of both. Table 2 shows the SST in the three subareas, increasing from West (W Alboran) to East (Gulf of Vera) in the period of 1992 to 2009 (see that this period reflects the survey period, and therefore is shorter than that shown in Table 1), together with the mean density of animals, mean encounter rate of groups and mean group size in the same areas and period, which are, at the end, three different ways of looking at the relationship between density of animals and SST. As mentioned before, density of animals increases from East to West towards cooler waters, mainly due to a higher encounter rate (or density) of groups. Group sizes are in average, however, larger in Eastern Alboran with intermediate SST as described above. In the Gulf of Vera, where SST is considerably higher, all values are considerably smaller. Figures 5 to 7 in ANNEX V shows the three surface maps of the response variables in Table 2 for the whole period 1992-2009, where these differences West-East can be clearly observed (shown below in Figure 11 in small size for easy comparison).

Table 2. Mean SST (ºC), mean density of animals (animals/km^2), mean encounter rate of groups (n/length of track on effort) and mean group size for the period 1992 to 2009 in the three subareas.

	Western Alboran	Eastern Alboran	Gulf of Vera
Mean SST	21.90	22.50	23.56
Mean density of animals	1.137	0.6692	0.4255
Mean encounter rate	0.0316	0.0167	0.0067
Mean group size	63	79	50

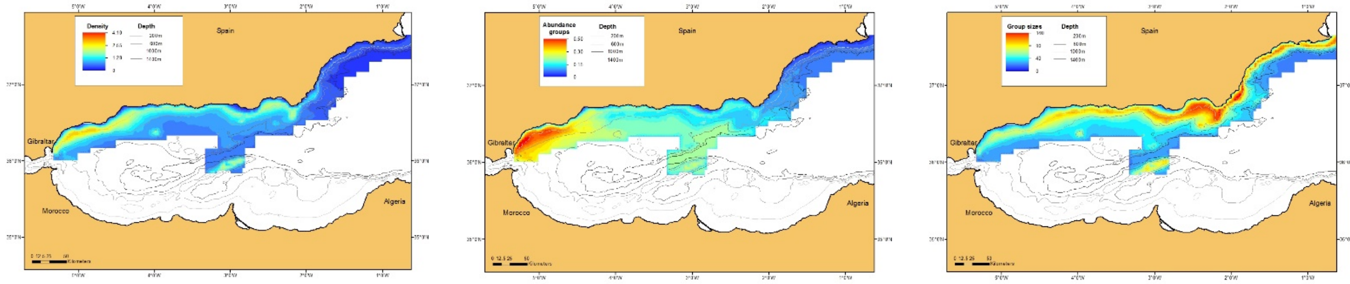


Figure 11. Animals density surface map (left), groups density surface map (center) and groups sizes surface map (right) for the period 1992-2009.

Looking at temporal variation of SST (or its derivate SST anomaly), there seems to be a pattern in which years with higher SST have lower density of animals and vice versa, and this is especially true for years with more extreme anomaly in SST. This pattern can be observed in the three sub-areas considered, as shown by Figures 11 to 13. The years with lower SST (1992, 2002, 2005 and 2008 in Alboran W and E and 1992-1993 followed by 1995-1996in the Gulf of Vera) show the highest values of animal density in those respective areas with respect to adjacent years. On the other hand, the years with highest SST (2000, 2003-2004 and 2009 in Alboran W, 1998-200, 2003-2004 and 2009 in Alboran E, and 1994, 2003-2004 and 2009 in the Gulf of Vera) show the lower animal density with respect to adjacent years. Furthermore, in the Gulf of Vera there is a strong overall pattern of decrease in density over the years, paired with an increase in SST anomaly. In Alboran E and W the rates of increase in SST anomaly over the years is less marked (and almost nothing in Alboran W) and basically no overall pattern can be observed in density of animals (Figures 12 to 14).

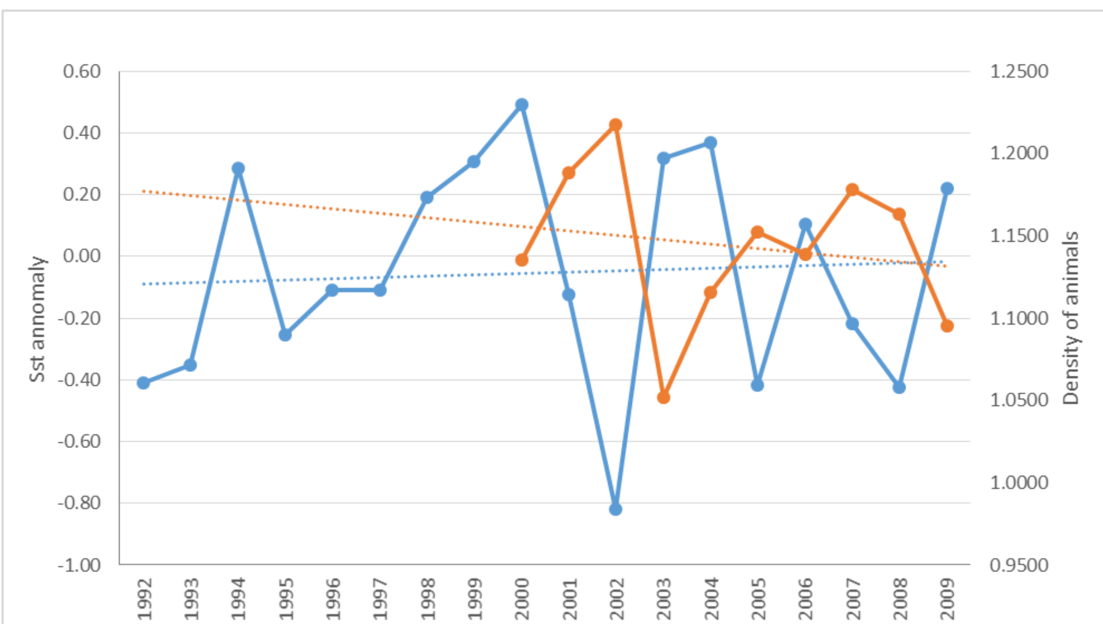


Figure 12. Plot of SST anomaly (blue) and density of animals (orange) in Alboran W from 1992 to 2009. Dash lines represent the linear regression lines for SST and density.

