Model-based abundance estimates for bottlenose dolphins off southern Spain: implications for conservation and management

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ABSTRACT

An EU-funded Life project was initiated off southern Spain in 2002, with the objective of developing a Conservation Plan for bottlenose dolphins in the area. Baseline information and monitoring of abundance and distribution is needed to determine if the conservation objectives are met in the long-term. To estimate abundance, 12,568km of non-systematic line transects conducted from 2000 to 2003, with 72 sightings, were analysed using spatial modelling methods. Transects were divided into 4,575 small segments (average 2.8km) with similar values for sightability conditions and environmental variables. The point estimate of bottlenose dolphin abundance in the area was 584 dolphins (95% CI=278-744). The same method was applied to investigate changes in abundance since 1992 in the eastern section of the research area, where most dolphins were concentrated, stratifying by three groups of years. Point estimates were 111 dolphins for 1992-97, 537 for 1998-2000 and 279 for 2001-03. The higher abundance between 1998 and 2000 corresponded with the observation of an 'immigrant' group of dolphins in these years. These results highlight the importance of long-term studies to understand natural variation in abundance in a specific area subject to conservation activities.

KEYWORDS: ABUNDANCE ESTIMATE; BOTTLENOSE DOLPHIN; ALBORÁN SEA; TRENDS; CONSERVATION; MODELLING; EUROPE; NORTHERN HEMISPHERE; SURVEY-VESSEL

INTRODUCTION

The bottlenose dolphin is widely distributed in the Mediterranean Sea, but is thought to be declining in numbers in this basin (Notarbartolo di Sciara, 2002), with recent genetic studies suggesting fragmented populations (Natoli, 2004). This species is listed in Annex II of the EU Habitats Directive, which considers it a priority species for conservation, and requires the creation of SACs (Special Areas of Conservation) in European waters.

According to the Habitats Directive[1], SACs should be managed through a Management Plan to contribute to the maintenance or restoration of favourable conservation status of the target species and their habitats. There is also a requirement within the Habitats Directive (Article 17) for developing a Monitoring Plan to provide information on the conservation status of the habitats and species which SACs aim to conserve and to assess the effectiveness of the Management Plan in achieving its conservation objectives. The results of the monitoring should inform management and allow for effective revision of any management measures.

In this context, in a previous study for the Spanish Ministry for the Environment between 2000 and 2002, three SACs were proposed in Southern Spain for bottlenose dolphins: one in the Strait of Gibraltar, one around the Island of Alborán and one in southern Almería (Cañadas *et al.*, 2005).

As a follow-up to this study, a project entitled 'Conservation of cetaceans in Murcia and Andalucía' was initiated in 2002, supported by the EU Life Nature programme (LIFE02NAT/E/8610). The main aims are to develop both Management and Monitoring Plans for bottlenose dolphins in the region. Under Spanish legislation, a Conservation Plan for the species that applies not only to the SACs, but to the whole region also needs to be developed. The logic of this is that a Monitoring Plan that only covers the SACs is likely to be inadequate for assessing the conservation status of a mobile species in a highly dynamic environment. In the long term, a Monitoring Plan covering a wider region may pick up shifts in distribution that may lead to revision of SAC boundaries. It may also lead to greater understanding of the causes of any change in abundance within managed sites. The impact on SAC management of a range expansion in bottlenose dolphins off the east coast of Scotland has been discussed by Wilson *et al.* (2004).

Although the Management and Monitoring Plans are still under development within the framework of this project, two main conservation objectives are foreseen as inevitable, arising from the definition of 'favourable conservation status' by the Habitats Directive (Article 1): (1) to avoid a long-term decline in dolphin population (maintaining a stable or increasing population); and (2) to avoid a long-term reduction in the areas used by the population. To determine whether these conservation objectives are being met, monitoring will need to record changes in the population with respect to baseline information.

The main objective of the work presented here was to estimate the current abundance of bottlenose dolphins in the region and to investigate variability in abundance and distribution of this species over recent years. This information will constitute the first step in the development of the Monitoring Plan by serving as a baseline for future work.

Although the project covers the whole area off Southern Spain, including the Gulf of Cádiz, Strait of Gibraltar, Alborán Sea and Gulf of Vera, the work presented here concentrates on the central section; the Alborán Sea. This area is the westernmost part of the Mediterranean Sea, where it connects to the Atlantic Ocean. It is highly dynamic and productive, of great importance for the hydrology of the

[1] *http://europa.eu.int/comm/environment/nature.*

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whole Mediterranean basin and hosts a high biodiversity (Rodríguez, 1982; Gascard and Richez, 1985; Parrilla and Kinder, 1987; Tintoré *et al.*, 1988; Rubín *et al.*, 1992; Templado *et al.*, 1993; Cañadas *et al.*, 2002; 2005).

A standard technique for estimating the abundance of biological populations such as cetaceans is line transect sampling (e.g. Hammond, 1986a; Buckland *et al.*, 2001). For this, transects are surveyed in the field and observers record the perpendicular distance (or angle and radial distance) from the line to the detected targets. The most common way of estimating abundance from such data is the 'design-based' method (Buckland *et al.*, 2001), based on a survey design that ensures equal (or at least calculable) coverage probability is achieved across the whole study area, or at least that all portions of the study area have a non-zero coverage probability (Hiby and Hammond, 1989; Buckland *et al.*, 2001). Design-based surveys have been widely used to estimate the abundance of a range of cetacean species (e.g. Gunnlaugsson and Sigurjónsson, 1990; Schweder *et al.*, 1997; Forcada and Hammond, 1998; Hammond *et al.*, 2002).

An alternative technique suitable for estimating abundance from surveys that have not been designed to achieve equal coverage probability, is the model-based approach (Hedley *et al.*, 1999; Marques, 2001), in which line transect sampling is combined with spatial analysis. The perpendicular distance data are used to estimate a detection function, which allows abundance to be modelled as a function of physical and environment data associated with the surveyed transects. Abundance can then be estimated for the entire study area through extrapolation and maps of density created. Model-based abundance estimation does not require a randomised or systematic sampling scheme, and is therefore suitable for data collected from platforms of opportunity or dedicated surveys that did not follow a systematic design. Using features of the environment to predict abundance may increase precision and a further advantage is that abundance can be estimated for any subarea within the study area (Hedley *et al.*, 1999). Although a systematic design is unnecessary, reasonable coverage across the range of values for the explanatory variables used is required, including location. The relatively large number of observations needed to allow modelling means that the method may not work very well in areas of low density without a large amount of effort (Williams, 2004). There is a risk of creating an 'edge-effect'; extrapolation of unrealistically high density at the edges of the study area, where coverage is usually poorer (Clarke *et al.*, 2000; Bravington, 2003). This is a relatively new method that has not yet been widely applied.

This study uses model-based methods to estimate the abundance of bottlenose dolphins in the northern section of the Alborán Sea, following the methods of Borchers and Burt (2002) and Burt *et al.* (2003).

The abundance of naturally marked cetacean species, including bottlenose dolphins can also be estimated using mark-recapture methods applied to data on photo-identified individuals (e.g. Williams *et al.*, 1993; Wilson *et al.*, 1999; Stevick *et al.*, 2003b). Photo-identification can also provide other useful information on movements, birth rates and survival (e.g. Hammond *et al.*, 1990; Barlow and Clapham, 1997; Stevick *et al.*, 2003a; Larsen and Hammond, 2004) and mark-recapture is a possible alternative technique for achieving the aims of this study. Work on estimating the abundance of bottlenose dolphins in the Alborán Sea using these methods is in progress (S. Garcia Tiscar, pers. comm.). The assumptions made by these methods are quite different to those for line transect and spatial modelling methods. One particularly important assumption concerns avoiding heterogeneity of capture probabilities, which is easy to violate, difficult to account for and can cause substantial bias in estimates of abundance (Hammond, 1986b). In addition, if the study area is not well delimited geographically, it can be difficult to define the population to which the abundance estimate refers. It will be informative to compare estimates of bottlenose dolphin abundance in the Alborán Sea from both methods but line transect/spatial modelling methods are likely to provide more robust estimates for this species in this area, and are more widely applicable for other species in this and other areas.

METHODS

Data collection

Survey area and survey design

Cruise tracks were conducted by the research vessel *Toftevaag* from 2000-03 in the whole northern section of the Alborán Sea, an area of 11,402km^2 (Fig. 1). In 1992 and from 1995-99, surveys were only conducted in the eastern part of this area, the waters off Southern Almería, an area of 4,188km^2 (Fig. 2). During 1993 and 1994, no surveys were conducted in this area. The study area was sampled in January, March, June to September and November from 1999 to 2003. Surveys were also made during March-April, and from June to September from 1992 to 1998. Transects did not follow a systematic design. The relatively small vessel used had a slow cruising speed, was very dependent on weather conditions and had to return to port every night. In addition, time was allocated to other activities during encounters, such as photo-identification. These constraints would reduce considerably the effectiveness of a systematically designed survey. Instead, cruise tracks were designed to cross depth contours and to cover as much of the area as possible (Figs 1 and 2). More detail is given in Cañadas *et al.* (2005).

