

# Abundance of small cetaceans in waters of the central Spanish Mediterranean

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**Abstract** Seasonal aerial surveys were conducted in the waters of the central Spanish Mediterranean from 2001 to 2003 using the line transect sampling methodology to estimate cetacean abundance. The density of the three most abundant species, striped dolphin (*Stenella coeruleoalba*), bottlenose dolphin (*Tursiops truncatus*) and Risso's dolphins (*Grampus griseus*), was estimated. In the case of the first two species, the density was estimated accounting for the proportion of submerged animals, while for Risso's dolphin only the surface density could be estimated. The striped dolphin was the most abundant species in the study area with a mean density of 0.489 dolphins km<sup>-2</sup> (95% CI = 0.339–0.705) and a mean abundance of 15,778 dolphins (95% CI = 10,940–22,756). This density is comparable to that obtained in the International Ligurian Sea Cetacean Sanctuary. Striped dolphins were observed throughout the whole year and no seasonal changes in the density were detected. The mean density of bottlenose dol-

phins was an order of magnitude lower than that of striped dolphins (0.041 dolphins km<sup>-2</sup>; 95% CI = 0.023–0.075) with a mean abundance of 1,333 dolphins (95% CI = 739–2,407). The Risso's dolphin had a surface estimated density of 0.015 dolphins km<sup>-2</sup> (95% CI = 0.005–0.046) and a mean abundance of 493 dolphins (95% CI = 162–1,498). These results provide valuable biological information useful to develop conservation plans and establish a baseline for future population trend studies.

## Introduction

Of the 20 species of cetaceans that have been cited in the Mediterranean Sea, only 8 occur regularly (Notarbartolo di Sciara 2002). Cetaceans are long-lived vertebrates situated in the highest levels of the marine tropic webs with a very low reproductive rate and are thus particularly vulnerable to threats deriving from human activities. These threats may be particularly severe in the semi-enclosed basin of the Mediterranean Sea because it supports a high human density in the coastal zone. Chemical pollution, marine debris, climate change, land-based changes (agriculture, industry, tourism, etc.), depletion of marine resources and acoustic contamination may all contribute to the degradation and loss of cetacean habitat in the Mediterranean Sea (Notarbartolo di Sciara 2002). Habitat degradation may intensify the natural factors causing cetacean mortality, such as the morbillivirus epizootic that affected the striped dolphin (*Stenella coeruleoalba*) in 1990 (Aguilar and Borrell 1994). In addition, collisions with ships and incidental captures by fisheries

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are sources of direct mortality (Notarbartolo di Sciarra 2002).

These threats may lead to declining populations in some Mediterranean species although, at the moment, this has only been demonstrated for the short-beaked common dolphin (*Delphinus delphis*) (Bearzi et al. 2003). A number of international frameworks have been established (the European Union's Habitat Directive, the Barcelona Convention or the ACCOB-AMS agreement) that require the implementation of conservation measures. To be effective, conservation actions require basic biological information about the species. In particular, obtaining abundance estimates is a priority to assess the status of the different cetacean species in the Mediterranean Sea and to evaluate the impact that human threats may have on the populations. To aid in this, the IUCN Cetacean Specialist Group has proposed, as part of its action plan, various projects to study the abundance and distribution of the Mediterranean cetacean species (Reeves et al. 2003).

Until now, there has been only one large-scale survey using suitable methodology to study the density and distribution of cetaceans in the Mediterranean Sea (Forcada et al. 1994; Forcada and Hammond 1998). This study in 1991 covered the entire western Mediterranean Sea, but the results are now more than 10 years old. More recently, absolute densities have been estimated for the striped dolphin and the fin whale (*Balaenoptera physalus*), but only in small parts of the Corso-Ligurian basin (Gannier 1997, 1998a; Notarbartolo di Sciarra et al. 2003).

To provide basic information on cetacean abundance and distribution to inform international frameworks, the Spanish Ministry of Environment conducted the "Program for the Identification of Areas of Interest for the Conservation of Cetaceans in the Spanish Mediterranean" between 2000 and 2002. This programme involved researchers from the University of Barcelona, the Autonomous University of Madrid and the University of Valencia. The latter team surveyed the central Spanish waters by means of seasonal aerial surveys using line transect sampling methods (Buckland et al. 2001). Seven species of cetaceans were observed during the surveys: fin whale, Cuvier's beaked whale (*Ziphius cavirostris*), pilot whale (*Globicephala melas*), common dolphin, Risso's dolphin (*Grampus griseus*), common bottlenose dolphin (*Tursiops truncatus*) and striped dolphin.

This paper presents the abundance results for the three most abundant species in the study area: striped dolphin, bottlenose dolphin and Risso's dolphin. For the striped dolphin, seasonal and geographical variation in the density and abundance were explored.

These results are used for conservation applications for Mediterranean populations.

## Materials and methods

### Study area and aerial survey design

The study area comprised the waters of central east Spain (western Mediterranean), from Delta del Ebro (Tarragona, 40°41'N–0°53'E) to Aguilas (Murcia, 37°22'N–1°38'W). An area approximately 32,270 km<sup>2</sup> from 30 to 80 km in width from the coastline was surveyed, with depths ranging from 10 to 2,800 m (Fig. 1a).

