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Abundance and distribution of the endangered loggerhead turtle in Spanish Mediterranean waters and the conservation implications

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loggerhead turtle; abundance; distribution; Western Mediterranean; aerial survey.

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Abstract

During 2 years (2001–2003), we performed seasonal aerial surveys in the central Spanish Mediterranean following the transect line methodology in order to determine the abundance and distribution patterns of loggerhead turtles *Caretta caretta*. We surveyed a total of 16 700 km, accounting for 770 turtle sightings. Loggerhead turtles were present with high abundance all year round. No seasonal differences in abundance were found, except in spring 2001, where the density of turtles was higher than in the other seasons. Our results show that the Western Mediterranean is not a 'summer' feeding area as proposed previously, as a high number of turtles are present throughout the year. The average surface density of turtles in the whole study area was 0.21 turtles km^{-2} [95% confidence interval (CI): 0.17–0.25], and the mean abundance was 6653 turtles (95% CI: 5514–8027). The data relate to the number of turtles on the surface only, as diving turtles escape observation. Correcting our estimations of diving behaviour data in the area, the absolute abundance was 18 954 turtles (95% CI: 6679–53 786). Bearing in mind that around 25 000 loggerheads are caught per year in the Spanish Mediterranean, our results indicate that accidental captures seem to be a significant threat for this species, and conservation measures have to be implemented to avoid a non-sustainable situation.

Introduction

Three species of sea turtles can be found regularly in the Mediterranean Sea: the loggerhead turtle *Caretta caretta*, the green turtle *Chelonia mydas* and the leatherback turtle *Dermochelys coriacea*. Only two of them, the loggerhead and the green turtle, nest in this area, and nesting is confined almost exclusively to the eastern basin (Kasparek, Godley & Broderick, 2001; Margaritoulis *et al*., 2003). The loggerhead turtle is the most abundant sea turtle in the Mediterranean. In the juvenile stage, this species inhabits the pelagic habitats of both the western and the eastern basin. The Western Mediterranean is a very important feeding area for juvenile and subadult loggerhead sea turtles, bringing together individuals originating from the Mediterranean eastern basin, and from the Atlantic (Laurent *et al*., 1998). In these waters, loggerhead populations are subjected to several anthropogenic threats including marine pollution, collisions with boats, debris ingestion and habitat degradation (Tomás *et al*., 2002; Margaritoulis *et al*., 2003). However, the major anthropogenic mortality factor affecting loggerhead sea turtles in the region is the incidental capture by fisheries. Studies in different Mediterranean regions have estimated the highest incidental captures rate around the Balearic Islands (Spanish Mediterranean) (Margaritoulis *et al*., 2003 and references therein). About 20 000 loggerhead turtles are estimated to be caught each year by the Spanish long-line fishery, with a mortality rate of at least 34% (Aguilar, Mas & Pastor, 1995). The latest study (Camiñas, 2002) estimated that more than 29 000 loggerheads were captured in 2000 by the Spanish long-line fishery. At present, the loggerhead turtle is classified worldwide as endangered (IUCN, 2004) and as a 'priority' species according to the Habitats Directive of the European Union. Thus, urgent conservation measures are needed. Currently, conservation research concentrates on estimating and reducing the number of loggerhead turtles incidentally captured and killed by fisheries, but no study has been developed to estimate the absolute abundance of turtles. The estimation of the number of killed turtles cannot be used to assess the impact of accidental catch unless the total number of turtles present is known (Gerrodette & Taylor, 1999). In addition, other basic information about the biology of this species, such as distribution patterns or temporal changes, is also needed to implement conservation measures.

