Abundance of fin whales and striped dolphins summering in the Corso-Ligurian Basin

by J. FORCADA [1], G. NOTARBARTOLO DI SCIARA [2] and F. FABBRI [3]

[1] *Department of Animal Biology (Vertebrates), Faculty of Biology, University of Barcelona, Diagonal 645, 08028 Barcelona, Spain*
[2] *Tethys Research Institute, Via Giusti 5, I-20154 Milano, Italy*
[3] *Greenpeace Italy, viale Manilo Gelsomini 28, I-00153 Roma, Italy*

Summary. – A sightings survey was carried out in the western Ligurian Sea and in the offshore waters off western Corsica during August 1992, to estimate the density and absolute abundance of cetacean species in the area. Standard line transect analysis could be applied to the two most abundant species encountered, striped dolphins *(Stenella coeruleoalba)* and fin whales *(Balaenoptera physalus)*. Whale abundance was estimated as 901 individuals (coefficient of variation (CV) = 0,217 ; 95 % confidence interval : 591-1,374 whales), and striped dolphin abundance was estimated as 25,614 individuals (CV = 0.253 ; 95 % confidence interval : 15 377-42 658 dolphins). Densities of cetaceans presented here, compared to densities estimated in previous surveys across the entire western Mediterranean, highlight the importance of the Corso-Ligurian Basin as a main habitat for pelagic cetacean populations.

Résumé. – Une croisière d'échantillonnage par observation visuelle sur transect linéaire a été conduite dans la mer ligure occidentale et au large de l'ouest de la Corse pendant le mois d'août 1992 pour une estimation de la densité et de la taille des populations de cétacés dans la zone. Une analyse par transect linéaire standard a pu être appliquée aux deux espèces les plus abondantes, le dauphin bleu et blanc *(Stenella coeruleoalba)* et le rorqual commun *(Balaenoptera physalus)*. L'abondance du rorqual commun a été estimée à 901 individus (CV = 0.217 ; intervalle de confiance à 95 % : 591-1 374 rorquals), et l'abondance de dauphin bleu et blanc a été estimée à 25 614 individus (CV = 0.253 ; intervalle de confiance à 95 % : 15 377-42 658 dauphins). Les densités présentées ici, comparées aux densités estimées lors de campagnes sur l'ensemble de la Méditerranée occidentale, mettent en relief l'importance du bassin Corso-Ligurien comme habitat préférentiel pour les populations pélagiques de cétacés.

INTRODUCTION

In recent years, studies on cetacean populations in the western Mediterranean have emphasized the importance of the Corso-Ligurian Basin as one of the pelagic areas

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with highest cetacean densities in the entire western Mediterranean sea (Notarbartolo di Sciara *et al.* 1993, Forcada *et al.* 1994, Forcada *et al. in press a*). Increasing concern for the survival of cetacean populations in this area, subject to major accidental capture in large-scale pelagic driftnet fishing activities (Notarbartolo di Sciara 1990, Di Natale and Notarbartolo di Sciara *in press*), have led scientists and conservation organizations to put forward proposals aimed at the protection of key marine pelagic habitats and of their cetacean diversity (Notarbartolo di Sciara *et al.* 1992, Orsi Relini *et al.* 1992). Such efforts have resulted in the declaration by France, Italy, and the Principality of Monaco of a 70,000 km^2 wide International Marine Sanctuary for cetaceans – specifically designed to protect cetacean populations in the Corso-Ligurian Basin – encompassing offshore and coastal waters between the west coast of Corsica and the mainland coast from Toulon to La Spezia (Notarbartolo di Sciara *in press*).

As part of the studies conducted to support the implementation of appropriate conservation measures, and specifically to assess cetacean abundance and distribution within the sanctuary boundaries, a line transect shipboard survey of the western Ligurian Sea and Corsican Sea was carried out from 6 to 20 August 1992 by the Tethys Research Institute (Milan, Italy), in cooperation with the Greenpeace Mediterranean Sea Project and the Department of Animal Biology of the University of Barcelona. Data for the two most abundant species, the striped dolphin *(Stenella coeruleoalba)* and the fin whale *(Balaenoptera physalus)*, were analysed to produce estimates of density and abundance within the surveyed area. These results, when compared with similar data collected in 1991 over a wider expanse of the western Mediterranean (Forcada *et al.* 1994, Forcada *et al. in press a*, Forcada *et al in press b*) strongly emphasize the faunal importance of the Corso-Ligurian Basin, and highlight the need for the implementation of appropriate cetacean conservation policies in that region.