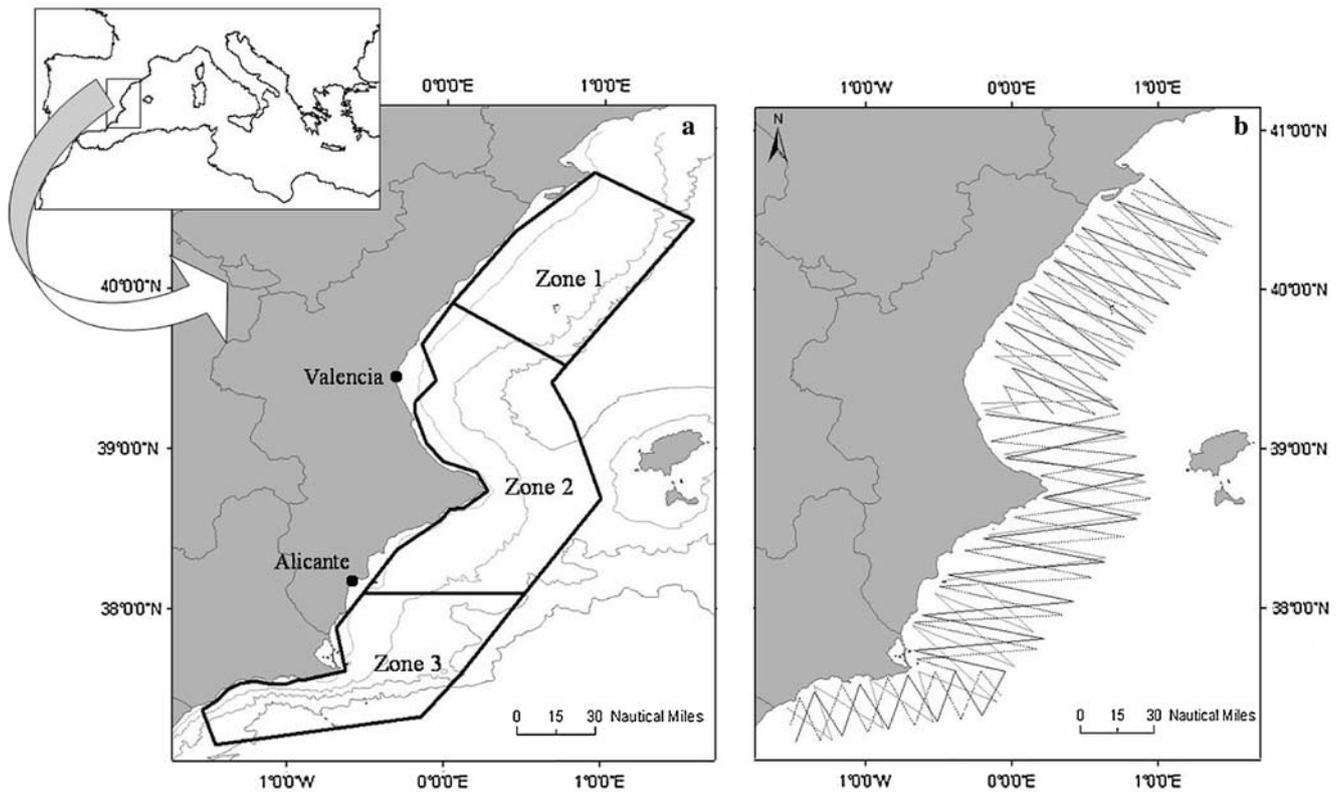
To investigate the geographical differences in density, the study area was stratified into three zones based on the differences in seabed topography and water currents (Fig. 1a). Zone 1 is characterised by a wide continental shelf and by the presence of the Columbretes Islands which have been protected as a marine reserve since 1990. Zone 2 is characterised by a medium width shelf and an important current passing between the island of Ibiza and the Iberian Peninsula. Zone 3 is characterised by a very narrow shelf and a steep slope to the shelf edge close to the coast (Fig. 1a).

Different starting points were used in the track design of each season to cover completely the study area (Fig. 1b). In all of them, the transects were oriented approximately perpendicular to the depth gradient following a systematic saw-tooth pattern from a random start point. The coverage of each design was approximately 4.5% of the total area (coverage = total transect length × width observed on both sides of the plane/total area).

### Aerial surveys

Seasonal aerial surveys were conducted from May 2001 to March 2003 following the line transect sampling methodology (Buckland et al. 2001) (Table 1). Two preliminary surveys were carried out during 2000 to train observers; these data were not included in the analysis. Seasons were defined as: winter, January–March; spring, April–June; summer, July–September and autumn, October–December.

Surveys were conducted from a high-wing twin-engine aircraft ("push-pull" Cessna 337) that allowed side-viewing. Bubble windows were not fitted, so the trackline was not visible. Survey altitude was maintained at 152 m (500 ft) and the transects were flown at a groundspeed of approximately 166 km h<sup>-1</sup> (90 knots).