Searching effort data

The *Toftevaag* is a 18m long motor-sailer with two (non-independent) observation platforms, one on the crow's nest with an eye height of 12m and another on deck with an eye height of 2.5m. Cruising speed was 5 knots (9.3km h^{-1}). Sighting effort was measured as the number of kilometres travelled with adequate sighting conditions (i.e. with sea state Douglas[2] 0 to 2 and good visibility) and observers on the lookout posts. Sighting effort stopped with sea states of Douglas 3 (Beaufort 3 to 4) or more. Sighting effort was categorised into 'effort types' according to sea state and position of trained observers, because crow's nest observations were cancelled with excessive swell: 1 (sea state 1 in Douglas scale and one observer in the crow's nest), 1S (sea state 1 and no crow's nest watch), 2 (sea state 2 with crow's nest watch) and 2S (sea state 2 and no crow's nest watch). Any change of effort type was recorded in the log book and in the Logger[3] software, used for real time data logging.

During searching on effort, data were recorded every 20 minutes ('sampling stations') on: (1) type of effort; (2) sea state; (3) number of ships (discriminating by type) in a radius of 3 n.miles; and (4) other environmental data.

[2] e.g. see *www.eurometeo.com/english/read/doc_douglas* and *ibid doc_Beaufort.*

[3] *www.ifaw.org/ifaw/general/default.aspx?id=25693.*

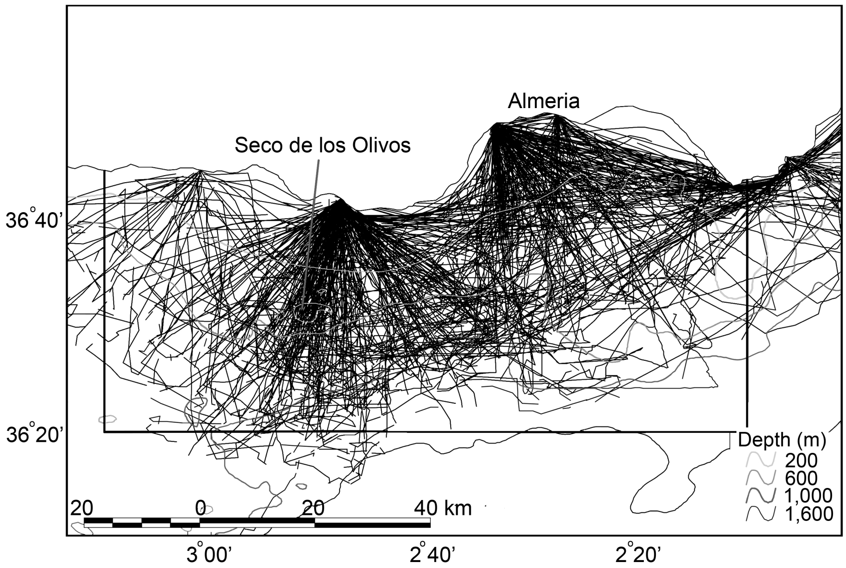

Fig. 1. Study area and cruise tracks 1992-2003 in Southern Almería.

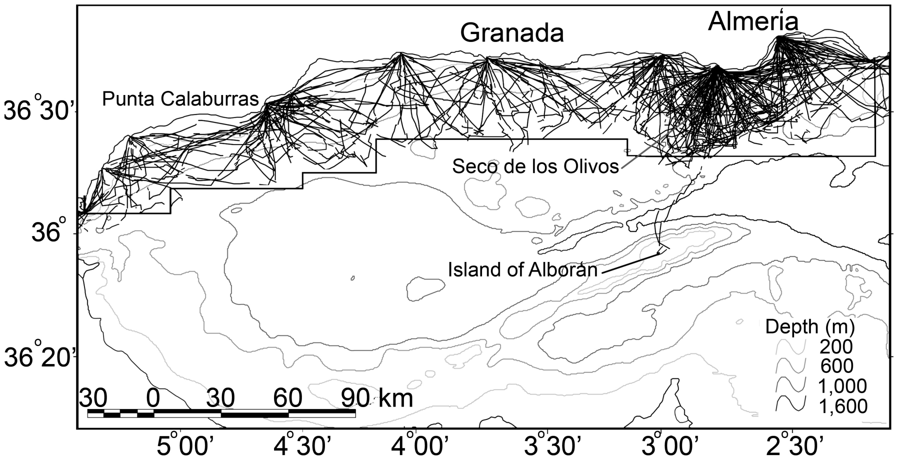

Fig. 2. Study area and cruise tracks 2000-03 in the Alborán Sea.

In this study it was not possible to implement the accepted methodology using double platforms to estimate the proportion of animals or clusters missed on the transect line (e.g. Borchers *et al.*, 2002; Hammond *et al.*, 2002). As a result, all abundance estimates are potentially negatively biased. Double platform methods would also allow responsive movement to be accounted for (a potential positive bias for bottlenose dolphins); however, no evidence was found for this (see Results).

Sightings data
Once an animal or group of animals was detected, immediate 'primary data' were taken: time, position, name of the observer making the sighting, position of the observer (mast or deck), type of effort, angle from the detected group to the trackline, estimated radial distance from the detected group to the ship, species, cue (blow, jump, splash, fin or back, birds, other), initial behaviour (see below), direction of swimming, wind and sea state. Before 2001, angle boards were not used and all angles were generally rounded to the nearest 10°. Since 2001, angles were measured with an angle board on the crow's nest or on the bridge, avoiding any rounding. Distances were always estimated by naked eye. No distance estimation experiments were carried out before or during the surveys. If distances were consistently under or overestimated, there is a potential for bias in estimates of density. Nevertheless, no changes in methods to collect distance data were made over the course of the study so this should not affect trends in abundance. Distance training and experiments will be carried out in the future.

All detected animals or groups were approached to a distance of 100m or less, at which point new 'contact data' were recorded: time, position and confirmation of species. If the animals allowed a close approach, the encounter could be prolonged up to several hours to carry out other tasks (e.g. photo-identification). On leaving the animals, data were recorded again on time, position, wind, sea state and final behaviour, and searching effort started again.

Behaviour was divided into five categories: (1) feeding-foraging (animals observed chasing or eating fish, long synchronised and repeated dives or following trawling fishing boats and repeatedly diving at the level of the trawler net); (2) resting (stationary in one place, almost without movement); (3) socialising (clear and constant interaction between the animals in the group, normally with much aerial activity and stationary in the area); (4) travelling (moving animals, either on steady course or not, differentiated as travelling slowly (0.1-2 knots), travelling moderately (2.1-4 knots) and travelling fast (>4 knots)); and (5) milling (none of the previous categories, usually stationary in the area, with non-synchronised movements and very active).

Group size was assessed several times during the encounter. Animals were counted repeatedly to obtain the best estimate of group size. The number of calves and the estimated number of animals in any subgroups were also recorded. Any changes in group composition (subgroups joining or leaving) were recorded to ensure that the best estimate was of the group initially sighted.

Environmental data

Data were collated throughout the entire study area on physical and environmental features. Depth and slope of the seabed were extracted from nautical charts of the Hydrographic Institute of the Spanish Navy. Sea surface temperature (sst) and chlorophyll concentration (chl) data were obtained from the CREPAD service of INTA (the Spanish Space Agency), which consisted of NOAA AVHRR images with a pixel resolution of $2km^2$ and their associated ascii data. For sst, data were available for the years 1998-2004. For chl, data were available for the years 2000-04. Sst averages were calculated for 1998-2000 and 2001-04, and chl averages were calculated for 2000-04.

Data analysis

Data organisation

The data were organised at two levels: (1) the whole northern section of the Alborán Sea, which was covered from 2000-03; and (2) the waters off southern Almería, using data from 1992-2003. Given the small number of sightings for each year, it was not possible to analyse them separately. The Alborán dataset was therefore pooled over years. In the Almería dataset, samples sizes were also too small to be analysed by year, but did allow grouping over years. Observations in the field recorded the arrival in late 1997 of at least one 'immigrant' group of dolphins (some easily recognisable due to very conspicuous marks) into the study area. These conspicuous animals have not been seen again since 2001. The data were therefore divided into three strata: (1) 1992-97; (2) 1998-2000; and (3) 2001-03 to investigate any changes in abundance resulting from these observations.

The study area was divided into 1,086 grid cells, with a cell resolution of 2 minutes latitude by 2 minutes longitude each. The grid cells were characterised according to several spatial and environmental variables (see below).

All on effort transects were divided into small segments (average 2.8km, maximum 4km) between two consecutive sampling stations, with homogeneous 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.

Encounter rates for each dataset, both of groups and of individuals, were calculated as the average across grid cells. In Almería, only grid cells surveyed during all three periods were considered. To avoid the problems caused by low effort, grid cells with less than 2.8km (1.5 n.miles) of effort were discarded for the calculation of encounter rates.

Spatial modelling of abundance

For model-based abundance estimation, five steps were followed: (1) a 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 and Thompson, 1952; Borchers *et al.*, 1998); (3) the abundance of groups was modelled as a function of spatial and environmental covariates; (4) the groups sizes were modelled as a function of detection probabilities and covariates; and (5) steps (3) and (4) were combined and extrapolated to the whole study area to obtain the final abundance of animals.