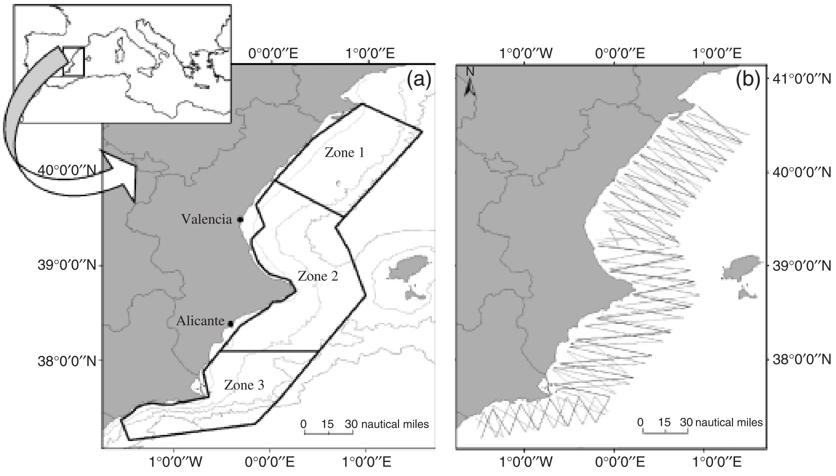

Figure 1 Study area of loggerhead sea turtle where aerial surveys were conducted. (a) Study area divided in to three zones to study geographical changes. The 50, 200, 1000 and 2000 m isobaths are shown. (b) Survey designs carried out during the two years of the study.

Information on the biology of the Mediterranean loggerhead turtle in the pelagic stage is scarce as this habitat is difficult to access. No specific survey has been carried out to study the density or the distribution patterns of loggerhead turtles in the Western Mediterranean. Information on these aspects is limited to incidental captures and data from strandings (Camiñas & de la Serna, 1995; Tomás, Fernández & Raga, 2003), but these data can incorporate large biases because of the spatial and temporal differences on fishing effort, mortality rates or water currents.

In 2000, the Spanish Ministry of Environment started a 3-year project to identify areas of interest for cetacean conservation in the Spanish Mediterranean. Within this project, seasonal surveys of cetaceans in the waters of central east Spain were conducted from the air, using the line transect method. Thereby, information was also gained on sea turtles. The aims of the present study were as follows: (1) to obtain an absolute abundance estimate of loggerhead turtles present in the Western Mediterranean for conservation applications, (2) to ascertain seasonal changes in the density of turtles in order to better understand the migratory movements of this species in these waters and (3) to identify high-density areas.

Materials and methods

Study area and survey design

The study area comprised the Spanish Mediterranean waters between the Ebro Delta (40°41′N–0°53′E) and Aguilas (37°22′N–1°38′W), extending from the coastline to *c*. the 1000-m isobath. In the southern zone, the area was extended to the 2800-m isobath because of the narrow continental shelf. The overall area was *c*. 32 000 km^2 (Fig. 1a).

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

In order to study geographic density differences, the area was poststratified into three zones (north to south) (Fig. 1a). The limits of the zones were set based on oceanographic features; i.e. sea floor contour and water currents. Zone 1 is characterized by a wide continental shelf and includes the Columbretes Islands Marine Reserve. Zone 2 is characterized by a medium width shelf and an important water current passing between the island of Ibiza and the Iberian Peninsula. Zone 3 is characterized by a very narrow shelf and a step slope to the shelf edge close to the coast (Fig. 1a).

Aerial surveys

Seasonal aerial surveys were conducted following the transect line methodology (Buckland *et al*., 2001), from May 2001 to March 2003 (Table 1). Seasons were determined by means of water temperature: Winter (January–March), spring (April–June), summer (July–September) and autumn (October–December).

Surveys were taken from a high-wing aircraft (‘push-pull’ Cessna 337) with flat windows as described in Gómez de Segura *et al*. (2003). Altitude was maintained at 152 m (500 ft) and transects were flown at a groundspeed of *c*. 166 km h^{-1} (90 kn). 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 the species, number of animals, location (obtained with a GPS), time and angle between the horizon and the target. The angle between the horizon and the animal was estimated using a hand-held clinometer that, in conjunction with aircraft altitude, provided an estimate of the perpendicular distance to the animal. Environmental conditions, including Beaufort sea state, were also updated at the beginning of the transect and whenever changes occurred. We conducted surveys only at Beaufort sea state ≤ 3 because visibility is lower in bad weather conditions. GPS provided a continuous record of position (updated every few seconds).