**Fig. 1** Study area off the Spanish Mediterranean coast covered by aerial surveys. **a** Study area divided in three zones. The 50, 200, 1,000 and 2,000 m isobaths are shown. **b** Survey designs carried out during the 2 years of the study

**Table 1** A summary of the aerial surveys carried out in the study area with the effort (km) and the number of schools and animals of the different species of cetaceans observed

Survey	Date	Effort	Sc schools	Sc animals	Tt schools	Tt animals	Gg schools	Gg animals
Spring 2001	May-01	2,109	7	193	1	20	1	7
Summer 2001	Jul-01	2,009	5	154	2	17	0	0
Autumn 2001	Oct-01	2,105	26	506	2	37	2	14
Winter 2002	Mar-02	2,091	15	294	2	42	3	4
Spring 2002	Jun-02	2,193	12	408	2	12	1	3
Summer 2002	Aug-03	1,946	26	490	0	0	1	18
Autumn 2002	Dec-02	2,201	26	206	4	44	1	2
Winter 2003	Mar-03	2,099	45	296	6	33	6	12
Total		16,754	162	2,647	19	205	15	60

Sc *Stenella coeruleoalba*, Tt *Tursiops truncatus*, Gg *Grampus griseus*

The crew consisted of the pilot, a recorder and two observers positioned behind them, one on each side of the aircraft. The data recorded were: species, number of animals, location (obtained from a GPS), time, observer making the sighting, angle between the horizon and the target when perpendicular to the aircraft and environmental conditions, including the Beaufort sea state, sun glare, percent cloud cover and visibility (an overall subjective assessment of the sighting conditions). Environmental conditions were updated whenever changes occurred and the GPS provided a continuous record of position (updated every few sec-

onds). The angle between the horizon and the animal was estimated using a hand-held clinometer that, in conjunction with the aircraft altitude, provided an estimate of the perpendicular distance to the animal or group of animals. Surveys were limited to the optimum sea conditions for small cetaceans: Beaufort sea state  $\leq 3$ . When the observers were not certain about the species identification or the number of animals in the school, the aircraft left the transect, circled the school to allow confirmation and returned to the same point of the track. Other schools sighted during this off-effort time were not considered in the analysis.

## Small-boat surveys

During the aerial surveys of most cetacean species, observers can miss animals on the trackline because they are diving (known as the availability bias). One method of correcting for the availability bias when estimating the abundance of marine mammals is the use of independent diving information (Barlow 1999). To obtain these data, boat surveys were conducted during 2004. An 8-m yacht was used in the northern study area and a 16-m motor-sailing vessel was used in the southern zone. Data on the dive and surface times were collected following Laake et al. (1997). Dive time was defined as the length of time when all animals of the schools are underwater for more than 30 s. Surface time was the length of time when one or more individuals of the school are at or near the surface or when the dive time is < 30 s. This period of time was selected to compensate for the horizontal perspective, which does not allow a full assessment of dolphin visibility from the aircraft (Laake et al. 1997; Barlow et al. 1988). Sightings of Risso's or bottlenose dolphin were too infrequent during the boat surveys to obtain enough data to estimate the availability bias. However, the same methodology was previously used in the northern Spanish Mediterranean to estimate the availability bias in aerial surveys of bottlenose dolphins (Forcada et al. 2004). And because of the similarity of the aircraft and the proximity of the area these data were used to correct our bottlenose dolphin abundance estimate. Diving data from small schools ( $\leq 15$  individuals) and large schools ( $> 15$  individuals) were collected separately because the probability of detection of the different size schools was also different (see below).

## Data analysis

Dolphin density ( $D$ ) was estimated using standard distance sampling methods applied to clusters of animals (Buckland et al. 2001). Data were analysed using the program DISTANCE 4.1 (Thomas et al. 2004). Essentially, the program fits a detection function to the distribution of perpendicular distances and this function is used to estimate the effective strip half-width, ESW. Then, the density is given as:

$$D = \frac{nE(s)}{2L \text{ ESW}g(0)},$$

where  $n$  is the number of sightings (i.e. schools) on effort,  $L$  is the total search effort,  $E(s)$  is the mean school size and  $g(0)$  is the detection probability on the

trackline. The quantity  $n/L$  is referred to as the encounter rate, which is the number of sightings per kilometre surveyed. In the case of Risso's dolphin,  $g(0)$  was assumed to be equal to one because no data on diving behaviour could be collected. For striped and bottlenose dolphins,  $g(0)$  was substituted by  $\hat{a}(S, 0)$ , the availability probability on the trackline. The parameter  $\hat{a}(S, x)$  was defined as the probability that a dolphin school at a perpendicular distance  $x$  was at the surface and within the observer's field of view (event  $S$ ). It was estimated according to Forcada et al. (2004) from the boat survey data as:

$$\hat{a}(S, x) = \frac{E(sf)}{E(sf) + E(d)} + \frac{w(x) - w(x)^2 E(d)^{-1} 0.5}{E(sf) + E(d)},$$

where  $E(sf)$  is the average length of a surfacing and  $E(d)$  is the average length of a dive.  $E(sf)/[E(sf) + E(d)]$  was evaluated with a ratio estimator of the length of time at the surface and the total time observed. The parameter  $w(x)$  is the amount of time the ocean is in the observer's view at a perpendicular distance  $x$  and it was calculated based on the aircraft properties and speed  $v$  following Forcada et al. (2004) due to the similarity of the aircrafts used:

$$w(x) = \frac{x}{v} [\cot(40) + \cot(35)],$$

where 40 and 35 correspond to the angles obstructing the horizontal scan field in the aircraft.

Variance of density was estimated empirically using the "delta" method (Seber 1982):

$$\text{Var}(D) = D^2 \left[ \frac{\text{var}(n/l)}{(n/l)^2} + \frac{\text{var}(\text{ESW})}{\text{ESW}^2} + \frac{\text{var}(E(s))}{E(s)^2} + \frac{\text{var}(\hat{a}(S, 0))}{\hat{a}(S, 0)^2} \right],$$

where the variance of each element was estimated using survey legs as replicate transects, except in the case of  $\hat{a}(S, 0)$  where the variance was estimated independently from the boat survey data.

