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Preliminary patterns of distribution and abundance of loggerhead sea turtles, *Caretta caretta*, around Columbretes Islands Marine Reserve, Spanish Mediterranean

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Abstract Aerial surveys were conducted to estimate the abundance and distribution of loggerhead turtles (*Caretta caretta*) in the Columbretes Islands Marine Reserve and surrounding waters (western Mediterranean). Four surveys were carried out during 2000 and 2001, following the line transect methodology. Loggerheads appeared to be present at high densities in the area throughout the whole year, although density varied between seasons, being more abundant during the spring. Mean density in the study area was 0.322 turtles/km^2 (range 0.200–0.516) and the mean abundance was 1,324 turtles (range 825–2,124). The turtles were distributed homogeneously throughout the study area, we found no difference in loggerhead density between the water around the reserve and that in the rest of the study area. Current conservation measures planned by the local authorities, which include increasing the area of the reserve, would be very positive for the conservation of this stock.

Introduction

The loggerhead sea turtle, *Caretta caretta*, is a species with worldwide distribution that is currently classified as "endangered" by the 2000 IUCN Red List of Threatened Species (Hilton-Taylor 2000). Conservation in foraging habitats is considered a priority for population management and survival of sea turtles (Bjørndal 1999). Western Mediterranean waters provide important feeding grounds for juvenile loggerheads from two different rookeries, the Mediterranean and the western Atlantic (Laurent et al. 1998). There are several human threats to this species in these waters (Margaritoulis et al. 2003), fisheries and marine pollution being particularly serious. A high occurrence of marine debris has been found in the gut contents of Spanish Mediterranean loggerheads (Tomás et al. 2002). Solid debris has several lethal or sublethal effects on sea turtles and can seriously affect their populations (Bjørndal et al. 1994). But the major threat in the western Mediterranean is the incidental capture in fisheries (Laurent 1997). It is estimated that the Spanish long-line fishery is responsible for about 20,000 loggerhead captures each year with a mortality rate of at least 20% (Aguilar et al. 1995). A recent study (Camiñas and Valeiras 2001; Camiñas 2002) estimated that, in 2000, more than 29,000 loggerheads were captured by the Spanish long-line fishery. As a result, the Spanish Mediterranean is an interesting area in which to investigate measures for the conservation of loggerhead turtles. To make recommendations for conservation, it was necessary to gain information about turtles in this area, including aspects of their biology, conservation status and threats. In particular, information about their abundance and distribution is critical for the management of sea turtles (Gerrodette and Taylor 1999). To date, the only information available on abundance and distribution of loggerheads in Spanish waters is limited to opportunistic sampling from captures by the long-line fishery (Camiñas and de la Serna 1995). This type of sampling can incorporate large biases related to sampling within different fishing areas and with different fishing effort in each season. In contrast, the line transect methodology (Buckland et al. 1993, 2001) is more appropriate for studying abundance and distribution of wild animals. This method provides robust abundance estimations with less bias and allows the evaluation of the variance associated with natural variability as well as with the processes of gathering information. In addition,

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aerial surveys may be the only practical approach to obtaining abundance estimations for certain animals over extensive areas (Bayliss 1986). Line transect aerial surveys have been used previously and proved to be useful for the estimation of sea turtle abundance in other feeding areas (Shoop and Kenney 1992; Epperly et al. 1995a, 1995b; Braun and Epperly 1996; Davis and Fargion 1996; Preen et al. 1997; Davis et al. 2000).

Loggerhead turtles have been cited as being present around the Columbretes Islands (Spanish Mediterranean) year round (Camiñas and de la Serna 1995), so we chose the waters surrounding these islands for preliminary study. In addition, the Columbretes Islands are protected as a Marine Reserve, with all commercial and recreational fishery being forbidden in the area. This fact makes this zone an interesting study area, since it could be affecting the distribution of loggerheads or it could be the reason for the presence of turtles around the islands throughout the year. Finally, there are some conservation proposals for this zone, which include increasing the area under protection. Information about the abundance and distribution of an endangered species, such as the loggerhead turtle, may provide useful information to guide such decisions.

In this study we estimate the absolute abundance and distribution of loggerhead sea turtle in the waters around the Columbretes Islands, in different seasons, using line transect aerial surveys. We also tried to determine whether there is any effect of the marine reserve on the density and the distribution of turtles.