Data analysis

Turtle surface density (D) was estimated using the standard distance sampling methods applied to single animals (Buckland *et al.*, 2001) and the program DISTANCE 4.1 (Thomas *et al.*, 2001). The program fits a detection 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:

$$D = \frac{n\, f(0)}{2\, l\, g(0)}$$

where n is the number of sightings on effort, l is the total search effort and $g(0)$ is the probability of sighting an animal at zero distance. The encounter rate (n/l) is the number of sightings per km surveyed and it is used as a relative density measure. Variances of estimated densities were calculated empirically by means of the 'delta' method (Seber, 1982).

The methodology assumes that $g(0)$ is equal to one (all animals in the trackline are detected). In our case, $g(0)$ is much lower than one because of two reasons: (1) 'availability bias' i.e., a portion of the turtles are diving and hence unavailable for detection and (2) 'perception bias' i.e. observers may fail to detect animals on the trackline although they are available because of bad weather conditions, etc. (Marsh & Sinclair, 1989). The availability bias can be corrected provided that the percentage of time that loggerhead turtles spend on the surface is known. The only available data on juvenile loggerhead diving behavior in the Western Mediterranean are based on satellite tracking of five turtles satellite in spring and summer 2002 (Cardona *et al.*, 2005). Studies in the western Atlantic have observed seasonal changes in the percentage of time loggerheads spend at the surface (Renaud & Carpenter, 1994; Nelson, 1996). Thus, corrections for availability bias should be calculated for each season. However, although Cardona *et al.* (2005) do not provide seasonal results, we used their data, as they were derived from turtles of the same zone, and we corrected only the mean density in the area. Data from the western Atlantic were considered unsuitable for this study as the habitat is quite different, particularly the water depth (<100 m deep).

In order to estimate $g(0)$, we considered the availability bias as a static availability because loggerheads are inactive at the surface for a long time in relation to the detection period from the aircraft (*c.* 7 s) (Buckland *et al.*, 2004). Then, $g(0)$ was considered to be equal to the mean proportion of time that turtles spent at the surface: 35.1% [coefficient of variation (CV) = 56.1%] (Cardona *et al.*, 2005).

In summary, we estimated the surface density in each survey and each zone assuming $g(0)$ was equal to one in order to conduct seasonal and geographical comparisons. We also estimated the mean absolute density in the area using the value of $g(0)$ obtained from diving behavior. For comparisons with other studies, the mean surface density in the area was also provided.

Regarding the perception bias, we investigated the effect of sea state on the detection probability since this factor was found to affect aerial surveys of sea turtles most (Byles, 1988; Marsh & Saalfeld, 1989; Beavers & Ramsey, 1998). We analyzed data independently in each sea state and compared the values of the $f(0)$ and encounter rate (n/l). We observed no differences in $f(0)$ estimated for the different sea states; the confidence intervals of all of them overlapped widely. However, the encounter rate did change considerably between sea states; when sea state increased, the encounter rate decreased as expected (Table 1). The encounter rate of sea states 0 and 1 was quite similar, but the encounter rate of sea states 2 and 3 differed from these data (confidence intervals not overlapping). The encounter rate of sea state 2 was approximately half of that of state 0, and the encounter rate of sea state 3 was only 15% of the encounter rate for state 0. As $f(0)$ did not change between sea states, density estimations would also decrease as sea state increases. In order to reduce this effect, we did not use transects of sea state equal to 3 in the data analysis.

We subtracted 86 m from all the perpendicular sightings distances, corresponding to the blind distance under the plane because of flat windows (more than 60° from the horizon).

Following Buckland *et al.* (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 adjustment terms were selected through the likelihood ratio test ($\alpha = 0.05$), and potential models were compared using the Aikake information criterion (AIC) (Buckland *et al.*, 2001). Density estimates were made for the model with the smallest AIC.

We estimated the density in each survey using the same $f(0)$ obtained from all data, as no changes in the detection function were expected between surveys. We calculated a mean density in the study area by averaging the densities of the different surveys weighted by the total effort of each survey. We also estimated the density of turtles in the three different regions of the study area.