A distance of 86 m (the one corresponding to a clinometer angle of 60°) was subtracted from all the perpendicular distances because the flat windows in the aircraft did not permit the detection of animals at angles closer to the transect line.

Following Buckland et al. (2001), three potential functions were initially considered to fit the perpendicular distance data: uniform, half-normal and hazard rate, together with various adjustment terms. For each

model the number of adjustment terms required was selected using the likelihood ratio test ( $\alpha = 0.05$ ) and the final model selection was made using the Akaike Information Criterion (AIC) (Buckland et al. 2001).

#### Effect of covariates on detectability

In the western Mediterranean, striped dolphins and bottlenose dolphins are quite similar in body length, have similar behaviour at sea and no difference in the detection function of both species has been found in other aerial surveys (Forcada et al. 2004). Therefore, the sightings of the two species were initially combined in the analysis.

A high variability in the school size of the two species, particularly in the striped dolphin (1–100 individuals), was observed. It is known, from other studies (Forcada and Hammond 1998; Forney and Barlow 1998) and from our own experience, that school size affects the probability of detection; large schools are more easily detected than smaller ones, especially with increasing perpendicular distance. Other factors such as visibility conditions or species identity can also influence the shape of the detection function. The most recent approach to deal with this problem is to use these factors as covariates when fitting the detection function (Buckland et al. 2004). Therefore, multiple covariate distance sampling analyses were conducted within the program DISTANCE 4.1 using cluster size, species, Beaufort sea state and season to fit the detection function. Various models combining these factors were fitted and the AIC criterion was used to select the most parsimonious model (Buckland et al. 2004). The model with the lowest AIC included cluster size as the only significant covariate, i.e. cluster size was the only factor affecting the detection function. Unfortunately, DISTANCE 4.1 can only use covariates to estimate the overall density, but not when the data are post-stratified by season or zone. Moreover, the multiple covariate distance sampling procedure precludes the use of several multiplier values [e.g. different values of  $g(0)$ ] to estimate density. Thus, the density was estimated using conventional distance sampling methods, stratifying by school size (Buckland et al. 2001). Observations were divided into three school size groups based on the field experience of sightability and analysis sample size considerations: 1–4, 5–15 and > 15 individuals. Data for each group were analysed independently. There was no difference between the estimated ESW of the first two groups (1–4 and 5–15 individuals); the 95% confidence intervals overlapped substantially. However, the ESW of large schools (> 15 individuals) was significantly larger than

either of the other two groups (no overlap in confidence intervals). Based on these results, the data were stratified into two school size groups,  $\leq 15$  and  $> 15$  individuals. To account further for the relationship between school size and detectability, a regression of log school size against the estimated probability of detection [ $g(x)$ ] was computed for each group. If the regression is significant, the mean school size is then estimated by the predicted mean size of the detected schools in the region around the trackline, where detection is certain (Buckland et al. 2001). The mean school size of the striped and bottlenose dolphins was calculated separately in the two strata. Finally, the density of each species was calculated as the sum of the density of the two school size groups.

In the case of the striped dolphin, there were sufficient data to investigate changes in the densities among seasons and zones. Density in the  $i$ th season or zone was estimated as:

$$D_i = D_{is} + D_{il} = \frac{n_{is}E(s)_s}{2L_iESW_s\hat{a}(S,0)_s} + \frac{n_{il}E(s)_l}{2L_iESW_l\hat{a}(S,0)_l},$$

where the subscript  $s$  corresponds to small schools and  $l$  corresponds to large schools. As the school size changed between seasons, particularly for large schools (see Results),  $E(s)_l$  was estimated separately for each season when the density was calculated. For small schools, the same  $E(s)_s$  was used for all seasons. The mean density in the study area was calculated by averaging the densities of the different seasons over the total effort of each season.

The  $d$ -test (Sheskin 2000), assuming estimates are log-normally distributed, was used to test differences in the density between zones or seasons as follows:

$$d = \frac{x_1 - x_2}{\sqrt{\text{var}(x_1) + \text{var}(x_2)}},$$

where  $x = \log D$  and  $\text{var}(x)$ , the variance of  $\log D$ , is approximated as:

$$\text{var}(\log D) = \log \left( 1 + \frac{\text{var}(D)}{D^2} \right).$$

The use of a  $d$ -test to compare densities assumes that seasons and zones are independent, which is not true in this case because the same detection function,  $g(0)$  and mean school size (in some cases), was applied to estimate the densities. In order to deal with this problem, the proportion of the variance introduced by these in common factors (extracted from the DISTANCE 4.1 program output) was removed from the

total density variance. The resulting variance was then used to conduct the tests.

Finally, the probability values were adjusted using the sequential Bonferroni technique (Rice 1989) to correct for multiple comparisons.

In the case of the Risso's dolphin, the low number of sightings allowed neither the investigation of the effect of different factors in the detection function nor the estimation of seasonal or geographical densities.

## Results

### Aerial and ship surveys

Eight complete aerial surveys were conducted with 16,754 km searched on effort during which 162 striped dolphin schools, 19 bottlenose dolphin schools and 15 Risso's dolphin schools were observed (Table 1).