The method of fitting separate models for abundance of groups and group sizes (steps (3) and (4) respectively) was based on the two-step method developed by Borchers *et al.* (1997) for modelling the spatial distribution of fish eggs, fitting separate Generalised Additive Models (GAMs) to presence/absence data and to the non-zero egg count data. A similar approach with two steps was used in Cañadas *et al.* (2006) for modelling the habitat selection of several species of odontocetes off Southern Spain, using Generalised Linear Models (GLMs). In the latter case, first presence/absence and then group size were modelled, yielding a surface map of relative density. If school size is suspected to vary spatially across the study area, it is preferable to estimate spatial school size surfaces through spatial modelling (Marques, 2001; Borchers and Burt, 2002; Cañadas *et al.*, 2006). To estimate animal abundance, the estimated number of groups can be modelled instead of presence/absence, and the estimated abundance of groups multiplied by the estimated school size (Borchers and Burt, 2002; Burt *et al.*, 2003).

ESTIMATION OF DETECTION FUNCTION

For calculating the detection function, all sightings made on effort since 1992 were used, which totalled 212 observations (including sightings from adjacent study areas, not included here).

Angle data were rounded until 2000, and the distance data were rounded during the whole period because of being estimated by eye. A smearing procedure was adopted following the method described in Buckland *et al.* (2001). Distances were smeared for the whole research period, and angles only for years 1992-2000, keeping the non-rounded angles taken in the field since 2001. The parameters for the smearing procedure were chosen after visual inspection of the data.

The software *DISTANCE* 4.0 release 2 (Thomas *et al.*, 2002) was used to estimate the detection function, using the multiple covariate distance sampling (MCDS) method (Marques, 2001; Thomas *et al.*, 2002). The perpendicular distance data were right truncated prior to the analysis, following the recommendations of Buckland *et al.* (2001). All covariates given in Table 1 and combinations of them, were tried. The selection of the best detection function was made using Akaike's Information Criterion (AIC).

ESTIMATION OF NUMBER OF GROUPS PER SEGMENT

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

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

Table 1

Covariates incorporated in modelling the detection function, indicating if they were treated as a continuous variable or as a factor, and the levels used in this case.

Covariate	Type	Levels
Group size	Continuous	
	Continuous (logarithm)	
	Factor	3 levels: 1-10/11-40/41-180
Type of effort	Factor	4 levels: 1/1S/2/2S
		3 levels: 1/2/1S-2S
		2 levels: 1/1S-2-2S
Observer	Factor	2 levels: M (mast)/D (deck)
Year	Factor	11 levels: 1992 to 2002
		4 levels: 1992-1994/1995-1997/1998-2000/ 2001-2002
Cue	Factor	3 levels: FB (fin-back)/SP (splash)/OT (other)
		2 levels: FB (fin-back)/OT (other)
Sea state	Factor	2 levels: 0-1/2 (Douglas)

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

MODELLING ABUNDANCE OF GROUPS AND GROUP SIZE

For both models, the potential explanatory variables used were: longitude, slope of the sea floor (metres per km), relative sst in relation to overall average temperature, temporal variability of sst (standard deviation of the weekly average sst in a given grid cell over the year), trawling area (defined as 0 if trawlers were never observed fishing in a given location, and 1 if they were observed at least once), encounter rate of trawlers (number of trawlers observed fishing per sampling station), distance from the 'Seco de los Olivos' sea mount (an underwater mountain located in the north-eastern section of the study area, between 200 and 600m and rising up to 72m depth), and one of the following set of variables: depth, logarithm of depth, distance from the coast, distance from the 200m isobath, distance from the 1,000m isobath and latitude (only one of these was used at a time, because they are all correlated). Interactions between pairs of variables were also investigated.

The abundance of groups was modelled using a GAM with a logarithmic link function. A Poisson error distribution was not considered appropriate for the response variable due to over-dispersion. Therefore, a quasi-poisson family was used, with variance proportional to the mean. The general structure of the model was:

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

where the offset a_i is the searched area for the i^{th} segment (calculated as the length of the segment multiplied by two times the truncation distance), 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 1.0-5 for R (Wood, 2001). Automated model selection by a stepwise procedure was not implemented in the version of R used (1.9.0) (*http://cran.r-project.org*). Therefore, manual selection of the models was undertaken using three indicators: (a) the General Cross Validation score (GCV) which is in practice an approximation to AIC (Wood, 2000) and in which smoothing parameters (in terms of number of knots and degrees of freedom) are chosen by the software to minimise the GCV score for the model, unless they are directly specified; (b) the percentage of deviance explained; and (c) the probability that each variable is included in the model by chance. The decision to 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.

Group size was also modelled using a GAM with a logarithmic link function. In this case, the response variable was the number of individuals counted in each group (s_j) and, given the large overdispersion due to the wide range of group sizes (1-180), a quasi-poisson error distribution was used, with the variance proportional to the mean. In this case, the detection probability was included as a linear predictor (Borchers and Burt, 2002) in order to avoid the bias introduced by the selective detection of larger groups at larger distances or by other covariates affecting the detection of the groups (Universidad de Barcelona, 2002). The general structure of the model was:

$$E(s_j) = \exp\left[\hat{g}_j(y,\nu) + \theta_0 + \sum_k f_k(z_{jk})\right] \qquad (3)$$

where $\hat{g}_j(y,\nu)$ is the conditional detection probability of the j^{th} group given that it was detected at perpendicular distance y and with covariates ν, θ_0 is the intercept, f_k are smoothed functions of the explanatory covariates, and z_{jk} is the value of the k^{th} explanatory covariate in the j^{th} group. Manual selection of the models was done following the same criteria described for the models of abundance of groups.

ESTIMATES OF ABUNDANCE

Predictions of abundance of groups and of group size were produced over all the grid cells of the study area, according to the values of the covariates used in the final models. 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 final point estimate of abundance was obtained by summing the abundance estimate of all grid cells over the study area.

AVAILABILITY ON THE TRACKLINE

Availability was estimated following Forcada *et al.* (2004), to investigate how much the probability of detection on the trackline might be influenced by availability bias. The average dive time (68.7s) and average surface time (231.3s) used were those estimated by Forcada *et al.* (2004) for bottlenose dolphins in the Balearic Islands and northeastern waters of Spain. The amount of time the sea on the trackline was in the observers' view was estimated based on the distances at which bottlenose dolphins may be detected on the trackline (up to 20° on each side) and the speed of the ship.

Estimation of variance

Four hundred non-parametric bootstrap resamples of the whole process were obtained, using day as the resampling unit, to obtain the coefficient of variation and percentile based 95% confidence intervals. For both models in each bootstrap, 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 each subset was calculated using the delta method (Seber, 1982), combining the CV of the detection function with the CV of the models from the bootstrap. These values were plotted as surface maps of abundance and of variability.

Table 2

Days surveyed, total effort (in km), percentage of segments per effort type, number of groups (number of individuals), mean group size and encounter rates (ER) for groups and for individuals for each subset of data.

Year	Days	Total effort	Effort 1	Effort 2	Effort 1S	Effort 2S	Nº of groups (indiv.)	Mean group size (SE)	ER groups (SE)	ER indiv. (SE)
Almería										
1992 - 1997	136	6,251	52.6%	11.8%	13.4%	22.2%	41 (683)	16.8 (2.95)	0.0046 (0.0010)	0.073 (0.020)
1998 - 2000	181	7,715	51.5%	11.3%	17.3%	19.9%	84 (2,851)	33.2 (4.03)	0.0120 (0.0019)	0.406 (0.087)
2001 - 2003	143	5,520	48.2%	12.2%	22.8%	16.8%	34 (833)	26.4 (4.75)	0.0069 (0.0018)	0.164 (0.046)
TOTAL	460	19,485	50.8%	11.7%	17.8%	19.8%	159 (4,367)	27.5 (2.53)	0.0084 (0.0010)	0.238 (0.038)
Alborán										
2000 - 2003	306	12568	55.6%	13%	18.3%	13.8%	72 (2,071)	25.0 (2.84)	0.0043 (0.0008)	0.122 (0.034)
Total										
1992 - 2003	580	24,643	53.9%	11.7%	17.1%	17.3%	177 (3,625)	24.2 (2.19)	0.0052 (0.0009)	0.145 (0.035)

Random and responsive movement

The average searching speed of the ship was 5 knots, which is slow compared to most line transect surveys for cetaceans. Since random movement of animals leads to increasing bias as the ratio of animal speed to ship speed increases (Hiby, 1982), we investigated whether this was a problem in our data. The average speed of the dolphins (at the moment of the encounter) was calculated by assigning an average speed to each behavioural category (from the 'primary sighting data'): 0 knots for socialising, milling, feeding and resting; 1 knots for travelling slowly; 3 knots for travelling at moderate speed and 5 knots for travelling fast. The average speed for all sightings, according to their initial behavioural category was then obtained. For the analysis described here, all sightings of bottlenose dolphins since 1992 were considered.

The occurrence of responsive movement before detection was investigated by calculating the ratio of animals/groups with swimming direction in the third quadrant (180°-270°) to the first quadrant (0°-90°), relative to the transect line following Palka and Hammond (2001). The ratio between these quadrants was evaluated using a chi-square test, to see if there was any evidence of attraction (Q3/Q1>1) or avoidance (Q3/Q1<1).