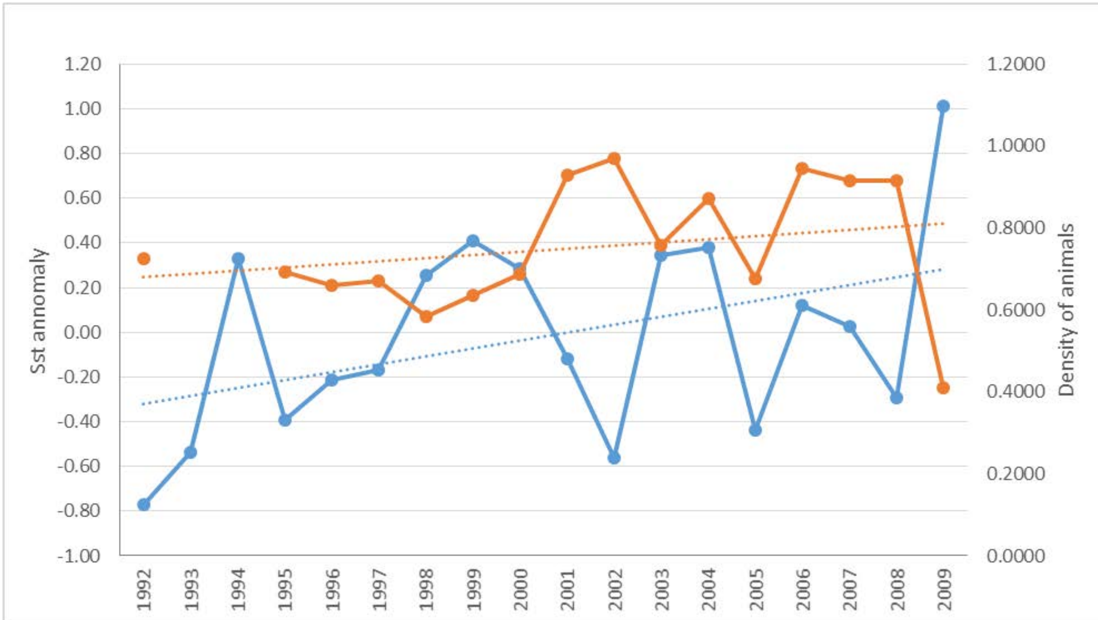


Figure 13. Plot of SST anomaly (blue) and density of animals (orange) in Alboran E from 1992 to 2009. Dash lines represent the linear regression lines for SST and density.

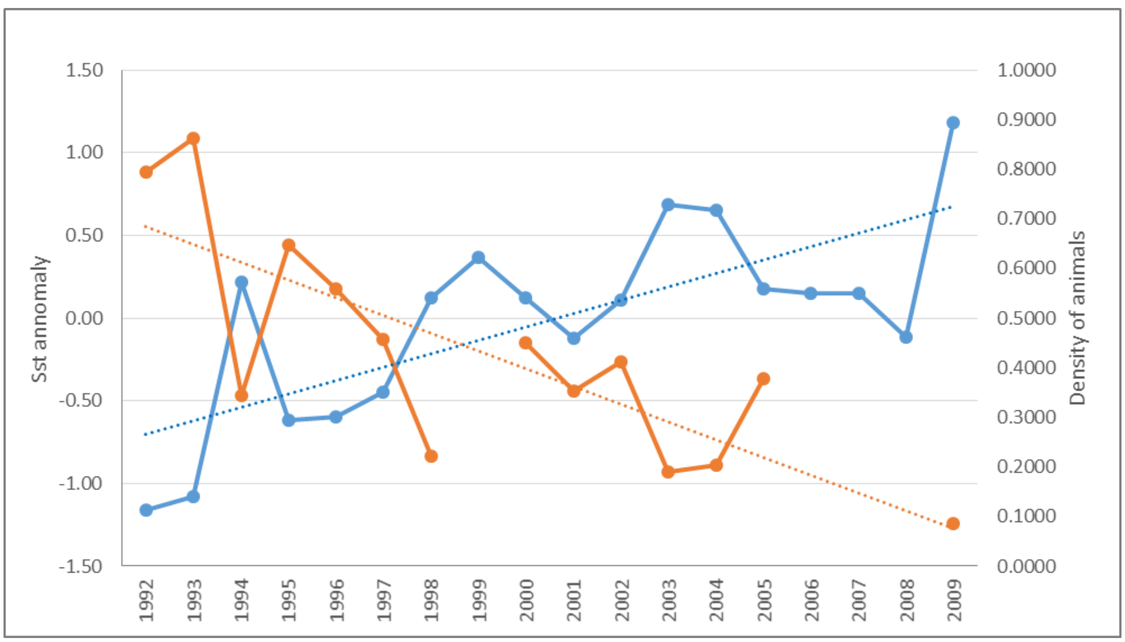


Figure 14. Plot of SST anomaly (blue) and density of animals (orange) in the Gulf of Vera from 1992 to 2009. Dash lines represent the linear regression lines for SST and density.

In summary, common dolphins density seems to have a strong relationship with SST with higher densities in cooler waters and vice versa. Therefore, a strong enough change in the SST may potentially affect their distribution and density at least at a local level (see Step 6).

Mark-recapture analysis

5.1 Bottlenose dolphins

The catalogue has been analyzed already for social structure. A previous published study showed an increase of dolphins in the area of Almeria from 1997 to 2001 when a new decrease in numbers was observed until 2003. Field observations suggested a new increase in numbers between 2004 and 2006 with a subsequent decrease after that. The hypothesis of the new growth of the abundance of the species in the area was attributed to the income of an immigrant group between 2004 and 2006. The results of the photo-identification showed two periods of immigration with a population increase between 1997 and 2001 of 5% followed by a decrease of 5% until 2003. Between 2003 and 2006 an important immigration occurred seeing the population growing at a mean annual rate of 24.8%.

5.1.1 Survival rates

A constant apparent survival rate was estimated throughout the study period at 0.91 (SE:0.01, 95%C.I.:0.89-0.93). This low estimate has to be interpreted in the light of the large immigration followed by an emigration which is included in the apparent survival rate estimate. Different hypotheses were then tested, taking into account the effect of transience on the survival rate in the dataset, first to look at the effect of time on the capture probability, then on the survival rate. Certain periods of year were put together to look at the effect of the presence of immigrant groups of bottlenose dolphins observed during those years (between 1997 and 2000 then between 2004 and 2006). Finally the years of arrival (1997 and 2004) and departure of immigrants (2000 and 2006) and all other years in-between were also modeled because we were estimating the apparent survival rate which is estimated from a combination of both natural mortality and individuals leaving the studied area. The best model, based on its AICc value showed an effect of transience and changes in the apparent survival rates between the years of arrival and departure of immigrants and all other years in-between and the probability of capture changing over time.