During small-boat surveys, a total of 24 schools of striped dolphins (15 schools with  $\leq 15$  individuals and 9 schools with  $> 15$  individuals) was closely followed for periods between 3.2 and 40.3 min. Total observation time was 4 h 31 min. The average surface interval for small schools was 132.8 s (SE = 76.34) and the average dive interval was 66.4 s (SE = 23.71) resulting in a mean proportion of the time spent at surface of 0.650 (SE = 0.1628). The availability bias on the trackline for small schools,  $\hat{a}(S, 0)_s$ , was estimated as 0.676 (SE = 0.1632). In the case of large schools none of them were underwater for more than 30 s, therefore  $\hat{a}(S, 0)_l$  was equal to 1. Values of the diving behaviour of the bottlenose dolphin were obtained from Forcada et al. (2004), where the mean surface interval was 231.3 s (SE = 29.4) and the average dive interval was 68.7 s (SE = 8.7). The availability bias for the bottlenose dolphin,  $\hat{a}(S, 0)$ , was estimated as 0.778 (SE = 0.031).

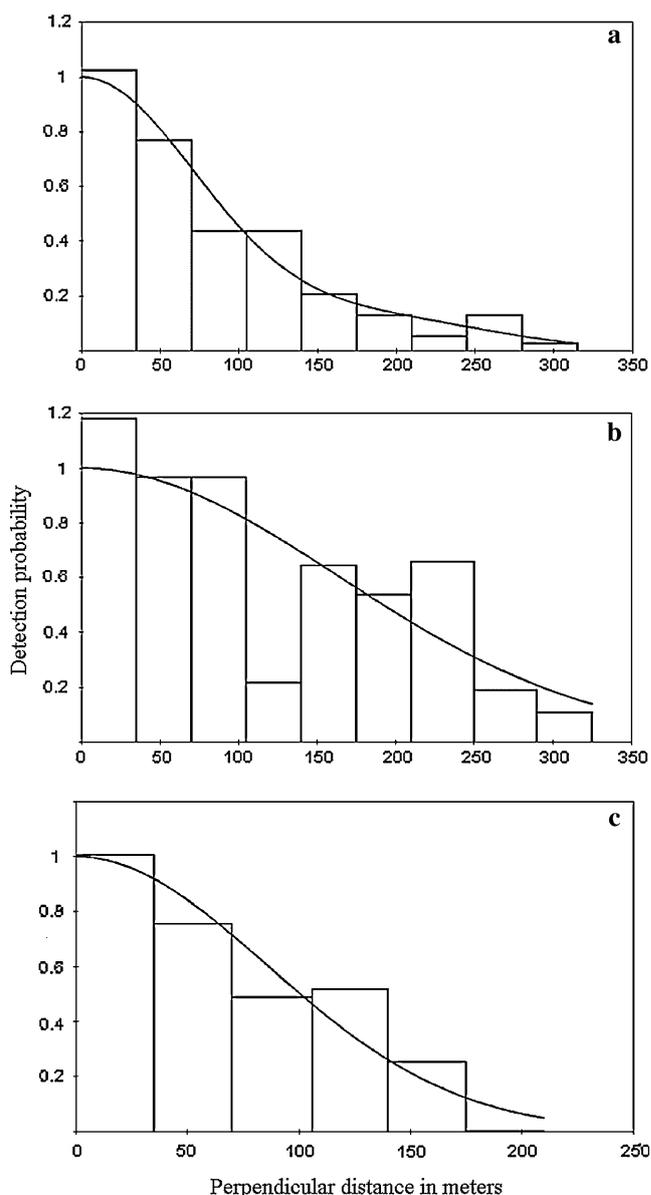
### Abundance estimation

#### Striped and bottlenose dolphins

Following the preliminary analyses described above, the detection function was fitted for the striped and bottlenose dolphins combined, but separately for the two school size groups,  $\leq 15$  individuals and  $> 15$  individuals. The best-fitting model for the small schools was the half-normal with one cosine adjustment term (Fig. 2a, Table 2). The regression of school size against detection probability was not significant for either species, so the average school size was used to estimate

density (Table 2). For big schools, the half-normal with no adjustment terms was the best-fitting function (Fig. 2b, Table 2). The regression of school size against  $g(x)$  was significantly positive in the case of both the striped and bottlenose dolphins, and the expected average school size was estimated using the regression estimator (Table 2).

The school size of the striped dolphins varied between 1 and 100 individuals with a mean of 15.7



**Fig. 2** Frequency distribution of perpendicular distances ( $- 86$  m) from the transect line. The *continuous curve* represents the detection function. **a** Frequency distribution of the striped and bottlenose dolphin sightings combined with  $\leq 15$  animals. **b** Frequency distribution of the striped and bottlenose dolphin sightings combined with  $> 15$  animals. **c** Frequency distribution of Risso's dolphin sightings

**Table 2** Values of the detection probability obtained from the different species and school size groups

Species	Parameter	Estimate	%CV	95% CI
Sc + Tt ≤ 15 individuals	ESW	112.0	9.18	93.4–134.2
	$E(s)$ Sc	5.46	6.99	4.76–6.27
	$E(s)$ Tt	4.75	18.2	3.20–7.06
Sc + Tt > 15 individuals	ESW	195.2	12.0	153.5–248.0
	$E(s)$ Sc	33.7	7.99	28.7–39.6
	$E(s)$ Tt	22.2	20.4	12.7–38.9
Gg	ESW	105.6	23.2	63.7–174.9
	$E(s)$	4.50	34.6	2.15–9.42

ESW effective strip width (m),  $E(s)$  estimated school size, %CV percentage of the coefficient of variation, CI confidence interval, Sc *Stenella coeruleoalba*, Tt *Tursiops truncatus*, Gg *Grampus griseus*

individuals and a median of 7 individuals (Fig. 3a). Seasonal differences were detected in the school size of this species (Table 3), particularly during the spring season, where the median school size was higher than in the other seasons. This indicates that during spring, most of the schools were large schools, while during the other seasons most of the schools were small. On the other hand, the estimated mean school size of small schools ( $\leq 15$  individuals) did not change between seasons, but it did in the case of large schools (Table 3). Therefore,  $E(s)_1$  was used separately to estimate the density for each season. No differences were detected in the school size between zones.