METHODS

Survey

The area covered by the survey, 58,268.64 km^2 wide, is delimited by the western coast of Corsica and the continental coasts of France and Italy (Fig. 1). This area covers the entire western Ligurian Sea and the Corsican Sea, and includes a major portion of the recently created International Sanctuary for Mediterranean cetaceans (Notarbartolo di Sciara *in press*).

Methods used in previous cetacean sightings surveys in the Mediterranean Sea, described by Forcada *et al.* (1994), were applied. Thus, the surveyed area contained a cruise track designed in a zig-zag pattern for a more efficient coverage, to provide a representative data set (Hiby and Hammond 1989) ; the starting point was placed at random. The survey was conducted aboard the 46 m-long Greenpeace ship M/V Sirius, at a constant cruising speed of 18.5 km h^{-1}. The observation platform was situated at a height of 8 meters above the sea level, where teams of 3-4 observers, provided with 8-10x binoculars, looked for cetaceans during day-light hours in regular shifts.

Data were collected following line transect sampling methods (Burnham *et al.* 1980, Buckland *et al.* 1993). Thus, sighting angles (measured with angle boards) and sighting distances (estimated by naked eye) were recorded for all cetacean groups encountered. Special training exercises were organized before the beginning of the survey to improve the observers' abilities to estimate distances (Forcada *et al.* 1994).

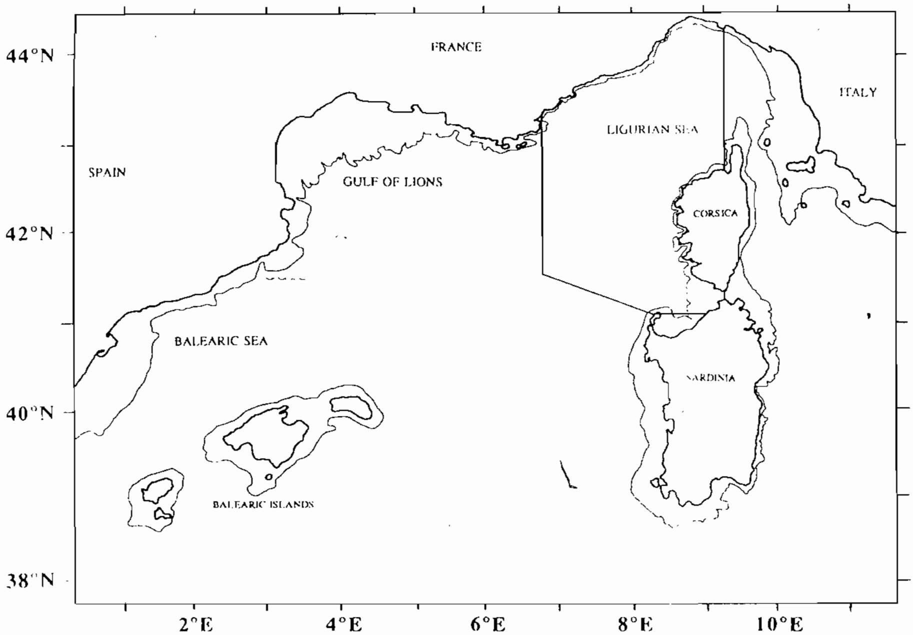


Fig. 1. – The northwestern Mediterranean sea with survey area.

All cetacean groups sighted while on effort on the track line (primary sightings) were approached after detection, to identify the species and estimate school size as accurately as possible. After confirmation, the track line was rejoined in a convergent course to avoid the potential repeating of sightings (Hiby and Hammond 1989).