Material and methods

Study area

Columbretes (39°54′N, 0°43′E) is an archipelago of volcanic origin 65 km from mainland Spain. The marine reserve includes these islands and the waters surrounding them, with a total surface of 44 km^2.

The study area comprises the waters bound by the co-ordinates: 40°15′N, 0°18′E; 39°52′N, 1°02′E; 39°26′N, 0°39′30″E; and 39°49′N, 0°03′W. The marine reserve is within these same co-ordinates. This zone stretches as far as 93 km from the coast, with depths ranging from 30 m to 1,000 m. The total area studied is approximately 4,107 km^2 . We hypothesised that the marine reserve could affect the abundance and distribution of sea turtles in the zone. To evaluate this effect, the study area was divided in two subareas: subarea A comprised the marine reserve and surrounding waters (9 km around the reserve) making a total surface of 616 km^2; subarea B comprised the rest of the area, with a surface of 3,491 km^2 (Fig. 1).

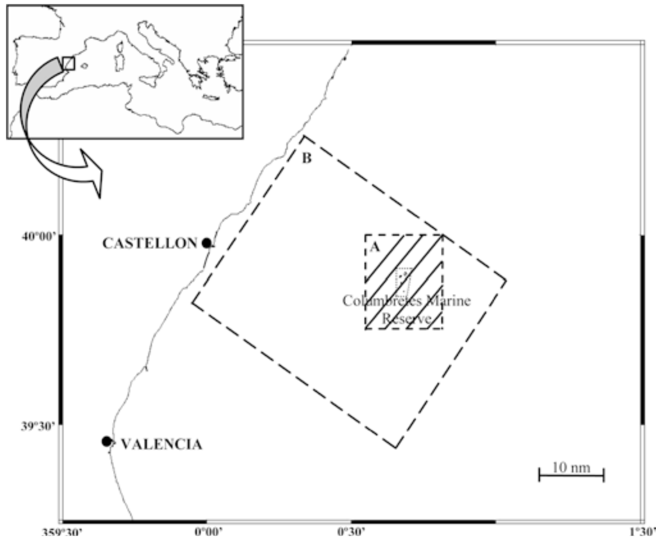

Fig. 1 Study area of loggerhead aerial surveys divided in two subareas: subarea A, comprising the marine reserve and surrounding waters; and subarea B, comprising the rest of the area

Aerial surveys

Four seasonal surveys were conducted following the line transect methodology: 2 June 2000 (spring season), 19 July 2000 (summer season), 22 February 2001 (winter season) and 25 July 2001 (summer season). The winter season was considered to be the first three months of the year, January–March; spring, April–June; summer, July–September and autumn, October–December. Table 1 shows the total effort and the effort by subarea for each flight.

The track design was different in the two years, but, in both designs, transects were oriented approximately perpendicular to the bottom slope. In 2000, the transects followed a systematic saw-tooth pattern, at random, covering approximately 6.5% of the total area (Fig. 2, design 1). In 2001, the track design was changed to evenly spaced (11 km) parallel lines in order to cover the surveyed area homogeneously. This new design increased the coverage to 7.5% (Fig. 2, design 2).

Surveys were taken from a high-wing aircraft (“push-pull” Cessna 337) that allowed a side-viewing platform. Thus, the flight line was not visible. Survey altitude was maintained at 152 m and transects were flown at a groundspeed of approximately 166 km/h (90 knots). This altitude and groundspeed are the most adequate for aerial surveys of sea turtle feeding habitats (Henwood and Epperly 1999).

The standard crew consisted of the pilot, a recorder, and two observers positioned behind them on each side of the plane. The recorder took note of data reported by the observers: species, number of animals, location (obtained from a GPS), time, observer making the sighting, angle between the horizon and the target, and environmental conditions, including Beaufort sea state, sun glare, percent cloud cover and visibility. Furthermore, environmental

Table 1 A summary of aerial sighting surveys carried out around Columbretes Islands Marine Reserve with the effort (in kilometres of flight path) and the number (n) of sea turtles sighted on each flight, by subarea (A and B)

Date	Design type	Subarea A		Subarea B		Total	
		Effort	n	Effort	n	Effort	n
2 June 2000	Design 1	82.9	11	240.8	47	323.7	58
19 July 2000	Design 1	80.5	7	243.3	11	323.8	18
22 February 2001	Design 2	55.5	3	314.5	30	370.0	33
25 July 2001	Design 2	57.7	3	312.3	16	370.0	19
Total		276.6	24	1,111.0	104	1,387.5	128