Results showed important changes in the apparent survival rate between the different periods due to the fact that the emigration rate is taken into account in the apparent survival rate showing lower survival rates during the years of arrival and departure of immigrant groups. All the other years had a relatively high survival rate estimate for the species. Table 3 below shows these results.

Table 3. Results of the survival rates estimated from the best model with standard error (SE), 95% Confidence Interval (CI) and Coefficient of Variation (CV).

Periods	**Survival rate**	**SE**	**95% CI**	**CV**
all other years	0.935	0.030	0.844-0.975	0.032
Arrival of Immigrants 1997-1998 2004-2005	0.774	0.073	0.602-0.886	0.094
Departure of immigrants 2000-2001 2006-2007	0.832	0.060	0.682-0.920	0.072

5.1.2 Social structure

The analysis of the photo-identification catalogue has shown that the social system was close to a system based in rapid disassociations and casual acquaintances.

The cluster diagram (Figure 1 in ANNEX VI, cophenetic correlation coefficient = 0.81) indicates that most individuals were sighted with preferred companions, expending for than 19% of their time together. Defined by the Knot diagram at a level of 0.19 HWI.

The social structure shows the typical structure for the species with a fission-fusion societies, characterized by dynamic associations of varying strength and temporal stability (Well et al. 1987; Connor et al. 2000; Gero et al. 2005; Foley et al. 2010), but showing an intrapopulation stable structure over the time (Gowans et al. 2007).

The social structure showed significant differences when we compared the three periods with a partial mantel test. This strongly confirms the presence of an immigrant group that interacted during 3 years with the local bottlenose dolphins of Almería.

5.1.3 Reproductive rates

The reproductive rate, in terms of proportion of groups with calves and the average number of calves in groups, has been investigated. The plot below (Figure 15) shows this for the summer months for Alboran E, as is the subarea with more consistent data over the years.

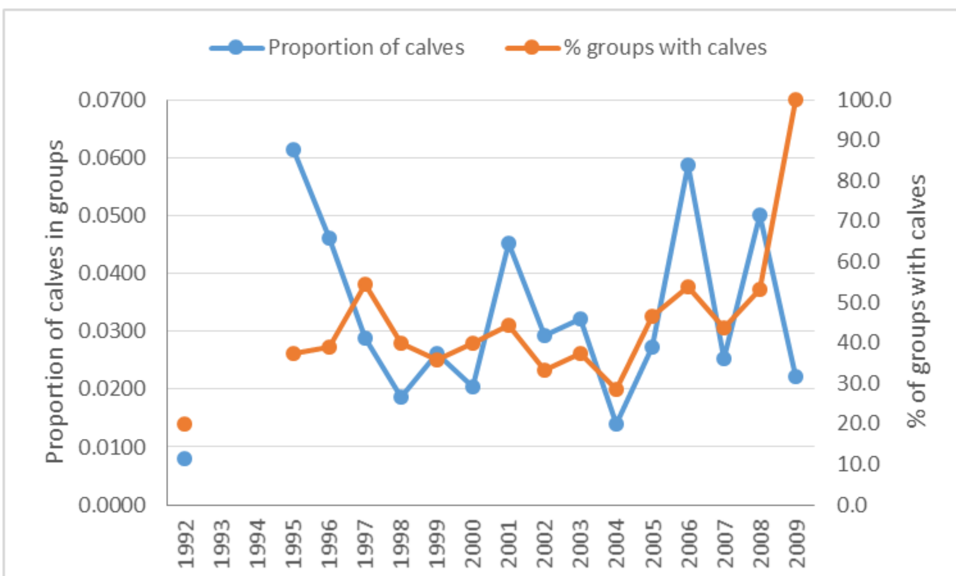


Figure 15. Reproductive rate of bottlenose dolphins during the summer months in the subarea of Alboran E.

No clear pattern has been observed over the years in any of both parameters, although there are important fluctuations. The overall mean proportion of calves in groups in Alboran E is of 0.04 (groups composed in average for a 4% of calves), and the mean percentage of groups observed with calves in the same area is 40.7%. Both values are lower in the other subareas.

When comparing with the SST anomaly, no relationship has been found. Figures 2 and 3 in ANNEX VI show the plot of proportion of calves in groups and proportion of groups with calves against the SST anomaly from 1992 to 2009.

5.2 Long-finned pilot whales

5.2.1 Survival rates

The photo-identification catalogue was completed until 2010. An analysis was done to determine whether survival rates differ between clusters of the Mediterranean Spanish waters population, as several clusters were identified, and how the Western Mediterranean epizootic of morvilivirus in 2006-2007 influenced survival rates.

A half weight association index was used to define clusters of individuals that associate with each other more frequently than with others (Figure 11 in ANNEX VII). A Cormack-Jolly-Seber survival rate model was then implemented. Apparent survival rate estimates varied from 0.82 to 0.99 over 11 clusters for the 1992-2009 period.

When the effect of the morbillivirus outbreak was modeled, three clusters with distinctly lower survival rates (0.821, 0.891 and 0.918) from previous models, presented lower estimates after the outbreak (survival rate dropped from 0.919 to 0.547), supporting a negative influence of the epizootic or other unknown and/or additive factors on certain clusters. To our knowledge, this is the first published study evaluating the effect of a Morbillivirus epizootic on a cetacean population. The results showed within population differences, as not all clusters were affected by the outbreak in the same way.

All this analysis has yielded a publication in Marine Ecology Progress Series, as Special Issue, with the master student who performed this analysis as the leading author. The publication is added as ANNEX VIII.

5.2.2 Reproductive rates

The reproductive rate, in terms of proportion of groups with calves and the average number of calves in groups, has been investigated. The plot below (Figure 16) shows this for the summer months.

There is a clear decrease in the proportion of groups with calves from 1992 until 1999 but then it starts recovering again. In terms of the proportion of calves in the groups, there seems to be strong interannual variations. All these variations were investigated in relationship with the environmental changes, but no pattern or relationship was found with the SST anomaly.

An important issue to consider is that, apparently, three distinct clans of pilot whales exist in the Alboran Sea. One would cover mainly the Strait of Gibraltar but with some incursions in the westernmost end of the Alboran Sea; a second one would cover the central part of the Alboran Sea from Almeria to Granada; and the third one would cover the area of the Gulf of Vera with some incursion down in Almeria. The last two groups seem to have more sporadic mixing than with the first one. This information comes, on one hand, from the photo-id catalogue (several recaptures between Almería-Granada and Gulf of Vera, and no recaptures between those and the Strait of Gibraltar), and on the other hand from satellite tagging of several pilot whales in collaboration with CIRCE (R. de Stephanis, pers. comm). Figure 17 shows an example of several pilot whales tagged with satellite tags and their cleaned and processed positions.