Striped dolphins were by far the most abundant species in the study area with a density of 0.489 dolphins  $\text{km}^{-2}$  and abundance of 15,778 dolphins (Table 4). Densities ranged from 0.334 dolphins  $\text{km}^{-2}$  during spring to 0.600 dolphins  $\text{km}^{-2}$  during autumn (Table 5). No significant differences were found in the density of striped dolphins between seasons (Table 6). Comparing the density between zones, the estimated

density for the northern area (zone 1) was lower (0.268 dolphins  $\text{km}^{-2}$ ), but this difference was not significant (Table 6).

In the case of bottlenose dolphins the school size varied between 2 and 40 individuals with a mean of 10.8 and a median of 7 individuals (Fig. 3b). Schools of bottlenose dolphins were observed year-round, although no seasonal densities could be estimated. The overall density was an order of magnitude lower than that of the striped dolphin (0.041 dolphins  $\text{km}^{-2}$ ) with a total number of 1,333 dolphins in the study area (Table 4).

### Risso's dolphins

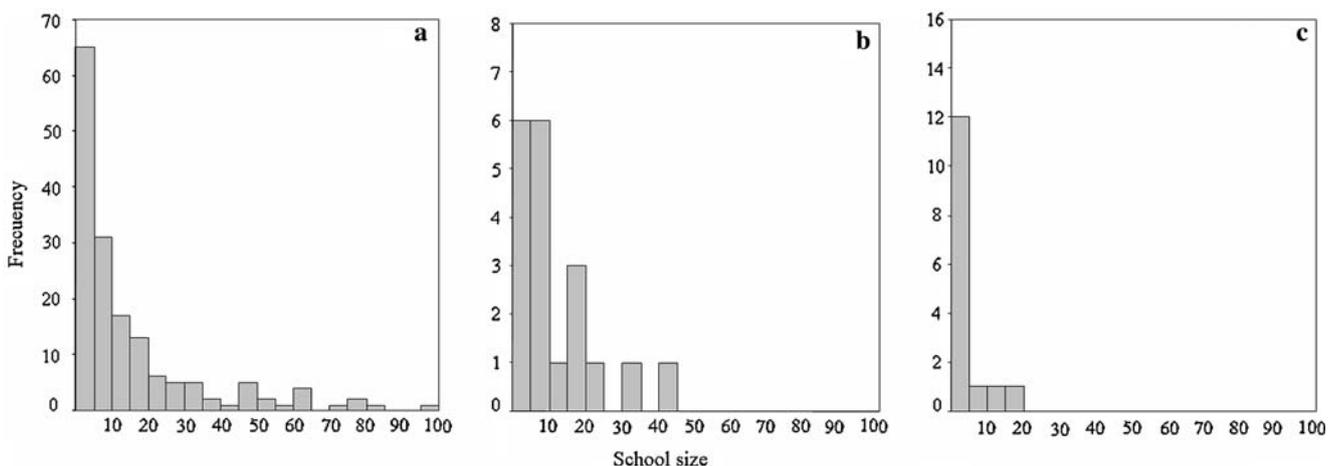
The best-fitting detection function for Risso's dolphin sightings was the half-normal with no adjustment terms (Fig. 2c, Table 2). The regression of school size against the detection probability was not significant, so the average school size was used in density estimation (Table 2).

Risso's dolphin was present in the study area throughout the whole year. School size varied between 1 and 18 individuals with a mean of 4.0 and a median of 2 individuals (Fig. 3c). It was estimated that 493 Risso's dolphins were presented in the study area giving a density of 0.015 dolphins  $\text{km}^{-2}$  (Table 4).

## Discussion and conclusions

### Methodological considerations

The most critical assumption in line transect methodology is that animals or schools directly on the line are always detected [i.e.  $g(0) = 1$ ] (Buckland et al. 2001).

**Fig. 3** Frequency distribution of school size. **a** Striped dolphin. **b** Bottlenose dolphin. **c** Risso's dolphin

**Table 3** Values of school size for the striped dolphins obtained for each season; the mean and median value for all schools observed and the estimated school size for small schools  $E(s)_s$ , and large schools,  $E(s)_l$ , with its coefficient of variation, %CV, and number of sightings,  $n$ , are shown

Season	Mean	Median	$E(s)_s$	%CV	$N$	$E(s)_l$	%CV	$n$
Spring	32	30	5.25	22.4	8	44.9	19.8	11
Summer	21	11	5.05	18.1	18	42.5	12.4	13
Autumn	14	7	5.66	12.6	36	33.4	14.4	16
Winter	10	6	5.50	10.9	50	24.5	18.9	10

**Table 4** Abundance estimates and related statistics of the striped dolphin (Sc), bottlenose dolphin (Tt) and Risso's dolphin (Gg) in the study area

Sp	Parameter	Estimate	%CV	95% CI
Sc	$D$	0.489	18.8	0.339–0.705
	$N$	15,778	18.8	10,940–22,756
Tt	$D$	0.041	30.8	0.023–0.075
	$N$	1,333	30.8	739–2,407
Gg	$D$	0.015	60.6	0.005–0.046
	At surface	$N$	493	162–1,498