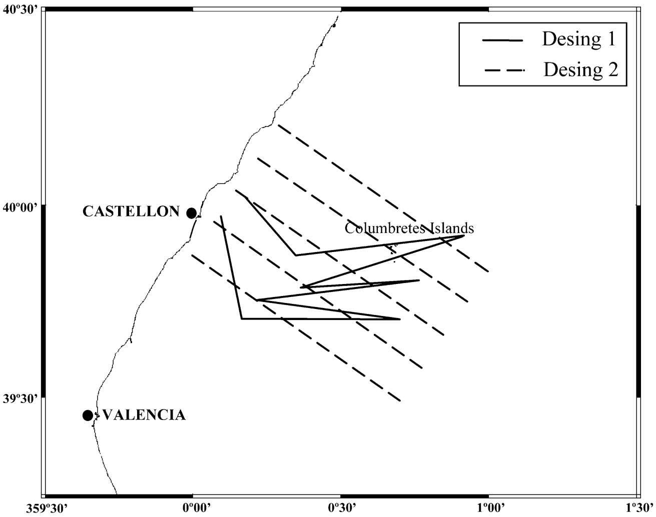

Fig. 2 The two different line transect designs for aerial surveys of loggerhead turtles in the study area

conditions were updated whenever changes occurred and GPS provided a continuous record of position (updated every few seconds). The angle between the horizon and the animal was taken by a clinometer. We used this angle and the altitude of the plane to calculate the distance from the trackline to the animal. We conducted surveys only in Beaufort (wind-speed scale) < 3, because sightability of turtles is reduced in bad weather conditions (Marsh 1990).

Data analysis

Turtle density (D) was estimated using the standard distance sampling methods applied to single animals (Buckland et al. 1993, 2001). Data were analysed using the programme DISTANCE 4.0 (Thomas et al. 2001). Essentially, the programme fits a detection-probability function to the distance–frequency histogram, and this function is used to estimate the probability density function evaluated at zero distance, $f(0)$. Then, the density is given as:

$$D = \frac{nf(0)}{2L} \quad (1)$$

where n is the number of sightings on effort and L is the total search effort.

We pooled all the observations to estimate $f(0)$ owing to the low number of sightings recorded on some flights. Furthermore, we subtracted 86 m (the blind distance under the plane due to the flat windows) from all the sighting distances.

Following Buckland et al. (1993, 2001), three potential functions were initially considered to fit the distance histogram: uniform, half-normal and hazard-rate, together with various adjustment terms. For each model the number of the adjustment terms was selected through the likelihood-ratio test ($\alpha = 0.05$), and finally models were compared with Aikake information criteria (AIC). Density estimates were made for the model with the smallest AIC (Buckland et al. 1993, 2001). Variances of estimated density, abundance and encounter rate were calculated by non-parametric bootstrap (replicates 1,000), using a transect line as a sampling unit. We calculated an average density in the study area from the densities of all the flights weighted by the total effort of each flight.

To estimate the density inside and outside the marine reserve, data were analysed independently in each subarea, but using the same $f(0)$ for both strata.

Results

We surveyed 1,387 km in the four flights; 128 loggerhead turtles were seen over the sampling period (Table 1). The position of turtles sighted during sampling in each flight is shown in Fig. 3. An additional 16 turtles were seen during non-sampling periods, but these were not included in the analysis. No estimation of body size could be made, owing to the high speed of the plane. However, based on stranding data (University of Valencia, unpublished data) and incidental captures