Analysis

Data were analyzed applying standard line transect methods (Buckland *et al.* 1993). Thus, perpendicular distances were calculated with sighting angles and distances of cetacean groups detected from the track line, while searching on effort. In order to avoid the effect of rounding of angles and distances to convenient values by the observers, sighting angles and radial distances measured were smeared into perpendicular distance intervals with method number 2 of Buckland and Anganuzzi (1988). With this method, an angle sector Φ around the angle measurement and a proportional sector of distance $\hat{s}$ to use as the basis for the smearing are defined. If an observation is measured at angle **a** and radial distance **r**, it is smeared uniformly in the sector defined by the angle $(\mathbf{a}-\Phi, \mathbf{a}+\Phi)$ and distance range $(\mathbf{r}(1-\hat{s}), \mathbf{r}(1+\hat{s}))$. Before smearing, 10% of the largest perpendicular distances were truncated. After truncation, several models were fitted to the perpendicular distance histogram, in order to obtain the effective strip width (*esw*). The effective strip width is the half-width of the strip extending either side of a track line such that as many objects are detected outside the strip as remain undetected within it (Buckland *et al.* 1993). The best model was selected by the minimum Akaike's Information Criterion (Akaike 1973).

Data were analyzed to determine appropriate stratification options to improve the estimation of abundance. For that purpose, two potential stratification factors were identified : Beaufort (a scale for wind speed, determined by sea state) and school size. Following Buckland *et al.* (1992), the effect of Beaufort on the abundance estimate was assessed comparing the estimates of *esw*, encounter rate and school size for each category of Beaufort in turn, and pooling across all school sizes. Standard errors of each parameter were calculated and differences were tested by means of z-tests (Buckland *et al.* 1993). To investigate the effect of school size on estimates, the *esw* and encounter rate of different size categories were compared in the same way as Beaufort. The number of stratification factors and different strata considered for the analysis of each cetacean species was assessed to reduce the bias in the estimate of *esw*. When sample size within a stratum was too small to allow estimation of *esw* but stratification was considered appropriate for encounter rate and school size by strata, stratification was undertaken assuming a common value of *esw*.

For every stratum, abundance was estimated following Burnham *et al.* (1980) as :

$$\hat{N} = \frac{n\hat{f}(0)\,\bar{s}A}{2L}$$

with variance

$$v\hat{a}r\,(\hat{N}) = \hat{N}^2 \left[\frac{v\hat{a}r\,(n)}{n^2} + \frac{v\hat{a}r\,\{\hat{f}(0)\}}{\{\hat{f}(0)\}^2} + \frac{v\hat{a}r\,(\bar{s})}{\bar{s}^2}\right]$$

where

n = number of primary sightings after truncation

$\hat{f}(0)$ = estimated probability density of perpendicular distances, evaluated at 0

$\bar{s}$ = mean school size

L = distance covered by the vessel on effort

A = size of the prospected area

and density of cetaceans was estimated as :

$$\hat{D} = \frac{n\hat{f}(0)\,\bar{s}}{2L}$$

with variance

$$v\hat{a}r\,(\hat{D}) = \hat{D}^2 \left[\frac{v\hat{a}r\,(n)}{n^2} + \frac{v\hat{a}r\,\{\hat{f}(0)\}}{\{\hat{f}(0)\}^2} + \frac{v\hat{a}r\,(\bar{s})}{\bar{s}^2}\right]$$

When stratification of the effort and sightings data was by Beaufort conditions, each category of Beaufort was assumed to correspond to a stratum, and each stratum provided an estimate of the whole population. Following Buckland *et al.* (1992), an averaged estimate of abundance weighted by effort was calculated as :

$$\hat{N}_{AV} = \frac{\sum_{i=1}^{b} L_i \hat{N}_i}{\sum_{i=1}^{b} L_i}$$

with variance

$$v\hat{a}r\,(\hat{N}_{AV}) = \frac{\sum_{i=1}^{b} \{L_i^2\, v\hat{a}r\,(\hat{N}_i)\}}{\left\{\sum_{i=1}^{b} L_i\right\}^2}$$

where $\mathbf{L_i}$ is the distance covered on effort for each of the ***b*** Beaufort categories or strata.

Cetacean schools can be detected as a function of its size ; if large schools are detected at greater distances, the average size of the schools can be positively biased. Detection of schools, **g (x)**, is the conditional probability of observing a school, given it is at a perpendicular distance **x** from the track line (Burnham *et al.* 1980). In order to check whether large schools of striped dolphins or fin whales were detected at greater distances than small schools, a regression of $\log_e$ school size against **g (x)** was computed. If the regression proved to be significant, a size-bias regression estimate (Buckland *et al.* 1993) was computed to calculate the expected average school size. Otherwise, the average size of schools was used and stratification by school size would be attempted, in a similar way as for Beaufort.