In the case of cetacean surveys, this assumption may be biased by the availability bias (when animals in the trackline are not observed because they are diving) and the perception bias (when the observer fails to detect an animal on the trackline although it is available). The availability bias, that is probably the most important bias in this study, has been corrected for the two principal species. In the case of Risso's dolphin, no correction for the availability bias could be conducted. Given that this species occur in small schools

**Table 5** Abundance estimates of the striped dolphin and related statistics divided by season and zones

Season/zone	Parameter	Estimate	%CV	95% CI
Spring	$D$	0.334	31.7	0.182–0.613
	$N$	10,788	31.7	5,885–19,778
Summer	$D$	0.522	24.5	0.325–0.839
	$N$	16,859	24.5	10,499–27,072
Autumn	$D$	0.600	26.0	0.363–0.991
	$N$	19,357	26.0	11,720–31,971
Winter	$D$	0.580	30.8	0.321–1.047
	$N$	18,721	30.8	10,373–33,790
Zone 1	$D$	0.268	30.9	0.149–0.485
	$N$	2,332	30.9	1,291–4,215
Zone 2	$D$	0.529	21.9	0.346–0.808
	$N$	7,609	21.9	4,981–11,623
Zone 3	$D$	0.672	23.3	0.428–1.054
	$N$	6,176	23.3	3,938–9,685

$D$  density (number of dolphins  $\text{km}^{-2}$ ),  $N$  abundance (number of dolphins), %CV percentage of the coefficient of variation, CI confidence interval

(median = 2 animals) and that the availability bias increases when the school size decreases it is likely that the abundance estimations reported here are underestimates of the true population size.

Perception bias could not be estimated for any of the species presented here. However, it is expected to be small, as in the other cetacean aerial surveys (Laake et al. 1997; Carretta et al. 1998; Forcada et al. 2004; Slooten et al. 2004), bearing in mind that the observers used in this study were experienced.

Finally, another bias could be affecting the estimations because the flat windows of the aircraft permitted the observation only from 86 m out of the trackline. In this study the probability of detecting an animal at 86 m was assumed to be the same as at 0 m. However, the detection probability at 86 m should be lower than on the trackline unless a shoulder is present in the detection probability function, but this could not be assessed because of the lack of data. Bearing in mind that the observers concentrated their sighting effort at this distance, our assumption that the detection probability at 86 m was similar to that on the trackline is likely to cause only a small positive bias.

#### Abundance estimates

Two other research teams conducted additional surveys in the same period to study the distribution and abundance of cetaceans in the north and south Spanish Mediterranean waters. To date, from these studies, only the results of the absolute abundance of bottlenose dolphins have been published (Forcada et al. 2004; Cañadas and Hammond 2006); thus, this is the only species with which comparisons can be made.

**Table 6** Results of tests of the difference in densities of the striped dolphin between seasons and zones

Season	Spring	Summer	Autumn	Winter
Spring	–	–	–	–
Summer	0.52	–	–	–
Autumn	0.75	0.26	–	–
Winter	0.65	0.18	0.06	–
Zone	1	2	3	
1	–	–	–	
2	0.84	–	–	
3	1.27	0.61	–	

Values of the  $d$  statistic are given; the value at the 5% significance level is  $d = 1.96$

None of the comparisons were significant after the sequential Bonferroni correction

*Bottlenose dolphin*

The density of this species estimated in waters around the Balearic Islands was 0.109 dolphins km<sup>-2</sup> (CV = 0.52) and the density estimated in the waters off Catalonia was 0.036 dolphins km<sup>-2</sup> (CV = 0.56) (Forcada et al. 2004). In the Alboran Sea the density of bottlenose dolphins was estimated as 0.049 dolphins km<sup>-2</sup> (CV = 0.28) (Cañadas and Hammond 2006). Although there are differences in the methodology (e.g. ship vs. aircraft), the density in our study area (0.041 dolphins km<sup>-2</sup>; CV = 0.19) is very similar to that obtained along the Spanish coast and about half of that around the Balearic Islands. This latter zone and the Alboran Sea are considered key areas for this species in the western Mediterranean (Notarbartolo di Sciara 2002).

*Striped dolphin*

As in the earlier cetacean survey in this area (Forcada et al. 1994), the striped dolphin was the most abundant species in the study area. In 1991, after the epizootic mass mortality, the density of the striped dolphin was estimated as 0.20 dolphins km<sup>-2</sup> in all of the western Mediterranean (Forcada et al. 1994). Forcada and Hammond (1998) also estimated the density in different geographical areas of the western Mediterranean (Balearic Sea, Alboran Sea, south Balearic area, etc.) but none of them can be strictly compared to that from our study area. However, a coarse comparison between the densities of similar zones estimated in Forcada and Hammond (1998) and in our study (Balearic Sea,  $D = 0.09$  vs. zone 1,  $D = 0.27$  dolphins km<sup>-2</sup>; Alboran Sea,  $D = 0.20$  vs. zone 3,  $D = 0.67$ ) suggests an increase in the density of striped dolphins in the region during the last decade, perhaps indicating a recovery of dolphin numbers after the epizootic mortality. In any case, caution should be applied to this hypothesis because of the different platform used (ship vs. aircraft) and the fact that Forcada and Hammond (1998) did not correct for the availability bias. Nevertheless, the availability bias of ship surveys is probably lower than that of aerial surveys because the lower speed of the ship allows for more time to observe a specific area of the ocean [ $w(x)$ ].