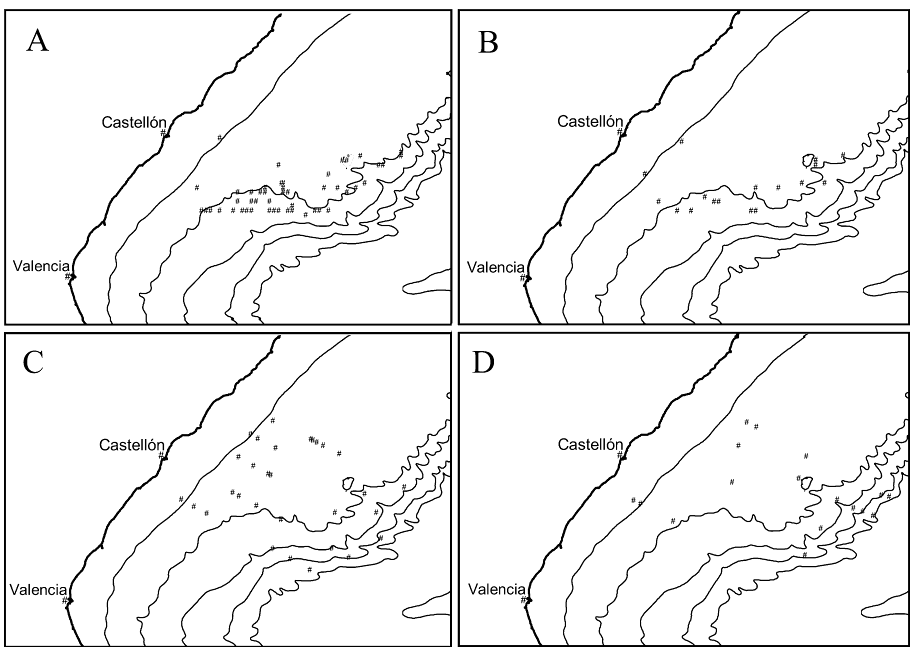

Fig. 3A–D Sightings of loggerhead turtles obtained during sampling effort per flight. **A** flight of 2 June 2000; **B** flight of 19 July 2000; **C** flight of 22 February 2001; **D** flight of 25 July 2001

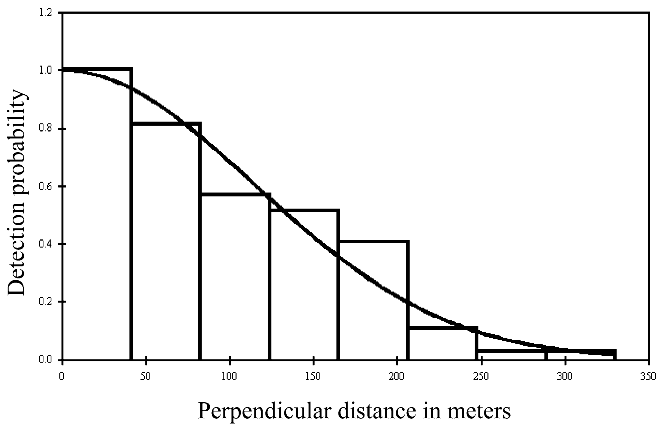

Fig. 4 Frequency distribution of perpendicular distances (minus 86 m) from the line transect to loggerhead sightings. Continuous curve represents the detection probability function based on fit of half-normal model to perpendicular distance data

(Camiñas 1997; Aguilar et al. 1995) we know that most of the turtles in the area are juveniles.

The detection model finally selected was the half-normal, with no adjustment terms arising from the comparison of the Akaike's Information Criterion (AIC 445.33) and the likelihood ratio test. The detection function obtained with this model was:

Table 2 Values of the detection probability obtained from turtle sightings during all flights; f(0) value of probability density function at zero (m^{-1}); p probability of observing an object in defined area; *ES*W effective strip width (in metres); *%C*V percentage of the coefficient of variation;*df* degrees of freedom; *C*I confidence interval (95%)

	Estimate	%CV	*df*	95% CI
f(0)	0.007	6.7	127	0.0061–0.0080
p	0.434	6.7	127	0.380–0.496
ESW	143.25	6.7	127	125.49–163.52

$$k(y) = e^{-\left(y^2/2 \times A_1^2\right)} \quad \text{with } A_1 = 114.8 \qquad (2)$$

The distance–frequency histogram and the result of the detection probability are shown in Fig. 4 and Table 2.

In the whole study area, loggerhead densities estimated per flight ranged from 0.18 turtles/km^2 to 0.62 turtles/km^2 and abundances ranged from 737 to 2,571 animals (Table 3). The highest density was obtained in June 2000 and the lowest in July 2001. Contrary to what was expected, we also obtained a high density of animals in the winter survey (February). The average density in the study area was 0.322 turtles/km^2 (95% CI 0.200–0.516) and the mean abundance was 1,324 turtles (95% CI 825–2,124).