The distribution of $\hat{N}$ is positively skewed and a poor lower confidence limit can be obtained if it is assumed to be normally distributed. Following Burnham *et al.* (1987), confidence limits were calculated assuming a log-normal distribution of $\hat{N}$. The 95 % confidence interval was then estimated as :

$$(\hat{N} / C,\ C\hat{N})$$

where

$$C = \exp\left[1.96 \sqrt{\{v\hat{a}r\,(\log_e \hat{N})\}}\right]$$

and

$$v\hat{a}r\,(\log_e \hat{N}) = \log_e \left[1 + \frac{v\hat{a}r\,(\hat{N})}{\hat{N}^2}\right]$$

Standard errors and confidence intervals of density were estimated by re-sampling methods using a non-parametric bootstrap (Efron and Tibshirani 1993). Sampling units chosen were replicate lines, with a line being all the effort carried out in a single day of survey. One thousand bootstrap samples were generated and re-sampling was within strata.

Abundance estimates were computed using the software package DISTANCE V.2.1 (Laake *et al* 1994).

RESULTS

Survey

Weather conditions precluded the completion of the survey with a total coverage of transects. However, 1151.8 km (77 % of the track line) were searched on effort, providing a representative coverage of the area. A total of 133 cetacean groups were sighted, belonging to five species. Of these, 53 % where striped dolphins and 40 % where fin whales. The remaining 7 % (Table 1) included Risso's dolphins *(Grampus griseus)* (7 sightings), long-finned pilot whales *(Globicephala melas)* (1 sighting) and common dolphins *(Delphinus delphis)* (2 sightings), a species which is now considered rare in the area (Notarbartolo di Sciara *et al.* 1993).

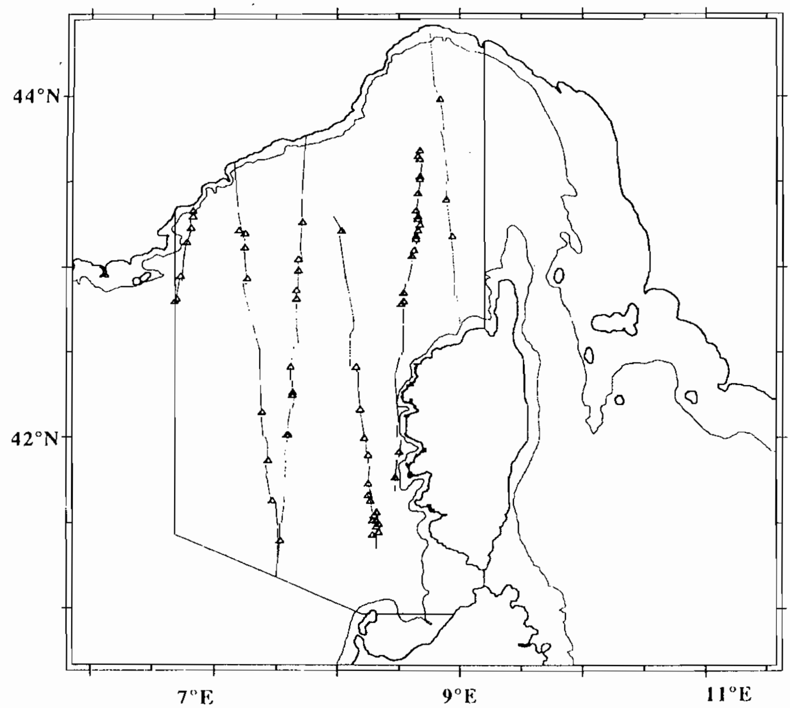
Figure 2 shows the cruise tracks surveyed on effort and the distribution of striped dolphin (a) and fin whale (b) groups sighted. The present paper deals with the abundance of these two species in the Corso-Ligurian Basin.

TABLE 1. – Number and size of cetacean schools detected during the survey.