On the other hand, Forcada and Hammond (1998) concluded that the central Spanish region was a very low density zone for striped dolphins in the western Mediterranean. However, the density estimated in our study (0.49 dolphins km<sup>-2</sup>) was similar to the density estimated more recently in the Corso-Ligurian Basin (0.56 dolphins km<sup>-2</sup>, Gannier 1998a). This area is

considered one of the most populated zones for striped dolphins in the western Mediterranean (Forcada et al. 1995) and it is currently protected as an International Marine Sanctuary for cetaceans due to the high density of several species (Hoyt 2005).

Despite the high density, this species is at present subjected to several anthropogenic threats (including chemical pollution, fishing interactions and food limitations) that raise concerns about its conservation (Aguilar 2000). Furthermore, if epizootics are a density-dependent phenomenon, the high density observed in the area could facilitate the emergence and expansion of a new epizootic outbreak like the one that occurred in 1990.

Some temporal variability in the striped dolphin abundance was observed during the surveys. The number of animals sighted in the different seasons, even in the two surveys in the same season, varied considerably. However, no significant differences were detected in the densities estimated between seasons. While in some regions (e.g. portions of the US east coast), the striped dolphin is encountered in all seasons, in the other areas it appears to be associated with fronts of warm oceanic currents that move seasonally (Perrin et al. 1994 and references therein). The western Mediterranean Sea is a quite stable system without any important seasonal current. However, in the Liguro-Provençal basin, although striped dolphins are observed year-round, their abundance is much lower during winter and spring (Gannier and Gannier 1997; Gannier 1998b).

One of the principal factors affecting the distribution of cetaceans is prey availability. Cephalopods dominated in the stomach contents of stranded striped dolphins in the study area—*Abraliopsis pfefferi*, *Onychoteuthis banksii*, *Todarodes sagittatus* and *Brachio-teuthis riisei* being the most important species in the diet (Blanco et al. 1995). Information about seasonal abundances of these species in the Spanish Mediterranean is very scarce, but most of them are probably present year-round (Guerra 1992). Striped dolphins in the western Mediterranean are opportunistic in their feeding habitats (Blanco et al. 1995; Würtz and Marrale 1993; Meotti and Podestà 1997); therefore seasonal changes in the distribution of any particular prey may not greatly affect their distribution.

Although the difference was not significant at the 5% level, the estimated density in the northern zone of the study area was lower than the other zones. This zone has a wide continental shelf; 70% of the area contains waters less than 200 m deep. As the striped dolphin is mainly an oceanic species (Cañadas et al. 2002), the density in zone 1 is expected to be lower.

Future studies will analyse habitat usage of this species in the area to determine the factors affecting dolphin distribution and abundance (Gómez de Segura et al. 2006).

### *Risso's dolphin*

The abundance of Risso's dolphin is estimated for the first time in a part of the Mediterranean Sea. The precision of the abundance estimate was poor and the estimate is likely to be substantially underestimated because  $g(0) < 1$  and no correction was made. Other studies in areas of similar characteristics show, in some cases, densities comparable to the one obtained here (Wade and Gerrodette 1993; Barlow 1995; Dolar 1999; Mullin and Fulling 2003), but in others the difference is an order of magnitude higher (Forney et al. 1995). In all cases, the coefficient of variation of the estimates is similar to those obtained in this study indicating that the Risso's dolphin is not commonly encountered in relation to typical amounts of the survey effort.

### Conservation applications

This study provides valuable biological information for the conservation of cetaceans in the Mediterranean Sea. First, the abundance of the three most common cetacean species in the study area was estimated following one of the priorities of the ACCOBAMS agreement and one of the conservation action plans proposed by the IUCN—the abundance estimation of bottlenose dolphins in the Mediterranean Sea (Reeves et al. 2003). Furthermore, the estimates of striped and bottlenose dolphins presented here are precise enough to inform management measures (< 35%, Wade and DeMaster 1999). The results of this study have been used to draw up the boundaries of the most important areas for the conservation of cetaceans based on the distribution, abundance and diversity of the species (Raga and Pantoja 2005).

On the other hand, striped and Risso's dolphins are currently subject to incidental captures by different types of fishing gear in the Spanish Mediterranean waters (University of Valencia, unpublished data; Valeiras and Camiñas 2002). Absolute abundance results from this study are very useful to study the impact of the threats to the local populations. However, to date, there are no estimates of the number of animals killed by fisheries. Only the number of striped dolphins incidentally caught by the Spanish driftnet fishing in the waters around the Gibraltar Strait has been estimated (Silvani et al. 1999), but this fleet stopped fishing in 1994. However, illegal Moroccan driftnets are still

used in the Alboran Sea capturing accidentally more than 10% of the estimated population size of striped and common dolphins (Tudela et al. 2005). More by-catch studies are needed in the Spanish waters to implement another of the priorities of the ACCOBAMS agreement.

Finally, results from this study provide some insight into the population trend of striped dolphins 10 years after the density estimation obtained in the same region (Forcada and Hammond 1998). For the other species, although this study does not give any information about population trends, it does provide a baseline that will serve as a reference point for a future monitoring framework to indicate if populations are increasing, decreasing or stable in numbers. This monitoring is particularly important in the case of bottlenose dolphins, whose populations appear to be decreasing in the Mediterranean Sea, although scientific information is scarce. However, to overcome the current difficulties in detecting population trends (e.g. in the striped dolphin), it will be important for future monitoring to apply a consistent methodology and to conduct surveys with a coverage comparable with that used in this study.

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