RESULTS

Effort and sightings

For the sub-area of Almería, surveys were conducted on 460 days between 1992 and 2003, totalling 19,485km on effort (Fig. 1; Table 2). For the area of Alborán, surveys were conducted on 306 days between 2000 and 2003 (including the time spent in Southern Almería since 2000), totalling 12,568km on effort (Fig. 2; Table 2). In total, 24,643km were surveyed on effort in the whole study area since 1992, of which between 48% and 57% (depending on the year) were made under the best conditions (with effort type 1; Table 1). A total of 177 sightings of bottlenose dolphins were made while searching on effort. The effort, number of sightings, average encounter rate and average group size for each of the data subsets is shown in Table 2.

Detection function

Perpendicular distance was truncated at 2,500m after visual inspection of the data. This discarded 5% of the data with the largest distances, leaving 202 sightings for analysis (including those made outside the study area).

Ninety-two models were fitted, starting with single covariates and continuing with combinations of two, three and four covariates. Year had very little effect on the detection function and it is assumed, therefore, that detection probability had not changed over time and data for all years were pooled. The best fitting model was a half-normal key function with cosine series expansion and two adjustment terms. Four covariates were selected: position of the observer, sea state, group size, and cue. The next best models had ΔAIC>4, so they were not competitive. They all incorporated the position of the observer, the cue and the group size (or its logarithm) as important covariates. Effort type was selected also in all these models, with either 2, 3 or 4 levels, but the best model incorporated sea state instead (the definition of effort type includes sea state). In Table 3, the coefficients for the covariates and the parameters for the detection function are shown. Fig. 3 shows the observed frequencies at given distances, pooled over all covariates, and the fitted half-normal function.

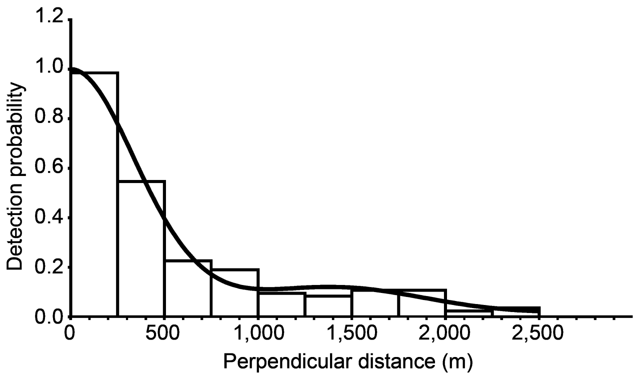

Fig. 3. Perpendicular distance distribution, pooled over all covariates (histograms) and fitted half-normal detection function, conditional on the observed covariates (line).

Table 3

Coefficients for the covariates and parameters for the detection function. Covariates modelled together with perpendicular distance for each sighting in these models are: position of the observer (OBS), sea state (SEA), group size (CLSIZE) and cue with 2 levels (CUE).

Parameter	Point estimate	Standard Error
Intercept	773.1	25.92
Level D of factor covariate OBS	-0.5934	0.1241
Level 0-1 of factor covariate SEA	0.5520	0.1631
Covariate CLSIZE	0.0103	0.0041
Level FB of factor covariate CUE	-0.4206	0.1881
Adjustment term of order 2	0.1597	0.1693
Adjustment term of order 3	0.3932	0.1311
f(0)	0.001668	0.000114

Abundance models

The variables retained in the two steps of the model, for each data subset, are shown in Table 4. The shapes of the functional forms for the smoothed covariates used in the models for the four datasets are shown in Figs 4-7. The most important variables, selected in many of the models, were depth (or logdepth), distance from 'Seco de los Olivos' and slope. In the model of abundance of groups for Alborán, the encounter rate of trawlers was selected and in one of the Almería datasets the average chlorophyll concentration contributed significantly to the model, apparently with a preference for areas with high concentration.

The small number of sightings did not allow the use of the best fitting models in the bootstrap simulations in many cases. The best-fitting but more complex models caused the bootstraps to fail frequently, indicating possible overfitting of the data. Therefore, simpler models were used in some cases, both for the point estimate and for the bootstrap simulations, mainly by reducing the degrees of freedom allowed for variables such as depth or slope. This procedure had the disadvantage of using a model that explained a smaller percentage of the deviance. Furthermore, when modelling group size, the 'edge effect' constituted a problem in some models. When this occurred, the covariate causing the 'edge effect' (usually the slope) was either forced to use fewer degrees of freedom or was discarded, with the penalty of yielding a smaller percentage of deviance explained. Visual inspection of the residuals did not show any unacceptable pattern.

Estimated distribution, abundance and trend

Estimates of abundance and variability are given in Table 5. For the Alborán area, the point estimate of abundance for the whole period was 584 dolphins, mainly concentrated in southern Almería, the coastal areas of Granada and south of Punta Calaburras in Málaga (Fig. 8). This abundance estimate yields an estimated average density of 0.049 dolphins per sq km. In Figs 9 and 10, the lower and upper 95% confidence limits are plotted, respectively. The lower and upper 95% CL surface maps still show what seem to be the core areas for bottlenose dolphins.

For Almería, the surface maps of estimated abundance are shown in Fig. 11. The surface maps of variability are not included for the Almería datsets due to space limitations but also showed the core areas. In the second period, after the arrival of the 'immigrant' animals, estimated abundance increased markedly by a factor of four (Table 5). In 2001-03, estimated abundance decreased by a factor of two. The abundance estimate for the second period was significantly different from the first (d_{1-2}=-3.320, p<0.001), but abundance estimates in the first and third and second and third periods were not different (d_{1-3}=-1.786; 0.10>p>0.05; d_{2-3}=1.844, 0.10>p>0.05). Average encounter rates of individuals followed the same pattern and mean group size was also higher in the second period (Table 2).

To test the robustness of the abundance estimates, we ran two additional models: for Alborán 2001-03 to compare to that for Almería 2001-03; and for Almería 2000-03 to compare to that for Alborán 2000-2003. The estimates from the models of Almería were similar to those obtained by summing the estimated abundance of the grid cells corresponding to Almería in the models for Alborán in both periods tested: 2001-03, 228 animals (Alborán model) *vs*. 279 (Almería model); 2000-03, 372 animals (Alborán model) *vs*. 424 (Almería model). This, together with the strong similarities of all surface maps corresponding to different datasets, suggests that the estimates were robust.

Availability on the trackline

Bottlenose dolphins were seen up to a radial distance of more than 3,000m, and regularly up to 2,000m ahead of the ship. Small groups of dolphins (1-5 animals) were regularly detected up to a distance of 1,000m ahead of the ship. Given the average ship speed of 5 knots, the estimated time the 1,000m in front of the ship is in the view of the observer is 6 minutes. Using these data the Forcada *et al.* (2004) method estimates the probability of availability as 1.

Random and responsive movement

There were 271 sightings of bottlenose dolphins on effort (including sightings from adjacent areas) for which data on initial behaviour, and therefore estimated speed, were available. The average estimated speed of the dolphins was 1.3 knots (SE=0.11 knots). The ratio of dolphins speed to ship speed was therefore 0.26, well below the value of 0.5 considered as problematic (Hiby, 1982; Palka and Hammond, 2001).

For the study of possible responsive movement of the animals before detection, data on initial heading relative to the transect line were available for 86 sightings of bottlenose dolphins. Of these, 20 sightings (23.3%) were stationary and not heading in any direction. For the

Table 4

Model results for all the subset data analysed. For each row, the two models are shown (abundance of groups and group size), indicating the variables (':' indicates an interaction between two variables) retained in the best model (estimated degrees of freedom in parentheses: 1 means a linear relationship), and the percentage of deviance explained by the model. The variables are abbreviated as follows: lon = longitude, depth = depth of the sea floor, logdepth = logarithm of depth, slope = slope of the sea floor, distseco = distance from the 'Seco de los Olivos', dist200 = distance to the 200m depth contour, ertr = encounter rate of trawlers, cav0004 = average chlorophyll concentration for 2000-2004, $g(y,v)$ = conditional probability of detection (always as a linear predictor). Variables are ordered from more to less significant according to their p-value in the final model.

Subset	Model	Variables	% Deviance explained
Alborán	Groups	distseco (7.6) + logdepth:lon (13.2) + ertr (2.0)	19.0
2000-2003	Group size	depth:distseco (11.5) + $g(y,v)$	28.0
Almería	Groups	distseco (4.5) + cav0004 (4.3) + depth (3.2)	13.0
1992-1997	Group size	$g(y,v)$ + logdepth (2.4) + slope (5.3)	48.7
Almería	Groups	lat:lon (19.2) + dist200 (4.7)	15.3
1998-2000	Group size	distseco (4.2) + depth:slope (13.3) + $g(y,v)$	37.5
Almería	Groups	distseco (2.3) + logdepth (4.2)	17.8
2001-2003	Group size	slope (2) + $g(y,v)$	20.9