Ideally, all sightings should be assigned to one of these clans, and then obtain survival rates and habitat modelling for them separately to avoid confounding effects. That is being attempted with the spatial modelling by restricting some analysis to the Gulf of Vera and others to the area of Almeria, not considering the area of the Strait of Gibraltar and adjacent areas. A real assignment of groups to each clan might be much more difficult given the partial overlapping of the areas at their edges.

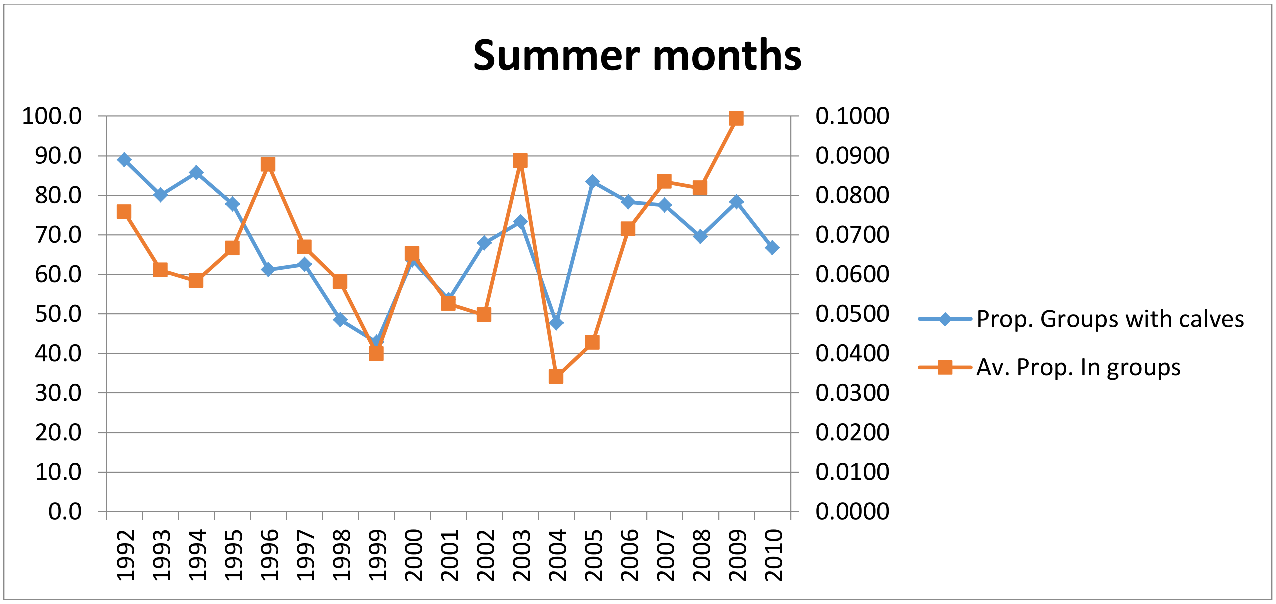


Figure 16. Reproductive rate of long-finned pilot whales during the summer months

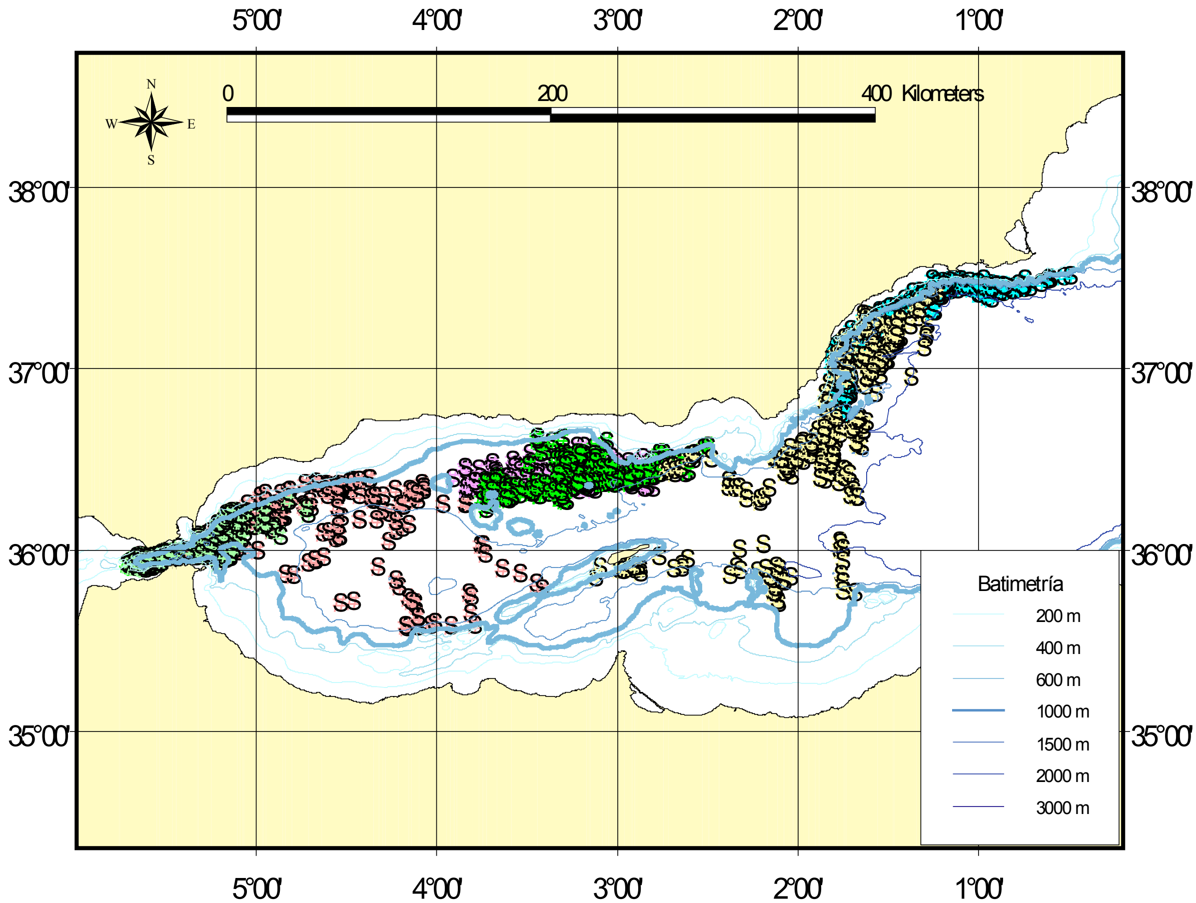


Figure 17. Satellite tracking of long-finned pilot whales in the Alboran Sea between December 2010 and September 2011. Each color is a different individual. (R. de Stephanis, pers. comm)

5.3 Common dolphins

A total of 18,321 photographs have been processed. Of these, 14,077 images of fins have been obtained from 1991 to 2011.