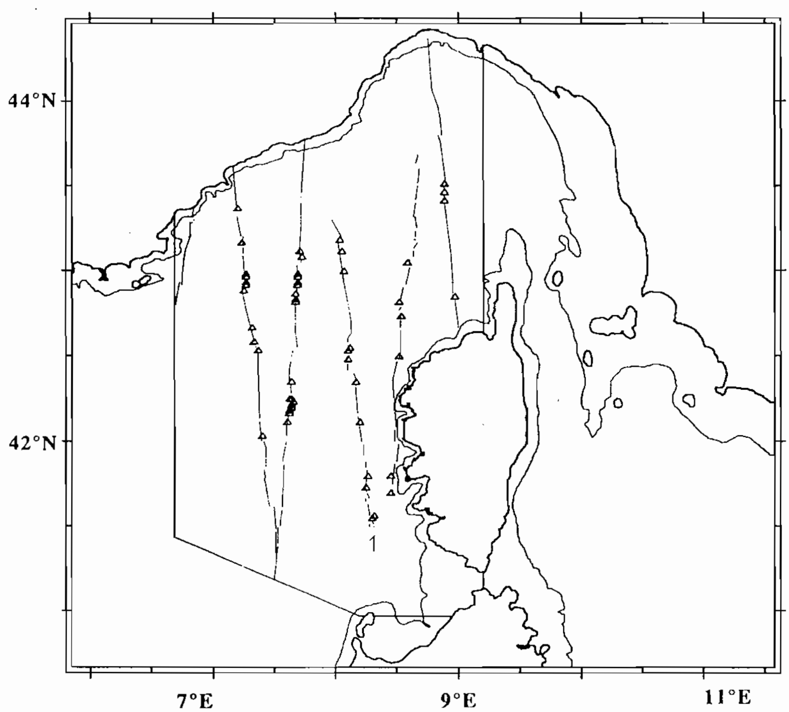
	Schools detected		School size (all schools)		
Species composition	Total	On-effort	Range	Mean	S.E.
Striped dolphin	70	67	2 - 150	22.5	3.2
Fin whale	53	48	1 - 3	1.5	0.1
Risso's dolphin	7	6	3 - 18	9.3	1.7
Common dolphin	2	2	3 - 40	21.5	13.1
Long-finned pilot whale	1	1	20	20	0

Fig. 2 *a*. – Distribution of striped dolphin schools sighted during the survey with cruise tracks covered on effort.

Fig. 2 *b*. – Distribution of fin whale schools sighted during the survey with cruise tracks covered on effort.



2*a*



2*b*

Abundance

Striped dolphins

Sixty-seven out of 70 sightings of striped dolphins were primary, and were used for the abundance estimate. Of these, 38 were sighted with sea conditions estimated at Beaufort 0, 21 with Beaufort 1, 7 with Beaufort 2 and 1 with Beaufort 3. Sightings were grouped in Beaufort categories 0 and 1-2 to obtain a reliable estimate of the *esw*. Table 2 summarizes the effects of Beaufort on the estimates of the 3 different parameters.

TABLE 2. – Striped dolphin sightings (after truncation), *esw*, encounter rate (n/L), mean school size and estimated expected school size by different Beaufort categories, with standard errors in parentheses.

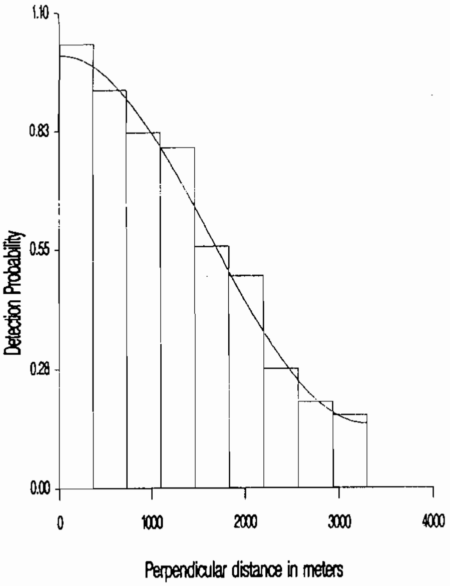
Beaufort	On-effort sightings	*esw* (m)	Encounter rate (schools / 100 km)	Mean school size	Estimated expected school size
0	32	1,892.4 (201.6)*	0.056 (0,013)*	20.15 (4.05)	13.77 (2.25)
1-2	26	1,325.8 (191.5)*	0,013 (0,003)*	21.50 (4.08)	18.35 (4.17)

Values with * in the same column are significantly different at the 5% level.