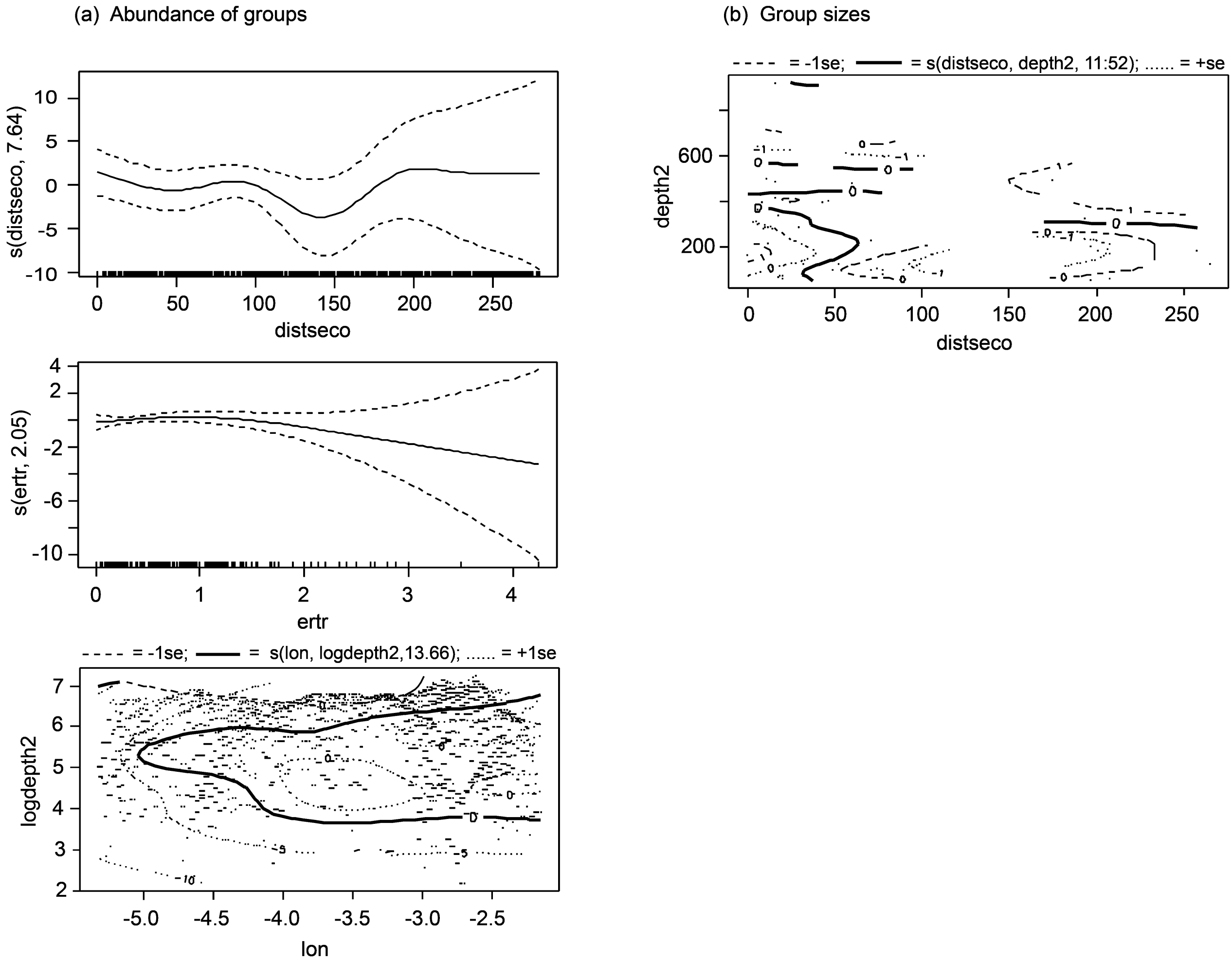

Fig. 4. Shapes of the functional forms for the smoothed covariates used in the models for the dataset of Alborán 2000-03. Zero on the vertical axes corresponds to no effect of the covariate on the estimated response (group density on the left and group size on the right). The dashed lines represent twice the standard errors of the estimated curve (95% confidence interval). The locations of the observations are plotted as small tick marks along the horizontal axes. The interactions between two variables are shown as two-dimensional plots. In these cases, the locations of the observations are plotted as small dots. The variables are abbreviated as in Table 4.

Table 5
Point estimates of abundance, density, and mean abundance, CV and 95% CI after 400 bootstrap resamples.

Subset	Area (km^2)	Period	Estimated abundance	Estimated density	Mean abundance after bootstrap	95% CI after bootstrap	CV after bootstrap
		1992-97	111	0.026	113	54 - 234	0.45
Almería	4,232	1998-2000	537	0.127	487	332 - 746	0.24
		2001-03	279	0.066	305	146 - 461	0.28
Alborán	11,821	2000-03	584	0.049	462	278 - 744	0.28

remaining sightings, the ratio Q3/Q1 was 0.83, which is not significantly different from one (χ^2=0.28, df=1, p>0.05), suggesting no responsive movement of the animals before detection.

DISCUSSION

Distribution and abundance

Bottlenose dolphins appear to respond to the different characteristics of their environment by clustering (both in terms of groups and by increased group size) in some parts of the study area, with a preference for waters between 200 and 600m depth and a steep sea bottom (especially around the 'Seco de los Olivos'), areas usually heavily used also by trawlers. This agrees with this species' most common feeding habits reported in the western Mediterranean (mainly demersal fish prey; Gannier, 1995; Blanco *et al.*, 2001; Cañadas *et al.*, 2002). In most models, depth (or logdepth) was the favoured variable over all other related covariates (e.g. distance from coast or from the 200m isobath), indicating that they prefer a certain range of depths, not necessarily linked to distance from features such as the coast. In the models, longitude takes the role of a proxy variable that helps explain the spatial distribution of this species from west to east in the study area. As expected, the results are similar to those from the habitat selection modelling undertaken in the same area (Cañadas *et al.*, 2005).

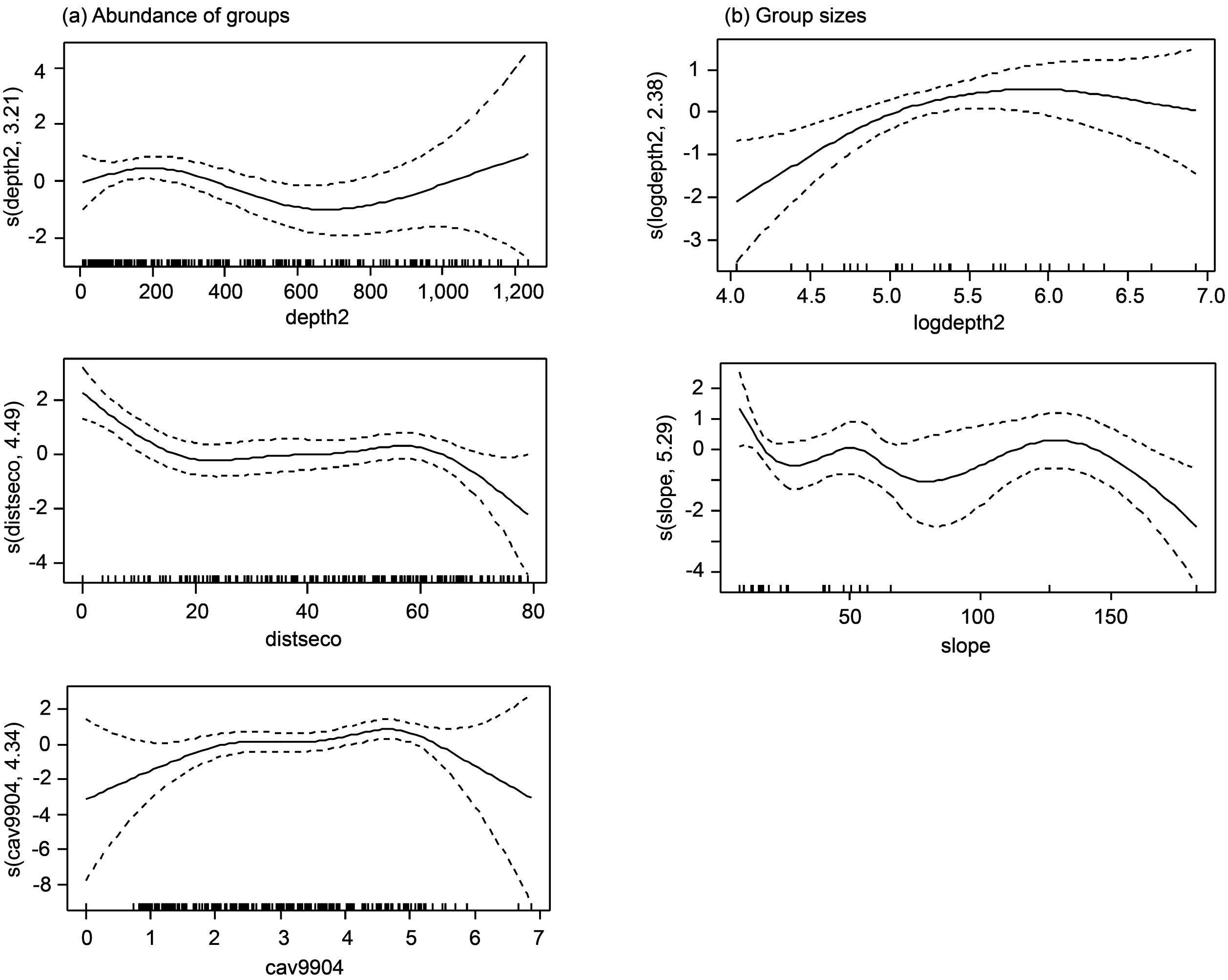

Fig. 5. Shapes of the functional forms for the smoothed covariates used in the models for the dataset of Almería 1992-97. Zero on the vertical axes corresponds to no effect of the covariate on the estimated response (group density on the left and group size on the right). The dashed lines represent twice the standard errors of the estimated curve (95% confidence interval). The locations of the observations are plotted as small tick marks along the horizontal axes. The interactions between two variables are shown as two-dimensional plots. In these cases, the locations of the observations are plotted as small dots. The variables are abbreviated as in Table 4.