An exploration of the catalogue has been done for year 2004, resulting in 278 individuals, of which 43 were positively females with calves. It was estimated that, on average, only 10% of the individuals in a group could be photo-identified, due to the difficulties of photographing all the animals in very large groups (of many dozens mostly and several hundreds many times), and the small percentage of marked animals. Only one animal was recaptured within those 278 individuals identified, pointing to the large population size of common dolphins in the area. More images were explored afterwards and it was concluded that the population is so large that the capture probability is way too small and this precludes all attempts to do proper mark-recapture analysis to be successful with this population. Therefore, no survival rates could be obtained.

The reproductive rate, in terms of proportion of groups with calves and the average number of calves in groups, was investigated. The plot below (Figure 18) show this for the summer months.

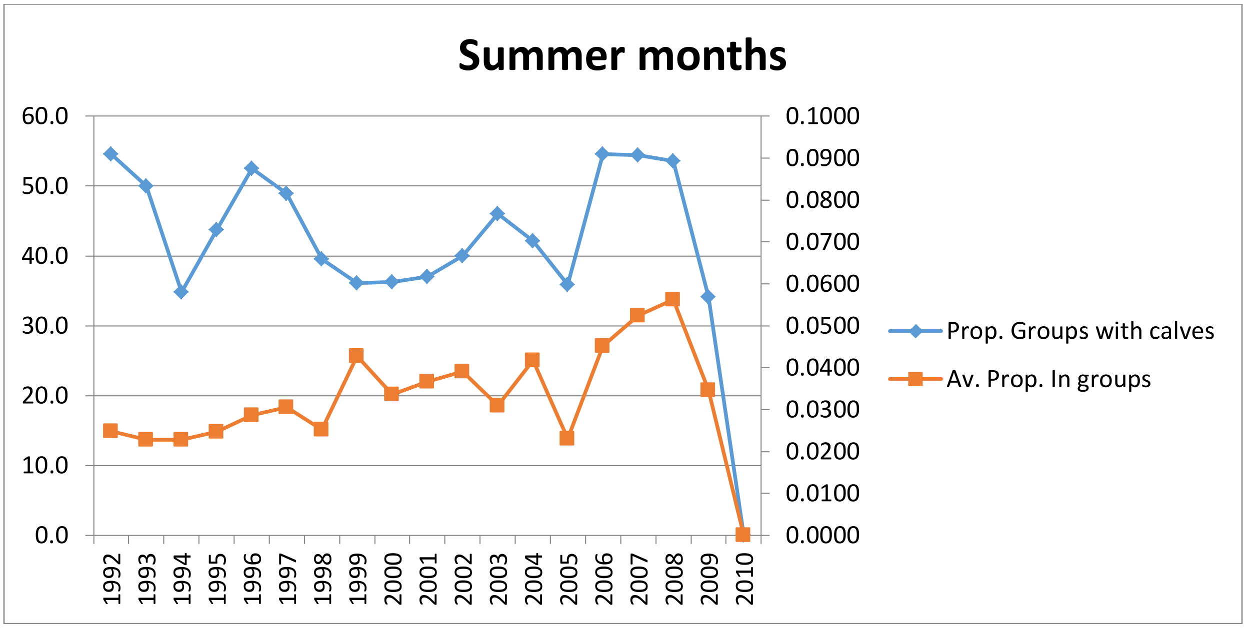


Figure 18. Reproductive rate of common dolphins during the summer months

The drop in 2010 is meaningless since only 4 sightings were recorded that year where the presence of calves could be assessed, so sample size for 2010 is too small (for the other years it varies between 24 and 111 sightings with assessment of presence of calves). No relationship has been found with environmental factors. Figures 1 and 2 in ANNEX IX show the plot of proportion of calves in groups and proportion of groups with calves against the SST anomaly from 1992 to 2009. There doesn't seem to be a clear pattern except a general slight increase in the proportion of calves in the groups over the years (not observed for the proportion of groups with calves).

Predictions into the future

Given that bottlenose dolphins and long-finned pilot whales did not present any detectable relationship with SST in the Alboran Sea over these 20 years, no projection was attempted. It was only done for common dolphins.

6.1. Projection of SST into the future

The previously agreed SST projection into 40 years was finally not available from IMEDEA. Therefore, two different approaches were used, using a regression line, and using the HadCM3 model with time-varying anthropogenic forcings (from Johns et al 2003).

<u>6.1.1 Projection using regression line</u>

Five potential scenarios (projections) were created: 20, 40, 60, 80 and 100 years counting from 2012, therefore, potential scenarios for 2032 to 2112 at 20 years interval. The procedure for the calculations of the potential SST at each scenario, based on a simple linear regression line (as the most parsimonic procedure) plotted over the SST anomaly from 1985 to 2012, is described in ANNEX X. The resulting projections are shown in Figures 2 to 6 of ANNEX X.

It needs to be highlighted that this is a very simple and basic projection based on the climatology of the past 28 years in the local area of this study, extrapolated to five potential scenarios in 20 years intervals. No considerations are given here to the variability, uncertainty or to the effect of factors potentially increasing of decreasing the SST anomaly in the future (e.g. anthropogenic activities). So it has to be taken as just the most parsimonic scenarios.

6.1.2 Projection from the HadCM3 climate model

In this approach, we used simulations of SST from the HadCM3 climate model and updated emissions scenarios projected into 2050 and 2100 (Johns et al 2003). Johns et al (2003) performed 6 scenario experiments including time-varying anthropogenic forcings with the HadCM3 climate model. Relative to 1900, simulated global warning spans a range of about 1.5 to 2.5º at 2050 rising to 2.6 to 5.3º in 2010 depending on the anthropogenic forcings simulations (see Figure 19).We have extracted the simulated warming from 2010 (instead 1900) from their work, spanning a range of about 0.5 to 1.5º at 2050 rising to 1.5 to 3.8º in 2010 depending on the anthropogenic forcings simulations. Figures 7 to 10 in ANNEX X show the projections at the minimum at maximum change at 2050 and 2100.