Table 3 Abundance estimates and related statistics for loggerhead turtles in the study area, by flight. Estimates are obtained both empirically and using bootstraps.*E*R encounter rate (number of turtles sighted per kilometre of flight path); D density (number of turtles sighted per square kilometre); N abundance (number of turtles sighted);*%C*V percentage of the coefficient of variation; *df* degrees of freedom;*C*I confidence interval (95%)

Flight	Parameter	Estimate		%CV	*df*	95% CI
2 June 2000	ER	Empirical	0.179	24.23	7	0.102–0.315
		Bootstrap	0.179	22.52	7	0.106–0.303
	D	Empirical	0.625	25.14	8	0.353–0.110
		Bootstrap	0.624	23.06	8	0.370–1.106
	N	Empirical	2,571	25.14	8	1,453–4,550
		Bootstrap	2,571	23.06	8	1,521–4,346
19 July 2000	ER	Empirical	0.056	15.91	7	0.038–0.081
		Bootstrap	0.056	15.44	7	0.039–0.080
	D	Empirical	0.194	17.26	10	0.132–0.284
		Bootstrap	0.194	18.13	10	0.130–0.289
	N	Empirical	798	17.26	10	545–1,169
		Bootstrap	798	18.12	10	535–1,191
22 February 2001	ER	Empirical	0.089	7.73	4	0.072–0.110
		Bootstrap	0.089	6.7	4	0.074–0.107
	D	Empirical	0.311	10.22	12	0.249–0.388
		Bootstrap	0.311	10.17	12	0.249–0.388
	N	Empirical	1,280	10.22	12	1,025–1,598
		Bootstrap	1,280	10.17	12	1,026–1,597
25 July 2001	ER	Empirical	0.051	32.66	4	0.021–0.124
		Bootstrap	0.051	29.31	4	0.023–0.114
	D	Empirical	0.179	33.34	4	0.073–0.441
		Bootstrap	0.179	30.38	4	0.078–0.408
	N	Empirical	737	33.34	4	299–1,815
		Bootstrap	737	30.38	4	323–1,682
Average estimates	D	Empirical	0.322	32.15	3	0.119–0.873
		Bootstrap	0.322	14.94	3	0.200–0.516
	N	Empirical	1,324	32.15	3	488–3,592
		Bootstrap	1,324	14.94	3	825–2,124

Table 4 Abundance estimates of loggerhead turtles and related statistics, by subarea (A and B). Estimates are obtained both empirically and using bootstraps. *E*R encounter rate (number of turtles sighted per kilometre of flight path); D density (number of turtles sighted per square kilometre); N abundance (number of turtles sighted); %*C*V percentage of the coefficient of variation; *df* degrees of freedom;*C*I confidence interval (95%)

Parameter	Estimate		%CV	*df*	95% CI
Subarea A					
ER	Empirical	0.085	14.15	13	0.063–0.116
	Bootstrap	0.085	13.69	13	0.064–0.114
D	Empirical	0.297	15.66	19	0.215–0.412
	Bootstrap	0.297	16.16	19	0.213–0.416
N	Empirical	184	15.66	19	133–254
	Bootstrap	184	16.13	19	132–257
Subarea B					
ER	Empirical	0.094	18.66	25	0.064–0.137
	Bootstrap	0.094	19.26	25	0.063–0.139
D	Empirical	0.328	19.83	32	0.220–0.489
	Bootstrap	0.328	19.13	32	0.223–0.482
N	Empirical	1,147	19.83	32	769–1,710
	Bootstrap	1,147	19.13	32	780–1,688

The mean densities of the two subareas, A and B, were quite similar and the 95% confidence intervals of both subareas overlapped substantially (Table 4).

Discussion

This is the first estimation of density of a loggerhead turtle stock in the western Mediterranean. Our results are comparable to those of other similar studies of foraging habitats of sea turtles (Table 5). However, when we make comparisons with specific studies on loggerhead turtles (Davis and Fargion 1996; Davis et al. 2000), the density values found in the present study are higher by at least one order of magnitude, with similar or lower coefficients of variation. Nevertheless, the estimates reported here should be considered as minimum estimates. Line transect models assume that the probability of sighting an animal on the trackline is 1, but a high percentage of sea turtles are below the surface and not visible to observers. Studies of loggerhead diving behaviour in the western Mediterranean waters are not available. Consequently there is a lack of information on surfacing and diving times that does not allow corrections to be made for these estimates. Studies of loggerheads in inshore waters in the Gulf of Mexico (Renaud and Carpenter 1994) and in the south-eastern United States (Nelson 1996 and references therein) show that the percentage of time that turtles remained at the surface varies between 4 and 20%. Another study, carried out in Atlantic offshore waters, indicates that, in the pelagic stage, loggerheads remain at the surface between 30 and 40% of the time (Dellinger and Freitas 1999). Based on these data we may assume that turtles in our study area will spend less than 50% of time at the surface; thus the density and abundance in the area is very likely to be at least twice the estimated values.