The distribution and abundance of species with complex ecology, social structure and behaviour living in a highly dynamic and, as yet, mostly unknown three-dimensional environment, are difficult to model. Variables that are expected to influence directly the distribution and abundance of dolphins in the open sea are at best difficult to measure (e.g. distribution and abundance of prey). Furthermore, the very low proportion of positive observations in the datasets (due to the low density of the species and the small size of the segments) might be limiting the variability that could possibly be explained with the available variables. This problem was increased by the need to discard variables yielding a strong ‘edge-effect’ and to fit simpler models for the bootstraps. Nevertheless, the surface maps, and the fact that they remain very similar across the datasets, suggest that the general distribution pattern of this species in the area has been satisfactorily reflected by the models (Figs 8 to 11). To check if there was overfitting, nominal parameter SEs and bootstrap SEs were compared. If the bootstrap SEs were substantially bigger than the nominal, then the model will tend to be overfitted and undersmoothed. The SEs from both sources in this work were comparable, suggesting that no problem of overfitting existed. Bootstrap at a week level was tried and compared with the daily level in order to explore if some underlying ‘spatial week effect’ was missed. SEs were similar and therefore the daily level was kept.

In the area of Almería, despite the differences in estimated abundance over time, the core area was the same in the three periods: around the ‘Seco de los Olivos’ sea mount. 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 Alborán Sea (Rubín *et al.*, 1992). In the second period with higher abundance, the most heavily used areas are more extensive; they narrow again in the third period following the decrease in estimated abundance. A possible explanation of this might be that when the abundance is relatively low, the dolphins tend to concentrate in the most productive areas, where they may have the highest possibilities of success in finding prey. When abundance is higher, they may also need to explore other areas.

There is potential for the trends in abundance to be confounded with changes in group size because $g(0)$ is assumed to be one but $g(0)$ is expected to be smaller for small groups than for big groups. In the second time period when estimated abundance was higher, group size was also higher than during the other two periods. Although perception bias cannot be estimated here, because there is no availability bias even for small groups of 1 to 5 individuals, we do not believe that the trend in abundance is a consequence of a change in $g(0)$ due to changes in group size.

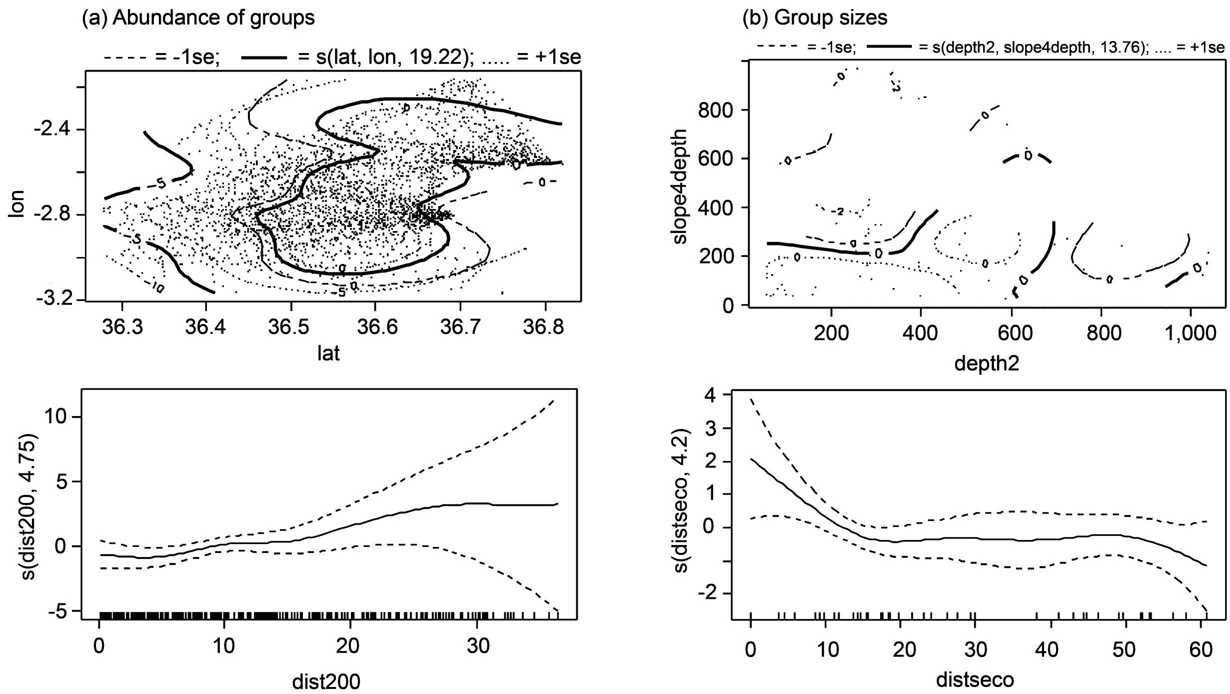

Fig. 6. Shapes of the functional forms for the smoothed covariates used in the models for the dataset of Almería 1998-2000. Zero on the vertical axes corresponds to no effect of the covariate on the estimated response (group density on the left and group size on the right). The dashed lines represent twice the standard errors of the estimated curve (95% confidence interval). The locations of the observations are plotted as small tick marks along the horizontal axes. The interactions between two variables are shown as two-dimensional plots. In these cases, the locations of the observations are plotted as small dots. The variables are abbreviated as in Table 4.

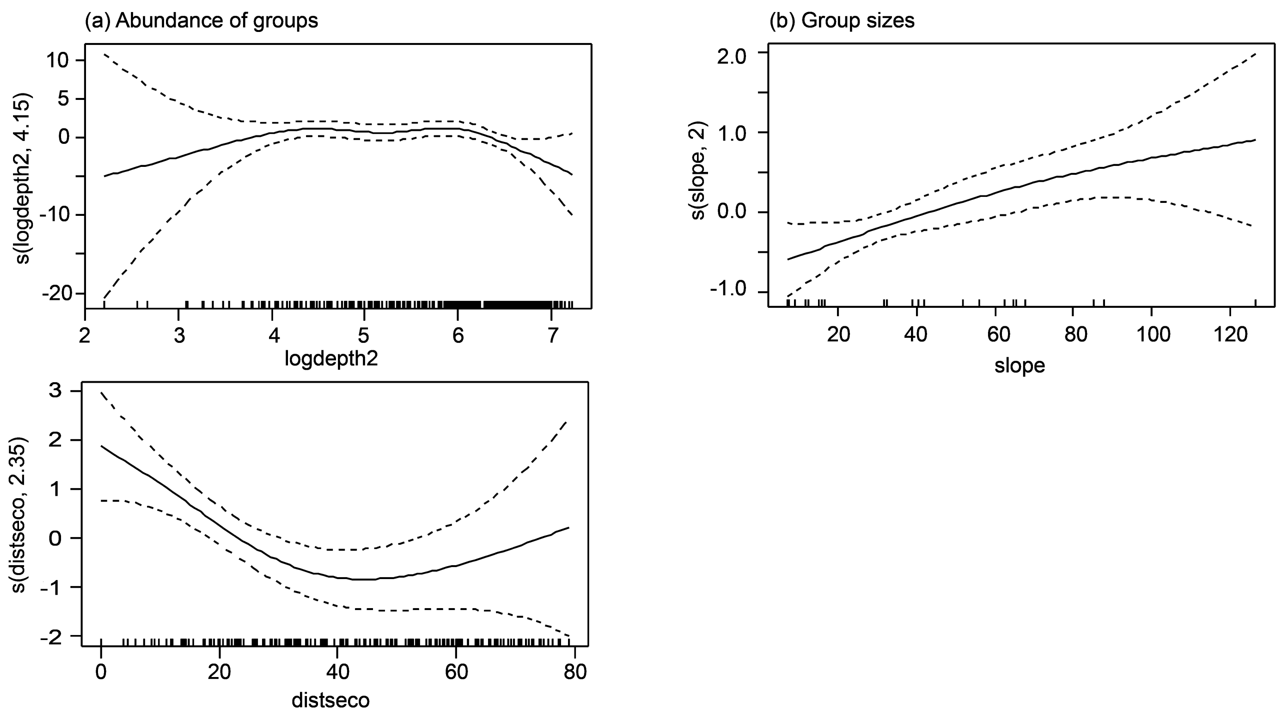

Fig. 7. Shapes of the functional forms for the smoothed covariates used in the models for the dataset of Almería 2001-03. Zero on the vertical axes corresponds to no effect of the covariate on the estimated response (group density on the left and group size on the right). The dashed lines represent twice the standard errors of the estimated curve (95% confidence interval). The locations of the observations are plotted as small tick marks along the horizontal axes. The interactions between two variables are shown as two-dimensional plots. In these cases, the locations of the observations are plotted as small dots. The variables are abbreviated as in Table 4.