6.1.3. Comparison between both approaches

The projection using regression line is the most simplistic one, but it is based solely on local information on the SST anomalies in the area over the last 28 years, with no implications of potential time-varying anthropogenic effects. The projection from the HadCM3 climate model is a much more complete procedure as it takes into account those time-varying anthropogenic effects. However, it is based on global change of SST, with no information on local dynamics. As was shown in Step 3, there are different observed rates of change at a very local scale, and even in some areas the overall trend is slightly negative. Therefore, the resulting projections from both approaches are quite different, with stronger increase (equal for the whole area) with the second approach as time increases (the increase is not linear).

However, even if the time scales are slightly different, the 2050 projection from the second approach would be comparable to the 2052 projection from the first approach, and the 2100 projection with somewhere in between the 2092 and 2112 projections. The overall increase (anomaly) in SST for 2052 with the first approach would be 1.29ºC; while the minimum and maximum change for the second approach for 2050 would be 0.5 and 1.5ºC (average 1ºC). Therefore, the projection from the regression line based on local SST for 40 years into the future falls perfectly within the range of simulations from the HadCM3 climate model for a similar period. For 2100, the second approach gives a range between 1.5 and 3.8º (average 2.65º), while the first one gives an overall increase of 2.4 and 2.9 for 2092 and 2112 respectively, both within the range of the second approach and close to the average between minimum and maximum.

Which one could be closer to the most probable scenario is impossible to say, as one is based on local information with no consideration for varying anthropogenic effects, and the other one takes into account the varying anthropogenic effects but with no local information. However, the fact that the projections from the simplistic regression line fall within the range of projections from the complex HadCM3 climate model with time-varying anthropogenic effects, and the fact that the first is based on local and locally, point to point, differentiated information, lead us to consider the first approach as probably the best for this relatively small area as is the Alboran Sea.

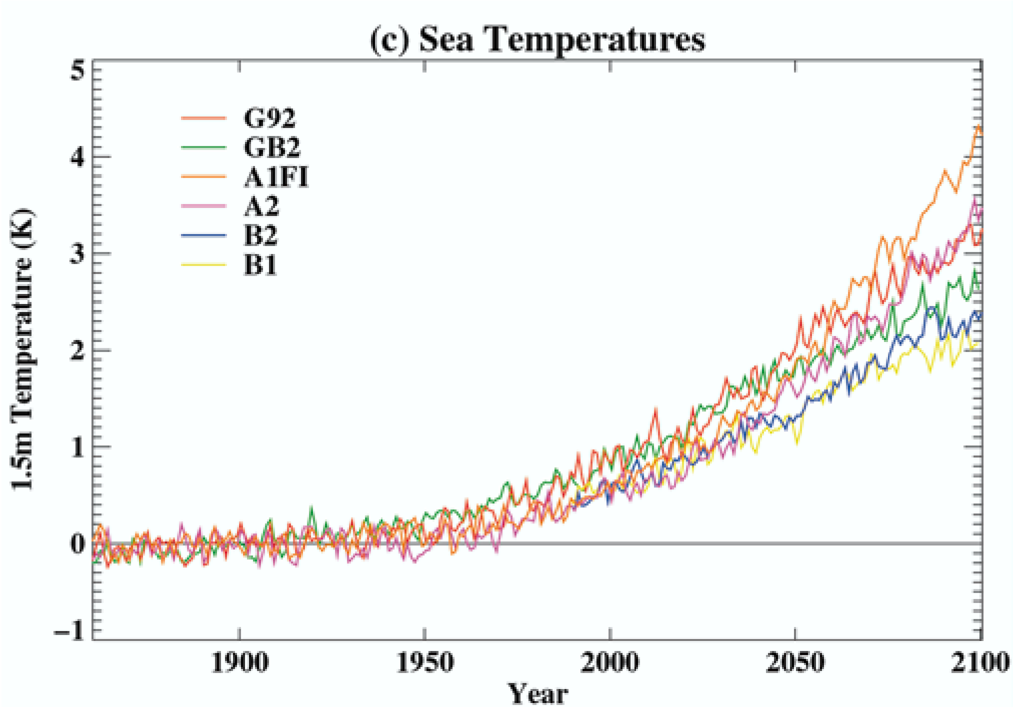


Figure 19. Time series of annual global mean sea temperatures in the 6 simulated scenarios for the period 1859-2100, each relative to their average over the period 1880-1920 (extracted from Johns et al 2003).

6.2. Predictions of common dolphin density into the future

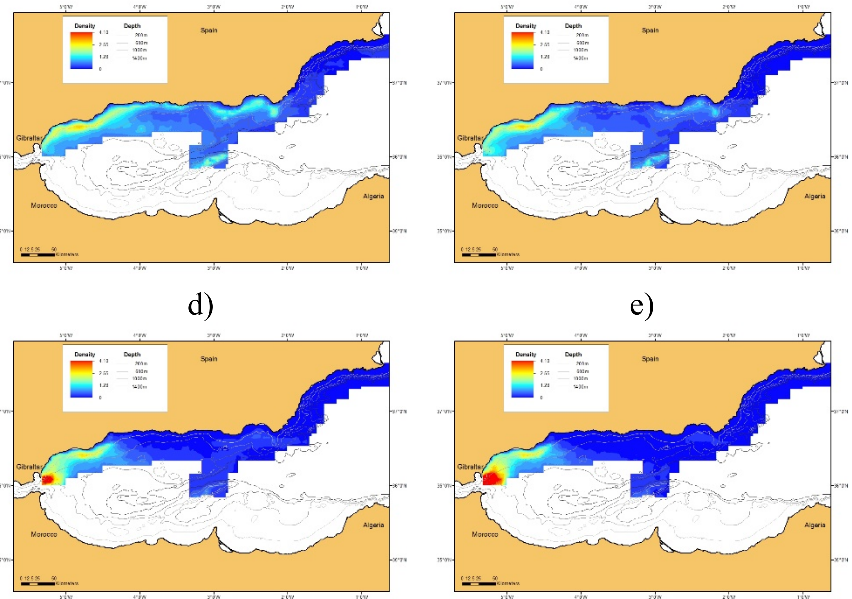
To do the predictions, the model results for abundance of groups and for group sizes, and their combination to get the abundance of animals, for the whole period 1992-2009 (global model, see point 4.4.2 under Step 4, and ANNEX V) were used. The SST values used for each prediction were the 9 projections described above, 5 from the regression line and 4 from the HadCM3 climate model.