Table 1 Parameters estimated from the different Beaufort sea states to evaluate the effect of weather conditions

Beaufort	Parameter	Estimate	%CV	d.f.	95% CI
0	*n/l*	0.060	15.9	63	0.044–0.082
	f(0)	0.007	6.73	121	0.006–0.008
1	*n/l*	0.055	13.3	153	0.043–0.072
	f(0)	0.008	4.43	271	0.007–0.009
2	*n/l*	0.030	18.9	155	0.021–0.043
	f(0)	0.008	5.80	156	0.007–0.009
3	*n/l*	0.009	28.0	75	0.005–0.016
	f(0)	0.008	15.6	21	0.006–0.011

n/l, encounter rate (number of turtles km^{-1}); *f*(0), value of probability density function at zero (m^{-1}); %CV, percentage of the coefficient of variation; d.f., degrees of freedom; CI, confidence interval.

Results

We conducted eight complete surveys between May 2001 and March 2003 with a total of 17 000 km navigated. We recorded a total of 770 turtle sightings during sampling effort. The effort and the number of sightings of the different surveys are listed in Table 2, and the distribution of the turtles observed during all the surveys is illustrated in Fig. 2.

The best-fitting detection function for loggerhead turtle sightings frequency histogram was the half-normal with no adjustment terms. The distance frequency histogram and the result of the detection probability are shown in Fig. 3 and Table 3.

The average surface density of loggerhead turtles in the whole study area was 0.208 turtles km^{-2} [95% confidence interval (CI): 0.172–0.251], and the mean abundance was 6653 turtles (95% CI: 5514–8027). The mean absolute density in the study area, corrected by the proportion of diving turtles, was 0.592 turtles km^{-2} (95% CI: 0.290–1.681) and the absolute abundance was 18 954 turtles (95% CI: 6679–53 783) (Table 4).

Loggerhead surface densities ranged from 0.051 turtles km^{-2} during summer 2002 to 0.430 turtles km^{-2} during spring 2001. Table 4 shows the surface density and abundance estimations of each survey, and Fig. 4 illustrates the temporal succession of surface density with the confidence intervals. Because of the nature of the data, we could not use any statistical test to detect significant differences between densities of seasons or zones. However, considering the confidence intervals, we found that the summer 2002 surface density was lower than others (CIs not overlapping). Surface density in spring 2001 was higher than in other seasons, but because of the large confidence interval, it overlapped with three other densities.

When we estimated surface density in the different regions, we also found differences between zones; density in zone 3 was higher than in the others (Table 4).

Table 2 Summary of aerial sightings surveys carried out in the study area with the effort (in km) and the number of sea turtles sighted (*n*) in each flight and divided by zones

		Zone 1		Zone 2		Zone 3		Total	
Survey	Date	Effort	*n*	Effort	*n*	Effort	*n*	Effort	*n*
Spring 2001	May-01	610.1	9	951.1	63	596.9	124	2158.0	196
Summer 2001	Jul-01	619.2	42	859.8	16	530.2	38	2009.1	96
Autumn 2001	Oct-01	597.5	20	855.4	29	652.5	22	2105.4	71
Winter 2002	Mar-02	584.2	21	944.3	35	562.4	75	2090.8	131
Spring 2002	Jun-02	584.5	14	978.1	8	630.8	77	2193.4	99
Summer 2002	Aug-03	429.9	5	855.3	12	660.5	3	1945.7	20
Autumn 2002	Dec-02	620.5	3	924.4	2	730.9	84	2275.8	89
Winter 2003	Mar-03	548.9	2	1035	14	604.3	52	2188.1	68
Total		4595	116	7403	179	4969	475	16 966	770