The *esw* differed significantly ($p < 0.05$) between Beaufort categories and, as expected, was wider for lower Beaufort. Therefore, several models were fitted to the perpendicular distances of each Beaufort category in turn. The best model chosen was a one term Fourier series (uniform key with a cosine adjustment of order 1) for Beaufort 0, and the best fit for Beaufort category 1-2 was a Half Normal model with no adjustment terms. Figures 3a and 3b show the plots of the histograms of the perpendicular distances of each Beaufort category data respectively, with the fitted detection curves.

As expected, the encounter rate was significantly higher ($p < 0.05$) at Beaufort 0 than at Beaufort 1-2, and was therefore estimated separately for each Beaufort category. By contrast, mean school size did not differ significantly among Beaufort categories. However, this parameter was also estimated separately for each sea-state, since it is unnecessary to assume that it is equal for each stratum, and there is little loss in precision from doing so.

Sizes of striped dolphin schools detected during the survey ranged between 2 and 150 animals, showing a positively skewed frequency distribution (Fig. 4). Using the mean of this distribution in the estimate of abundance would introduce a positive bias, on account of the effect of a few very large schools detected. Therefore, the use of a size-bias regression for the estimate of the expected school size seems justified. However, if schools are composed of loose aggregations of dolphins, the distance of the first aggregation detected can be closer of the track line than the geometric center of the school, compromising the use of the size-bias correction method. During the survey, large groups ($s > 20$) were encountered in tight aggregations of individuals with similar



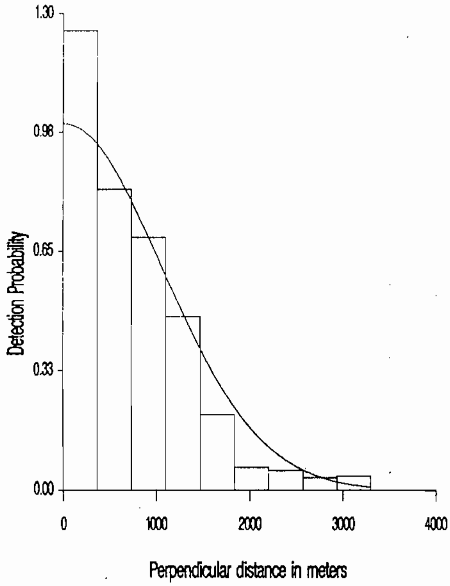


Fig. 3 *a*. – Fit of the one term Fourier series model to the striped dolphin perpendicular distance data under Beaufort 0.

Fig. 3 *b*. – Fit of the Half normal model to the striped dolphin perpendicular distance data under Beaufort 0.

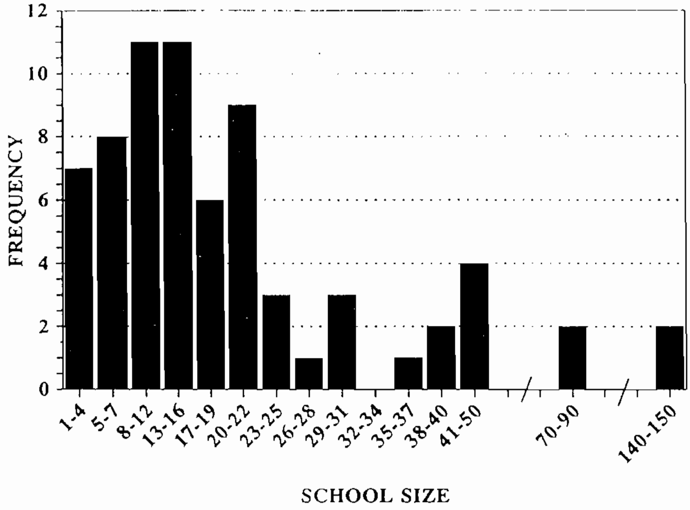


Fig. 4. – Frequency distribution of all the striped dolphin school sizes.

behaviour, and radial distances could be estimated to the geometric center of the school. Therefore, a size-bias regression was attempted.