6.1.1 From projection using regression line

Figures 11 to 15 in ANNEX X show the predictions of common dolphin density for 20, 40, 60, 80 and 100 years into the future according to the projections from the regression line. It is clear in this progression (Figure 20 in small size), that distribution gets more and more relegated to the west, i.e. density gets lower in the East and higher in the West. This is due to the preference of common dolphins for cooler waters in the area. Therefore, as the water gets warmer towards the East and slightly cooler (or very slightly warmer) towards the West (see point 6.1.1 in ANNEX X) over time, common dolphins potentially would tend to aggregate more towards the West.

However, it needs to be taken into consideration that it is well known that common dolphins avoid too cold waters; e.g. Lambert et al 2011 describe SST below 8º as unsuitable temperature and between 8 and 14 as marginal temperature, being above 14º the core temperature for common dolphins. In the projections from the regression line, the cooler SST predicted for the westernmost area are 17º and 14º in 2032 and 2052 respectively, while in the three next projections it goes down to 10 to 12º, which could be considered as marginal SST for common dolphins. Therefore the strong increase in density in the westernmost area in the last two predictions for 80 and 100 years is, at minimum, unrealistic; first because SST here is improbable that would go down so much during a global warming era; and second because even if it happens, it would become then a less than optimal habitat for common dolphins. Therefore, the most important issue to be highlighted with this exercise is that,overall, there would be likely a general decrease in density and reduction in suitable habitat for common dolphins in the Alboran Sea towards the West if the SST continues to change at the rate it has done it over the last three decades at the local level.

a) b) c)



d) e)

Figure 20. Predictions of common dolphin density for 20, 40, 60, 80 and 100 years into the future according to the projections from the regression line: a) 20 years (2032); b) 40 years (2052); c) 60 years (2072); d) 80 years (2092); e) 100 years (2112).

6.1.2 From projection from the HadCM3 climate model

Figures 16 to 19 in ANNEX X show the predictions of common dolphin density for 2050 and 2100 according to the minimum and maximum projections from the HadCM3 climate model with time-varying anthropogenic effects. It is clear in this progression (Figure 21 in small size), that distribution gets more and more relegated to the west, as in the previous projections, but with a progressive decline in all areas. Therefore, as the water gets warmer towards the East it becomes a less suitable habitat than the West, which is always cooler than the East.

a) b)

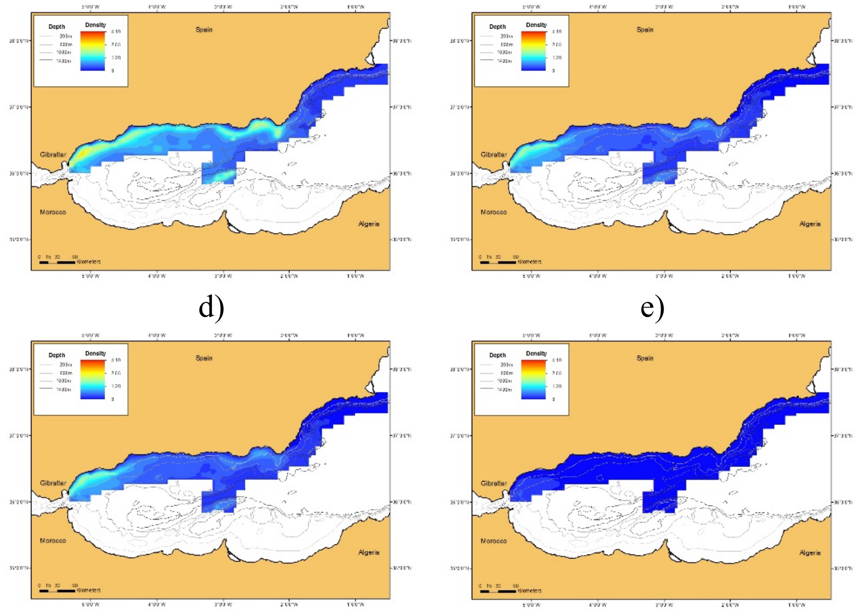


Figure 21. Predictions of common dolphin density for 2050 and 2010 according to the projections from the HadCM3 climate model: a) minimum change in 2050; b) maximum change in 2050; c) minimum change in 2100; d) maximum change in 2100.

Comparing the prediction for 2052 from the first approach and the predictions for the minimum and maximum projections for 2050 from the second approach (scales in the maps are the same), the density predictions are very similar and, in fact more or less the first one like an average of the two second ones. However, when comparing 2092 and 2112 from the first approach with 2100 from the second approach, the overall reduction in the eastern half of the area is very similar, but in the first case there is an increase towards the West while in the second case there is also a reduction here. This is because as a difference with the first approach, as already described, the second one does not have local information, and therefore the rate of change is assumed to be exactly the same everywhere. As was said for the SST projections themselves, the fact that the predictions from the simplistic regression line fall within the range of the predictions from the complex HadCM3 climate model with time-varying anthropogenic effects, and the fact that the first is based on local and locally, point to point, differentiated information, lead us to consider the first approach as probably the best for this relatively small area as is the Alboran Sea.

RESULTS

See section above (Work completed and Results) for all the detailed results. In this section, we provide a summary of the main conclusions of this project.

<u>Long-finned pilot whales:</u>

- **Maritime traffic** did not show any effect on the density and distribution of pilot whales. Probably these animals, being resident in the area, are habituated to the high level of presence of large ships and their noise. However, the risk of collision exists as does the potentially negative effects of the noise produced by this intense marine traffic. Therefore, comparing the traffic lines before and after the displacement of the TSS with the distribution of the animals, it is undeniable that it has been a very positive measure as it avoids now the main density areas of pilot whales.

- No effect at all was observed when trying to model pilot whale density with **fisheries** covariates. This makes sense considering that pilot whales are teutophagic, i.e. they feed on deep cephalopods, which are not targeted by the main fisheries.
- The density and distribution of pilot whales did not show any relationship with local dynamic features such as the **SST**, and therefore does not seem to being affected (at the temporal and spatial scale considered) by the warming of the waters in this area. However, it is also possible that the changes in SST could affect the tri-dimensional pattern of currents and therefore to the distribution of the cephalopods prey and, indirectly, the pilot whales. But so far this change has not been detected yet with the time scale considered and the available information to us.
- What seems to have had an effect on the population is the **morbillivirus epizootia** affecting long-finned pilot whales in the Strait of Gibraltar and the Alboran Sea in 2006-2007. There has been a reduction in abundance from before to after the epizootia, although not significantly different for the whole study area. The reduction was much more drastic in the Strait of Gibraltar.
- When the effect of the morbillivirus outbreak was modeled, three clusters with distinctly lower **survival rates** (0.821, 0.891 and 0.918) from the general models, presented lower estimates after the outbreak (survival rate dropped from 0.919 to 0.547), supporting a negative influence of the epizootic or other unknown and/or additive factors on certain clusters.
- In terms of **reproductive rate**, there is a clear decrease in the proportion of groups with calves from 1992 until 1999 but then it starts recovering again. There seems to be strong interannual variations in the proportion of calves in the groups. No pattern or relationship was found between these variations and the SST anomaly.