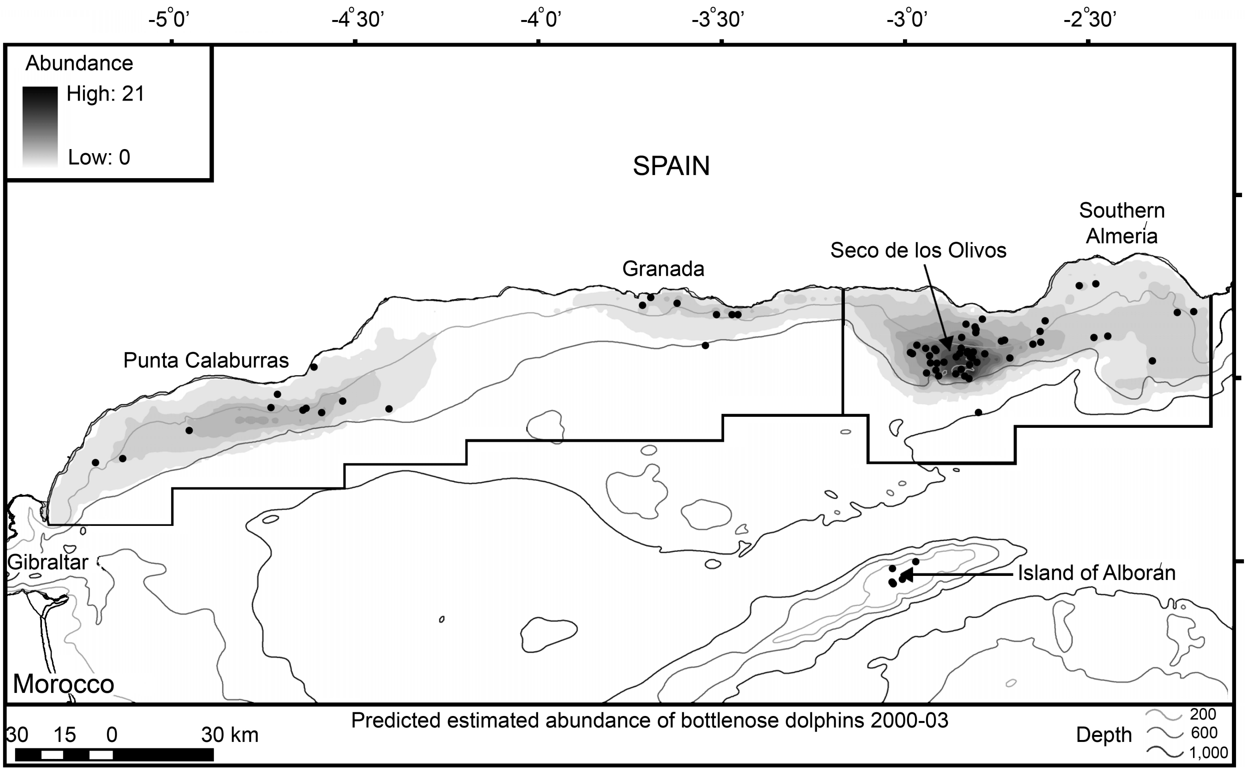

Fig. 8. Surface map of abundance for bottlenose dolphin in the northern section of the Alborán Sea, for 2000-03.

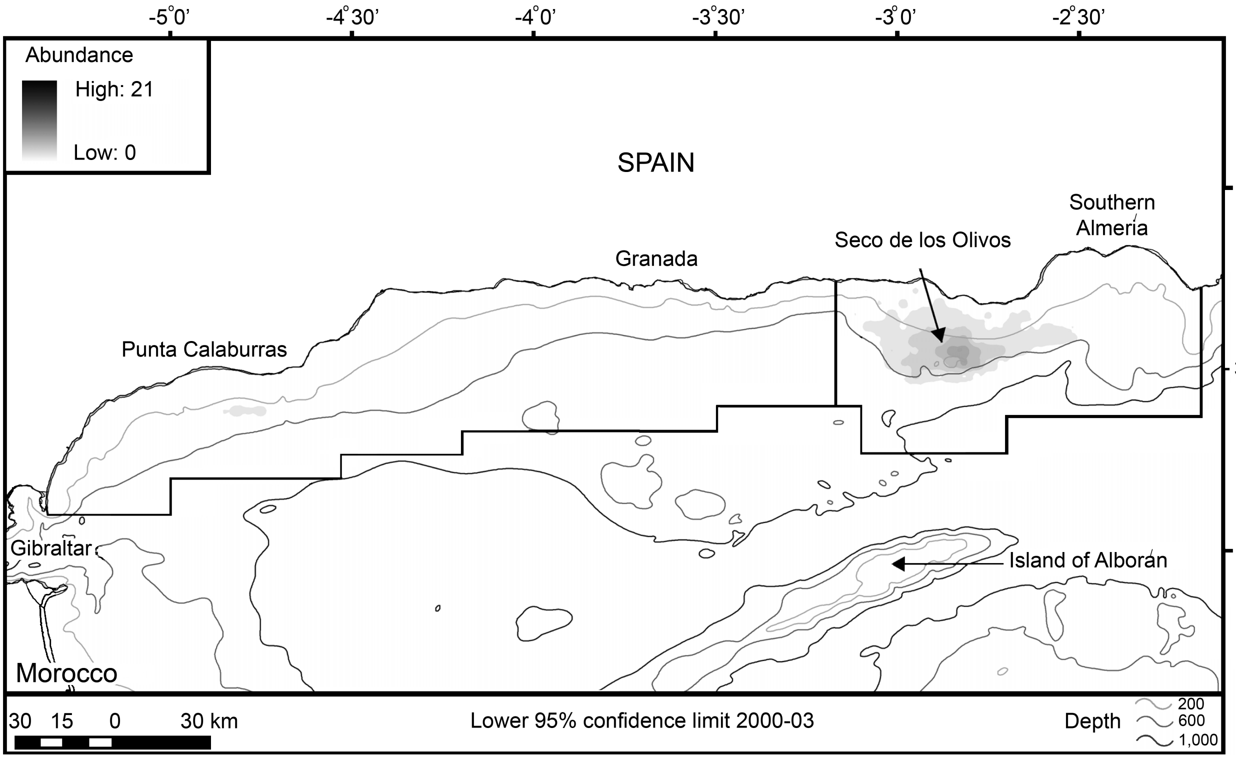

Fig. 9. Surface map of lower 95% confidence limit after 400 bootstrap resamples for the study area of Alborán, for 2000-03.

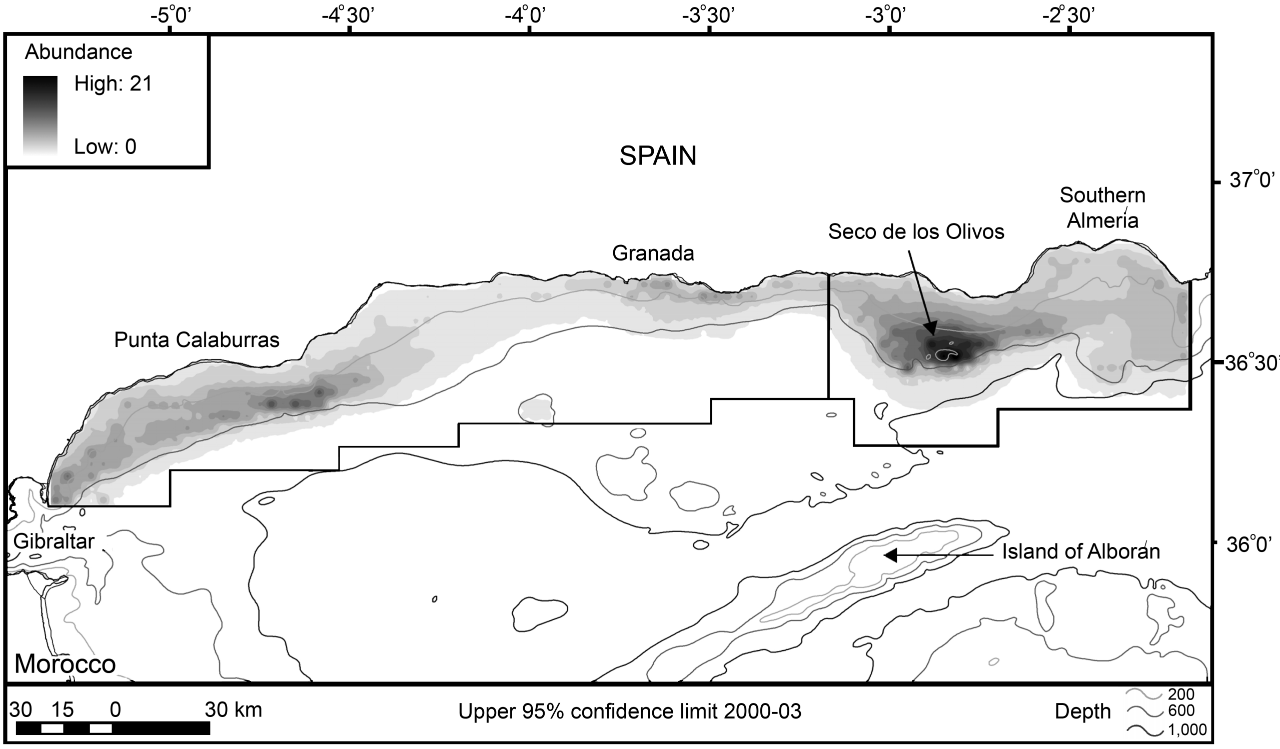

Fig. 10. Surface map of upper 95% confidence limit after 400 bootstrap resamples for the study area of Alborán, for 2000-03.