The regression of $\log_e$ school size against **g (x)** was significant for each stratum, with $r = 0.389$ ($p = 0.01$) for Beaufort 0 and $r = -0.275$ ($p = 0.07$) for Beaufort 1-2. After these results, stratification by school size was not attempted and a size-bias regression estimate of the expected school size by stratum was computed. The estimated expected school size was 13.77 (SE = 2.25) for Beaufort 0 and 18.35 (SE = 4.17) animals for Beaufort 1-2.

Abundance was then estimated as 25,614 individuals, % CV (Coefficient of Variation) = 25.34, with 95 % confidence interval (15,377 - 42,658) (Table 3).

TABLE 3. – Summary of pooled estimates of density and abundance of striped dolphins in the western Ligurian sea, with standard errors, % coefficients of variation and 95 % confidence intervals.

Parameter	Point estimate	Standard error	% CV	95% confidence interval
Density of schools (schools.km^{-2})	0.0271	0.0055	19.71	0.0178 - 0.0411
Density of dolphins (dolphins.km^{-2})	0.4396	0.1114	25.34	0.2639 - 0.7321
Number of striped dolphins	25,614	6,490	25.34	15,377 - 42,658

Fin whales

Of the 53 fin whale sightings made, 48 were primary. To assess the effect of the sea state and size of schools detected on the estimate, categories of Beaufort and school size were selected, according to the number of sightings, in order to produce a reliable estimate of *esw*.

Table 4 shows the *esw*, encounter rate and mean school size for each Beaufort category, either 0, 1 and 2-4. Since no significant differences were found in *esw*, encounter rate and school size among Beaufort categories, stratification was considered unnecessary.

Table 5 shows the *esw* and encounter rate for each school size category selected, either 1 and 2-4 whales. According to that table, the *esw* is almost identical for both categories so that stratification by school size for this parameter seemed unnecessary too. Moreover, sample size considerations precluded the estimate of a reliable *esw* for every stratum. The encounter rate was slightly higher for detections of 2 or more whales than for detections of single animals but no significant differences were found. Therefore, *esw* and encounter rates were not stratified by school size categories.

After these results a single detection function was fitted to all perpendicular distances, pooling across sea states and school sizes. The best model fit was a one-term Fourier series (uniform key with a cosine adjustment term of order 1) (Fig. 5).

The regression of $\log_e$ school size against **g (x)** was not significant ($r = -0.1287$, $p = 0.19$). Therefore, a size-bias regression was not attempted and the average size of schools was used instead.

Abundance was then estimated as 901 fin whales, % CV = 21.77, with 95 % confidence interval (591-1,374) (Table 6).

TABLE 4. – Fin whale sightings (after truncation), *esw*, encounter rate (n/L), mean school size and estimated expected school size by different Beaufort categories, with standard errors in parentheses.

Beaufort	On-effort sightings	*esw* (m)	Encounter rate (schools / 100 km)	Mean school size
0	14	2,125 (++)	0.0233 (0.0109)	1.29 (0.57)
1	19	1,657 (231.9)	0.0088 (0.0019)	1.69 (0.26)
2-4	15	1,760 (245.1)	0.0085 (0.0018)	1.57 (0.15)

Values with * in the same column are significantly different at the 5% level.
(++) Unreliable estimate of *esw* standard error.

TABLE 5. – Fin whale sightings (after truncation), *esw* and encounter rate (n/L) by different school size categories, with standard errors in parentheses.

School size	On-effort sightings	*esw* (m)	Encounter rate (schools / 100 km)
1	26	1,956.3 (215.1)	0.0019 (0.0004)
2-4	19	1,952.5 (248.9)	0.0014 (0.0004)

Values with * in the same column are significantly different at the 5% level.

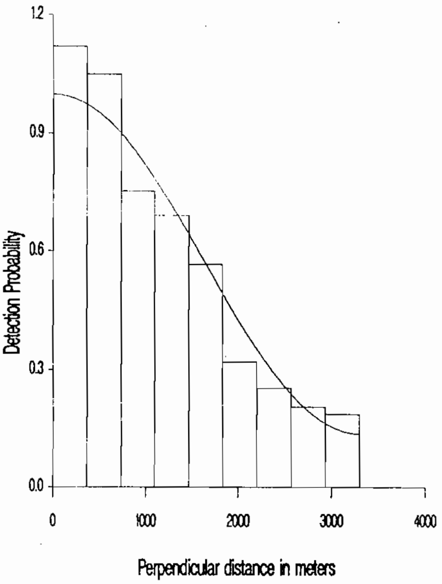


Fig. 5. – Fit of the one terme Fourier series to the pooled fin whale perpendicular distance data.