Bottlenose dolphins:

- **Maritime traffic** did not show any effect on the density and distribution of bottlenose dolphins. Probably these animals, being resident in the area, are habituated to the high level of presence of large ships and their noise. However, the risk of potentially negative effects of the noise produced by this intense marine traffic exists. Therefore, comparing the traffic lines before and after the displacement of the TSS with the distribution of the animals, it is undeniable that it has been a very positive measure as it avoids now the main density areas of bottlenose dolphins.
- Trawling **fisheries** were significant in the density and distribution of bottlenose dolphins when modelled individually, but lost their effect when modelled together with environmental covariates, which resulted much more relevant. Most probably, the significance in the individual models is due more to a "coincidence" of habitats (fisheries and dolphins) than to an issue of cause-effect.
- The density and distribution of bottlenose dolphins did not show any relationship with local dynamic features such as the **SST**, and therefore does not seem to being affected (at the temporal and spatial scale considered) by the warming of the waters in this area. However, it is also possible that the changes in SST could affect the tri-dimensional pattern of currents and therefore to the distribution of fish and, indirectly, bottlenose dolphins. But so far this change has not been detected yet with the time scale considered and the available information to us.
- A large **fluctuation in density** was observed, however, over time (which only affected the abundance, but not the distribution, which remained the same over time). These coincided with field observations of the arrival of immigrant groups in 1997 and 2005 and their subsequent gradual leaving during 2000-2001 and 2006-2007 respectively. No relationship was found between these fluctuations in abundance, encounter rates of groups and group sizes and SST or

any other environmental covariate. We don't have information on the origin or destiny of the immigrant groups; it could be the poorly studied southern section of the Alboran Sea, or somewhere to the East. No recaptures have been observed with photo-identification in the very well studied Strait of Gibraltar, so most probably they do not come from the West.

- A constant apparent **survival rate** was estimated throughout the study period at 0.91 (SE:0.01, 95%C.I.:0.89-0.93). This low estimate has to be interpreted in the light of the large immigration followed by an emigration which is included in the apparent survival rate estimate. In fact, results showed important changes in the apparent survival rate between the different periods considered also for the spatial modeling, due to the fact that the emigration rate is taken into account in the apparent survival rate showing lower survival rates during the years of arrival and departure of immigrant groups. All the other years had a relatively high survival rate estimate for the species.
- No clear pattern has been observed over the years in any of the parameters tested for **reproductive rate** (proportion of groups with calves and the average number of calves in groups), although there are important fluctuations. When comparing with the SST anomaly, no relationship has been found.

<u>Common dolphins:</u>

- **Maritime traffic** did not show any effect on the density and distribution of common dolphins. Probably these animals, being resident in the area, are habituated to the high level of presence of large ships and their noise. However, the risk of potentially negative effects of the noise produced by this intense marine traffic exists. Therefore, comparing the traffic lines before and after the displacement of the TSS with the distribution of the animals, it is undeniable that it has been a very positive measure as it avoids now the main density areas of common dolphins.
- None of the **fisheries**-related covariates showed any effect on the distribution and density of common dolphins, which was surprising as the fisheries considered here, especially purse seine, target the main prey for common dolphins.
- For common dolphins, the environmental covariates with most effect both on the density of groups and on the group sizes was depth and **SST**. In terms of depth, they have a preference for waters between 100 and 500 m although they are present in deeper waters too. In terms of SST, the pattern is different for density of groups and for group sizes. Group density increases almost lineally towards cooler temperatures (westernmost area of the Alboran Sea), while group sizes are generally larger at medium temperatures (22.5 to 24ºC, easternmost end of the Alboran Sea, not including the Gulf of Vera).
- There seems to be a pattern in which years with higher SST have lower **density** of animals and vice versa, and this is especially true for years with more extreme anomaly in SST.
- The capture probability in mark-recapture for common dolphins is way too small and this precluded all attempts to do proper mark-recapture analysis to be successful with this population. Therefore, no **survival rates** could be obtained.
- In terms of **reproductive rates**, there doesn't seem to be a clear pattern except a general slight increase in the proportion of calves in the groups over the years (not observed for the proportion of groups with calves). No relationship has been found with environmental factors.
- From the predictions of common dolphin density according to SST **projections into the future** based on the regression line, <u>overall density gets progressively lower in the East and higher in the West</u>. This is due to the preference of common dolphins for cooler waters in the area. Therefore,

as the water gets warmer towards the East and slightly cooler (or only very slightly warmer) towards the West over time, common dolphins potentially would tend to aggregate more towards the West. Therefore, overall, there would be likely a general decrease in density and reduction in suitable habitat for common dolphins in the Alboran Sea towards the West if the SST continues to change at the rate it has done it over the last three decades at the local level.

- From the predictions of common dolphin density according to SST **projections into the future** based on the HadCM3 climate model with time-varying anthropogenic effects, distribution gets more and more relegated to the west, as in the previous projections, but with a progressive decline in all areas. Therefore, as the water gets warmer towards the East it becomes a less suitable habitat than the West, which is always cooler than the East. A difference with the first approach, however, is that here there is no increase towards the West because, as it does not have local information, the rate of change is assumed to be exactly the same everywhere.
- **Comparing the predictions** for 2050-2052 from both approaches, the density predictions are very similar. However, when comparing 2092 and 2112 from the first approach with 2100 from the second approach, the overall reduction in the eastern half of the area is very similar, but in the first case there is an increase towards the West while in the second case there is also a reduction here. This is because as a difference with the first approach, the second one does not have local information, and therefore the rate of change is assumed to be exactly the same everywhere. The fact that the SST projections from the simplistic regression line fall within the range of the projections from the complex HadCM3 climate model with time-varying anthropogenic effects, and the fact that the first is based on local and locally, point to point, differentiated information, lead us to consider the first approach as probably the best for this relatively small area as is the Alboran Sea.
- At the relatively small spatial scale of the Alboran Sea and Gulf of Vera, an increase in SST will yield a reduction in suitable habitat for common dolphins, with a progressive reduction in density from East to West.

RELATED PROJECTS

None

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A particular publication will be prepared with the results from the SST projections and corresponding common dolphin density predictions.