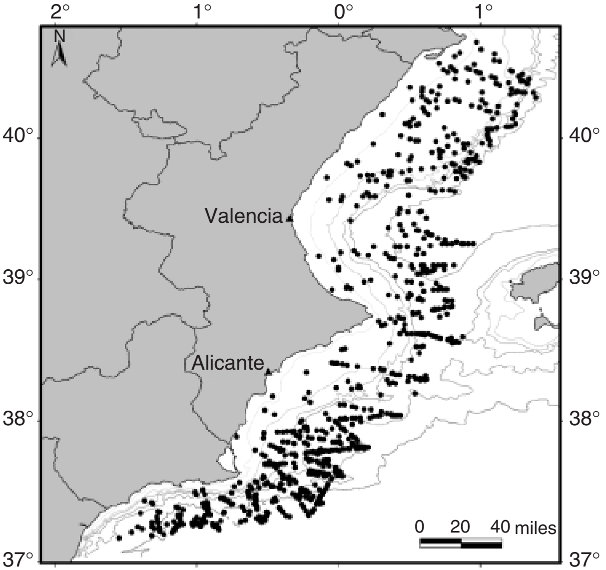

Figure 2 Distribution of loggerhead turtles observed in the surveys conducted in the communities of Valencia and Murcia during 2001–2003. The 50, 100, 200, 400, 600, 800 m, etc. isobaths are shown.

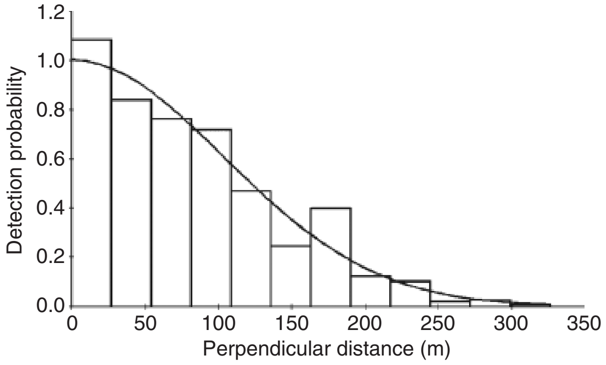

Figure 3 Frequency distribution of perpendicular distances (–86 m) from the line transect to loggerhead sightings. The continuous curve represents the detection probability function based on fit of the half-normal model to the perpendicular distance data.

Discussion

Abundance estimates

This is the first time that an extensive study of abundance and distribution of a loggerhead sea turtle stock has been performed in the Mediterranean. We provide the first estimation of absolute density in a large area of the Mediterranean, not only at a given time but considering seasonal differences. Preliminary results of a smaller zone, included in the study area, were presented in Gómez de Segura *et al.* (2003).

Our results on surface density are similar to other studies of sea turtle surface density in foraging habitats. However, comparison with specific studies on loggerhead turtles

Table 3 Values of the detection probability obtained from turtles sightings during all flights

	Estimate	%CV	d.f.	95% CI
f(0)	0.0077	2.69	746	0.0073–0.0081
P	0.3984	2.69	746	0.3779–0.4200
ESW	129.88	2.69	746	123.20–136.93

f(0), value of probability density function at zero (m^{-1}); *P*, probability of observing an object in the defined area; ESW, effective strip width (m); %CV, percentage of coefficient of variation; d.f., degrees of freedom; CI, confidence interval.

Table 4 Surface density and abundance estimations of loggerhead turtles divided by flight and zone

Survey	Parameter	Estimate	%CV	d.f.	95% CI
Spring 2001	*D*	0.430	16.5	29	0.307–0.601
	N	13 761	16.5	29	9838–19 247
Summer 2001	*D*	0.187	15.8	32	0.136–0.257
	N	5987	15.8	32	4351–8237
Autumn 2001	*D*	0.154	16.5	25	0.110–0.215
	N	4914	16.5	25	3508–6883
Winter 2002	*D*	0.271	23.7	33	0.168–0.436
	N	8661	23.7	33	5384–13 933
Spring 2002	*D*	0.191	24.7	35	0.117–0.312
	N	6112	24.7	35	3747–9984
Summer 2002	*D*	0.051	25.2	20	0.030–0.085
	N	1617	25.2	20	965–2709
Autumn 2002	*D*	0.183	34.5	34	0.092–0.361
	N	5848	34.5	34	2959–11 558
Winter 2003	*D*	0.155	32.6	32	0.081–0.295
	N	4942	32.6	32	2588–9439
Zone 1	*D*	0.118	13.1	66	0.091–0.153
	N	1025	13.1	66	790–1331
Zone 2	*D*	0.106	14.5	104	0.080–0.142
	N	1531	14.5	104	1150–2037
Zone 3	*D*	0.435	10.6	103	0.353–0.536
	N	3998	10.6	103	3243–4929
Average estimates	*D*	0.208	9.56	282	0.172–0.251
	N	6653	9.56	282	5514–8027
Corrected estimates	*D*	0.592	56.9	282	0.209–1.681
	N	18 954	56.9	282	6679–53 786

The average and corrected density in the study area is also shown. *D*, density (number of turtles km^{-2}); *N*, abundance (number of turtles); %CV, percentage of coefficient of variation; d.f., degrees of freedom; CI, confidence interval.