TABLE 6. – Summary of pooled estimates of density and abundance of fin whales in the western Ligurian sea, with standard errors, % coefficients of variation and 95 % confidence intervals.

Parameter	Point estimate	Standard error	% CV	95% confidence interval
Density of schools (schools.km^{-2})	0.0098	0.0016	17.00	0.0069 - 0.0138
Density of whales.km^{-2})	0.0155	0.0033	21.77	0.01014 - 0.0235
Number of fin whales	901	196.1	21.77	591 - 1,374

DISCUSSION

Striped dolphins

Three out of 70 sightings of striped dolphins were made off effort, but were not secondary (those made while the approach for the confirmation of primary sightings). Therefore, it is likely that very few sightings were lost because of the searching mode employed. The schooling behavior and sighting cues of striped dolphins made detection of schools while on effort very easy, and it can be assumed that the probability of detection on the track line is unity. Therefore, it is unlikely that the population is underestimated.

In a previous independent survey, conducted in 1991, striped dolphins density in the western Mediterranean basin was estimated at 0.198 (SE = 0.065) individuals/km^2 by Forcada *et al.* (1994) and at 0.205 (SE = 0.045) individuals/km^2 for the northwestern Mediterranean basin by Forcada *et al.* (in press *b*). The estimated density of 0.439 (SE = 0.111) striped dolphins/km^2 during the present survey is 63 % higher than the density of the northwestern Mediterranean in 1991 and 65 % higher than the density of the western Mediterranean in 1991. In both cases, the density estimated in the present survey is significantly higher ($p < 0.05$) than the densities found in 1991. These numbers highlight the importance of the Corso-Ligurian Basin for striped dolphins, as one of the most populated areas of the western Mediterranean.

The present survey was conducted one year after a similar survey which was carried out over the entire western Mediterranean (Forcada *et al.* 1994), following a severe viral epizootic that had hit the local striped dolphin population (Aguilar and Raga 1993). However, pelagic dolphin population trends cannot be easily assessed in open populations by means of comparisons between short-term replicate surveys, given the lack of information about dolphin movements and habitat use obtained during those surveys. The repeating of such surveys should therefore be undertaken in the long term to monitor trends in abundance and to evaluate the changes of the sanctuary and of the population itself.

Fin whales

All whales on or close to the track line were assumed to be detected, as the most commonly used sighting cue was the blow, which in this species is high and very conspicuous from the distance. Moreover, the survey mode employed allowed species identification of all whales sighted. However, 5 whales were sighted out of the cruise track, during the approach to confirm other sightings. These secondary sightings were caused by the high number of whale assemblages encountered, distributed in loose groups throughout part of the surveyed area. The exclusion of these sightings from the analysis migh result in a slight underestimation of the abundance of whales.

Density of fin whales in the Corso-Ligurian Basin estimated in the present survey did not differ significantly from the density found in 1991 in the entire western Mediterranean by Forcada *et al.* (*in press a*). In that survey, however, all fin whales were encountered in the Liguro-Provençal Basin, which includes the area covered in the 1992 survey. Densities of fin whales encountered in the Corso-Ligurian Basin are in the upper range of the densities estimated for other populations of that species sighted in the North Atlantic (Sanpera and Jover 1989, Hain *et al.* 1992), emphasizing the importance of the Corso-Ligurian Basin for the Mediterranean fin whale population.

The survey area is a major summer feeding ground for Mediterranean fin whales (Zanardelli *et al.* 1992). Seasonal variations of whale abundance and distribution within the sanctuary area should be described by replicating surveys in different times of the year. Furthermore, the distribution of whales within the study area is affected by the patchy distribution of their main prey, the euphausiid *Meganyctiphanes norvegica* (Orsi-Relini *et al.* 1992, Forcada *et al. in press a*), which may drastically change from one year to the next according to changing oceanographic conditions. Replicates of this survey in the medium term would thus provide a helpful background to monitor trends of fin whale across-years abundance in the sanctuary area.

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