Our data show that loggerhead turtles are present in high numbers in the study area during winter, spring and summer, suggesting that they remain in the area throughout the whole year. Camiñas and de la Serna (1995) proposed that, during the colder months (December–March), the stock of loggerheads in the western Mediterranean was reduced to a few specimens around the Balearic and the Columbretes Islands. However, our results show that the densities in the winter survey are similar or even greater than those present in summer (Table 3). In addition, during the present study, we found that turtles are distributed throughout the study area, not only around the islands. As the study of Camiñas and de la Serna (1995) was based on the analysis of by-catch, such discrepancy in the results could be a consequence of the lower fishing effort during the colder months, which resulted in underestimation of this stock.

These results are preliminary and more surveys are needed to make comparisons between seasons and to explore changes in density and distribution, particularly in autumn. Nevertheless, our data suggest that some seasonal effects are apparent, with a greater number of turtles in spring. This increase is possibly related to the entry of loggerheads from the Atlantic and from the central and eastern Mediterranean to central Spanish waters at the beginning of spring (April), as suggested by Camiñas and de la Serna (1995).

No significant differences were found in density between the two subareas. This high density throughout the study area may indicate that the marine reserve has no effect on the distribution of loggerheads or that the area influenced by the marine reserve is higher than expected. The marine reserve could provide food sources for this species, not only in the vicinity of the islands, but over a larger area. In addition, the fishing fleet may also contribute to the homogeneous distribution of turtles. Tomás et al. (2001) suggested that discarded by-catch is exploited as the main food resource by loggerheads in the western Mediterranean. If that is the case, the observed distribution pattern could be explained by the availability of food in the form of discards from high numbers of boats fishing outside the reserve.

Table 5 Comparison of the results of the present study with those of other aerial surveys of sea turtles. The measures of dispersion are given by the coefficient of variation (*CV*) or by the standard error (*SE*), depending on the study. In the North Carolina area it was estimated that 80% of sea turtles were *Caretta caretta*

Study area	Depth	Methodology	Species	Density	Measure of dispersion		Reference
					CV	SE	
Northern Gulf of Mexico	Continental self	Line transect	*Caretta caretta*	0.039–0.042	0.23–0.30	–	Davis et al. 2000
Northern Gulf of Mexico	Continental slope	Line transect	*Caretta caretta*	0.0003–0.004	0.27–0.77	–	Davis et al. 2000
North-central and western Gulf of Mexico	Continental slope	Line transect	*Caretta caretta*	0.0005	0.29	–	Davis and Fargion 1996
North Carolina	Inshore waters	Strip transect	Turtles	0–0.30	–	0.6–7.6	Epperly et al. 1995a
North Carolina	Inshore waters	Line transect	Turtles	0–0.37	–	0.5–11.6	Epperly et al. 1995a
North Carolina	Continental self	Strip transect	Turtles	0–0.123	–	0.8–6.2	Epperly et al. 1995b
North Carolina	Continental self	Line transect	Turtles	0–0.176	–	0.9–8.5	Epperly et al. 1995b
South Georgia	Estuarine and nearshore	Strip transect	Turtles	0–0.62	–	0.05–0.41	Braun and Epperly 1996
Central-western Australia	Inshore waters	Strip transect	Turtles	0.43–4.9	–	0.05–0.83	Preen et al. 1997
Western Mediterranean	Offshore waters	Line transect	*Caretta caretta*	0.18–0.63	0.11–0.30	0.03–0.14	Present study

Currently, the regional and national governments plan to extend the protected area of Columbretes and to reclassify it as a Marine National Park. The high density of loggerheads throughout the year and over the entire survey area leads us to conclude that the whole area is important for this stock and that the expansion of the reserve, in any direction, will favour its conservation. Furthermore, a change of status from Marine Reserve to Marine National Park will also help, because recreational activities will also be controlled under this legislation. This measure must be complemented with other policies outside the reserve where we also found a high turtle density. These politics should be aimed at decreasing incidental captures and reducing the dumping of human waste, both from land and from boats.

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