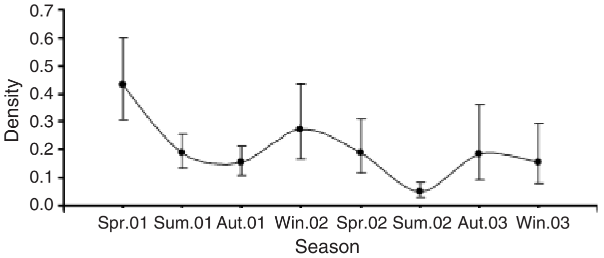

Figure 4 Temporal succession of the loggerhead surface density (number of turtles km^{-2}) obtained during the seasonal surveys including confidence intervals.

shows that the density values found in the present study are at least one order of magnitude higher, with similar or lower coefficients of variation (Table 5). Surface density obtained in the preliminary study (included in the northern zone of present study) was rather high, with an average density of 0.32 turtles km^{-2} (Gómez de Segura *et al.*, 2003). Almost all data used in the preliminary study were derived from surveys conducted in 2000. Therefore, it is possible that abundances differ between years. In order to evaluate the effect of incidental captures on loggerhead stock, Carreras, Cardona & Aguilar (2004) conducted two aerial surveys at the continental shelf of the Balearic Islands (adjacent to our study area) to estimate loggerhead abundance. Although the authors did not provide sufficient details in their methodology or results, the surface density was estimated at 0.056 turtles km^{-2}, a much lower value that the ones we obtained in our study area (0.21 turtles km^{-2}). As both studies were conducted during the same years and the coverage was quite similar, this difference could indicate that the waters of Valencia and Murcia concentrate a higher density of loggerhead turtles or that the strip transect method used by Carreras *et al.* (2004) is underestimating turtle density as it assumes that all turtles from 0 to 200 m are observed (see Fig. 3). The different water depths of the study areas could also cause a difference in turtle abundance; however, the density estimated in our northern zone, comprising mostly the continental shelf, was higher than that of Carreras *et al.* (2004) as well.

Seasonal and geographical changes

Our data show a high density of loggerhead turtles throughout the whole year. No time-related changes were detected between both the seasons and years with the assumption of two surveys, i.e. summer 2002 and spring 2001. The density obtained in summer 2002 was lower than others probably because of bad weather conditions as sea state varied between 2 and 3 in the zone 3 survey. In fact, the density in summer 2002 differed from other surveys exclusively in zone 3 (data not shown). Spring 2001 density was higher although its confidence interval overlapped with winter 2002 and autumn 2002 because of the high variance of the estimations. Camiñas & de la Serna (1995) proposed a model of migration of loggerhead turtles in the Western Mediterranean. It suggests that turtles coming from the Atlantic and Central-Eastern Mediterranean migrate into Spanish waters at the beginning of spring (April). During summer, turtles would spread to the whole zone and increase in number and in late summer–autumn they would leave these waters, with only a few specimens remaining in the Balearic and the Columbretes Islands in the colder months (December–April). Our results from 2001 supported the spring migration hypothesis as a higher number of turtles were found. These results also agree with information obtained from turtle strandings in the region of Valencia during 2001 (Tomás *et al.*, 2003). In our preliminary study

Table 5 Comparison of the results of the present study with other aerial surveys of sea turtles