As it was not possible to implement a double platform survey method for estimating $g(0)$, the abundance estimates presented here are potentially an underestimation of true abundance. Further data are being collected with a double platform installed on the research vessel, with the aim of estimating $g(0)$ in the near future and therefore correcting the abundance estimates. However, we do not expect this to change the results significantly. Availability bias is unlikely and we believe perception bias is also likely to be small given the sea states in which the survey was carried out, the relatively large group sizes encountered, the slow speed of the ship and the height of the observation platform. Therefore, it is likely that $g(0)$ is close to one.

Implications for conservation and management

It is important to highlight that these estimates represent the average number of bottlenose dolphins in the study areas during the defined periods, not the size of a population using the areas. Neither the area of Alborán nor the sub-area of Almería are closed areas and our results show that they do not contain a closed population, with movement of individuals into and out of the adjacent areas of the Strait of Gibraltar, the Gulf of Vera and the southern portion of the Alborán Sea. This, together with the negative bias produced by assuming $g(0)=1$, means that the size of the population of bottlenose dolphins that uses the study area is larger (by an unknown extent) than our estimates. In terms of monitoring conservation status within a defined area such as an SAC, we are interested in whether the average number of animals using the area changes over time. If $g(0)$ does not change across years (a reasonable assumption, given that the same research vessel, observers and methodology were used for the whole period and that there was no evidence of any changes in surface behaviour), the estimates obtained are valuable in assessing changes in abundance in the study area.

When dealing with the area of Alborán, four years of survey is too short a period to detect any trend in abundance, and long-term monitoring is required. In the area of Almería, the field observations of the presence of the conspicuous 'immigrant' group between late 1997 and 2001 was echoed by a significant change in estimated abundance. Analysis of the photo-identification data will help to provide more detail of this.

Our results highlight the importance of long-term studies to understand variation in abundance in a given area. For example, if this study had started in 1998, we could be alarmed at detecting an apparent decline in numbers of animals in the Almería area. Instead, the longer time series of data allowed the documentation of an increase and subsequent decrease in abundance that is likely a result of natural fluctuations in abundance. This highlights the need for an adequate long-term monitoring programme. An important question for the Monitoring Plan of the proposed SAC in this area is when should an abundance 'baseline' be established to base future assessments of conservation status. Should this be the lowest abundance estimated over the past 12 years, or perhaps the average over the last 12 years? This will depend in part on the conservation objectives of the Management Plan.

Ideally, the monitoring programme should be developed not only to allow the detection of changes in abundance in the long-term, but also the differentiation between natural fluctuations and real trends in the abundance of the population. The observed fluctuations in abundance in the Almería area stress the need for the monitoring programme to cover not only the proposed SAC but also a wider area outside it to improve our understanding of fluctuations or trends in numbers and shifts in distribution. This wider information may have important implications for the management of the protected areas (Wilson *et al.*, 2004).

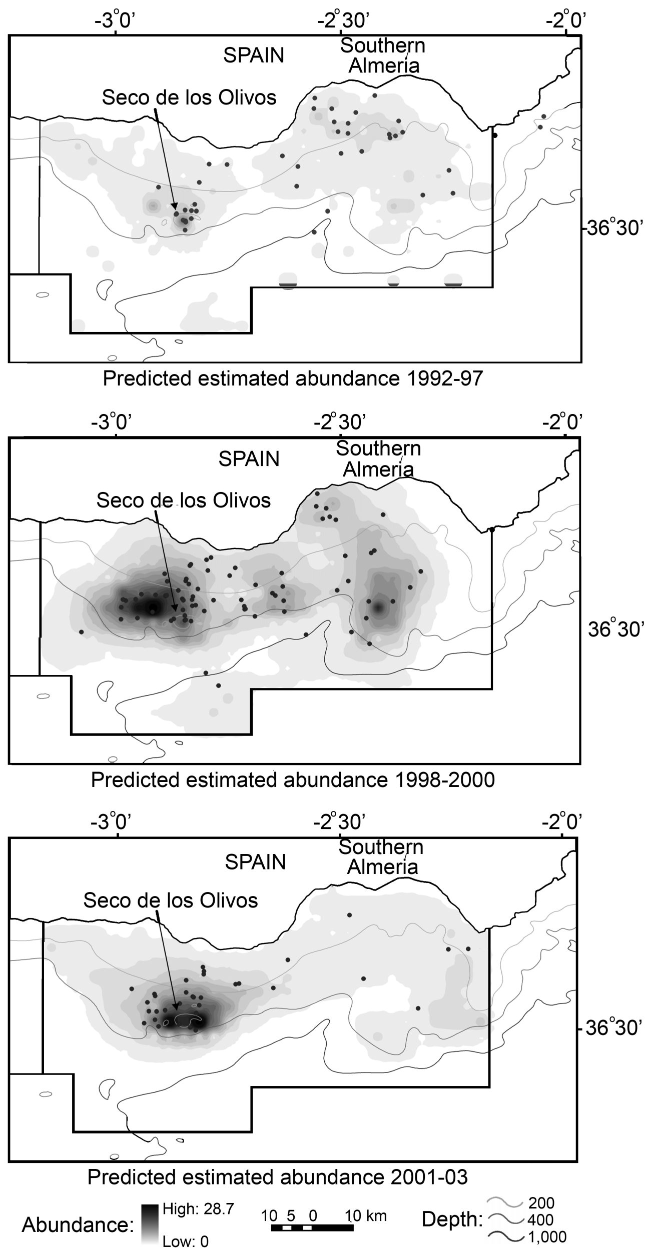

Fig. 11. Surface maps of abundance in the study area of Southern Almería for the three periods: 1992-97, 1998-2000 and 2001-03.

There is limited information on abundance of bottlenose dolphins in other areas of the western Mediterranean Sea. Aerial line transect surveys carried out off Valencia (Eastern Spain), from 2000 to 2002 (Gómez de Segura *et al.*, 2006) estimated a density of 0.041 dolphins per sq km, lower than estimated here, except for Almería in 1992-1997. The encounter rates of groups and of individuals were also much lower than in Almería, as was the mean group size (11 in Valencia *vs.* 24 in Alborán). However, caution must be exercised when comparing these results, as very different survey platforms were used (ship *vs.* aircrafts) and $g(0)$ was not estimated in either analysis. An abundance estimate for this species has been obtained recently also for the NW Mediterranean (north of Spain and Balearic Islands), from aerial survey data. The estimated density in this area was of 0.085 to 0.088 dolphins per sq km. In this case, the estimate was corrected for availability bias, and underestimation due to perception bias was considered to be small (Forcada *et al.*, 2004; Table 6). The available information suggests that encounter rates, and average group sizes, decrease from west to east in Spanish Mediterranean waters (Table 6). Although there are methodological issues with comparing these results, as described above, they suggest that the Alborán Sea, and especially the area off Southern Almería, are important areas for bottlenose dolphins in the westernmost part of the Mediterranean Sea.

Applicability of the method

The model-based method for estimating abundance is shown to be a good approach for describing cetacean distribution, and estimating abundance based on the data collected in this study. Much of the data on cetacean distribution and density in Europe is being collected through non-systematically designed surveys similar to those presented here. This method constitutes, therefore, a promising way to analyse these large collections of data.

Nevertheless, caution should be exercised when applying very flexible models like GAMs, especially to avoid overfitting the data and the 'edge effect', which could yield unrealistic densities and surface maps. This method is still in a relatively early stage of development, and some questions remain unsolved, such as whether the bootstrap is the most appropriate way of obtaining 95% confidence intervals, or how to deal better with the problem of the 'edge-effect'.

The models described in this paper should be revised when data on more potential explanatory variables become available, and especially when this method becomes better developed and tested (for example through analysis of simulated data).

Table 6

Encounter rates (ER) of groups and individuals (per km), and mean group sizes of bottlenose dolphins in Spanish Mediterranean waters. Encounter rates and mean group size were calculated as the average over grid cells for this work. Other data represent overall values. '*' means estimated density corrected for availability bias (Forcada *et al.*, 2004); all other densities are underestimations.

Area	Period	Density (animals km^{-2})	ER of groups	ER of indiv.	Mean group size	Source
Gibraltar	2001-02		0.0056	0.1157	27.8	De Stephanis *et al.* (in review)
Alborán	2000-03	0.049	0.0043	0.1220	25.0	This work
Almería	1992-97	0.026	0.0086	0.1356	16.7	This work
Almería	1998-2000	0.127	0.0222	0.7524	33.9	This work
Almería	2001-03	0.066	0.0128	0.3031	24.5	This work
Gulf of Vera	1993-2004		0.0016	0.0161	10.5	Unpublished data of the authors
Valencia	2000-02	0.026	0.0006	0.0066	11	Gómez de Segura *et al.* (2006)
Catalonia	2001-02		0.0017	0.0117	7	Universidad de Barcelona (2002)
Catalonia and Balearic Sea	2002	0.088*			7	Forcada *et al.* (2004)
Balearic Islands	2001-02		0.0018	0.0142	6.3	Universidad de Barcelona (2002)
Balearic Islands	2002	0.085*			7	Forcada *et al.* (2004)

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