					Measure of dispersion		
Study area	Depth	Methodology	Species	Density	CV	SE	Reference
North Carolina	Inshore waters	Line transect	Turtles[a]	0–0.37	–	0.5–11.6	Epperly, Braun & Chester (1995*a*)
North Carolina	Continental shelf 0–200 m	Line transect	Turtles[a]	0–0.176	–	0.9–8.5	Epperly *et al.* (1995*b*)
South Georgia	Estuarine and near shore	Strip transect	Turtles	0–0.62	–	0.05–0.41	Braun & Epperly (1996)
Eastern Gulf of Mexico	Continental shelf 0–200 m	Line transect	*Caretta caretta*	0.013	–	–	Griffin & Griffin (2003)
Northern Gulf of Mexico	Continental shelf 0–200 m	Line transect	*C. caretta*	0.039–0.042	0.23–0.30	–	Davis, Evans & Würsig (2000)
Northern Gulf of Mexico	Continental slope 100–2000 m	Line transect	*C. caretta*	0.0003–0.004	0.27–0.77	–	Davis *et al.* (2000)
Northern Gulf of Mexico	Continental slope 100–2000 m	Line transect	*C. caretta*	0.0005	0.29	–	Davis & Fargion (1996)
Northeastern USA	Continental shelf and slope 0–2000 m	Line transect	*C. caretta*	0.0016–0.5	–	–	Shoop & Kenney (1992)
Spanish Mediterranean	Continental shelf 0–200 m	Strip transect	*C. caretta*	0.056	–	–	Carreras *et al.* (2004)
Spanish Mediterranean	Continental shelf and slope 0–1000 m	Line transect	*C. caretta*	0.18–0.63	0.11–0.30	0.03–0.14	Gòmez de Segura *et al.* (2003)
Spanish Mediterranean	Continental shelf and slope 0–3000 m	Line transect	*C. caretta*	0.15–0.43	0.09–0.35	0.01–0.07	Present study

The measures of dispersion are given by the coefficient of variation (CV) or by the standard error (SE) depending on the study. In some studies only the confidence interval was estimated and in these cases no measure of dispersion is shown.

[a] The proportion of *C. caretta* in this study area is estimated to be 80% of the sea turtles.

(Gómez de Segura *et al.*, 2003), a higher density was also detected in the spring season. However, during 2002 this pattern was not observed; density did not change in the course of the year. These results suggest an entry of turtles into the study area in the spring months of some but not all years. This might be dependent on oceanographic conditions in each year. Furthermore, satellite-tracking studies in the area did not agree with a northward spring migration (Cardona *et al.*, 2005).

Regarding summer abundance, both the information from strandings (Tomás *et al.*, 2003) and data from by-catch and sightings of fishermen (Camiñas & de la Serna, 1995; Carreras *et al.*, 2004) suggested a peak of loggerheads in Spanish waters from late spring to late summer. However, the density obtained in our study area in summer surveys was not different from those of other seasons. We did not find a decrease of the number of turtles during autumn and winter as suggested by Camiñas & de la Serna (1995). Densities in the colder months were similar or even greater than those in the warmer months (Table 4). As previous studies were based on data from fisheries or stranding and not from a dedicated survey, such discrepancy in the results could be a consequence of the lower fishing effort during colder months and a higher one during warmer months, increasing the number of turtle deaths.

Seasonal movements of loggerhead turtles have been observed in the Atlantic waters of the USA (Shoop & Kenney, 1992; Epperly, Braun & Chester, 1995*a*; Epperly *et al.*, 1995*b*; Musick & Limpus, 1997) where the number of loggerheads decreased drastically during winter. However, in the areas of these studies, sea surface temperatures during the colder months drop below the thermal tolerance reported from sea turtles ($<10\,^{\circ}\mathrm{C}$; Schwartz, 1978). Thus, it is expected that turtles migrate to warmer areas. Studies in warm water areas (16–29 °C) show that loggerhead turtles are resident all year around (Bolten *et al.*, 1994; Musick & Limpus, 1997). In our study area, winter sea surface temperature did not drop below 11 °C. Thus, emigration movements because of thermal limits are not expected. This does not rule out the movements that each turtle can perform related to feeding activities or passive drifting by currents that have been observed by satellite telemetry studies in the western (Cardona *et al.*, 2005) and eastern basins (Bentivegna, 2002).

No differences were found in the density obtained in zones 1 and 2; however, the surface density in the southern zone was three times as high as the density observed in the other areas. This zone differs from the others because it presents a marked sea floor contour and very deep waters. Furthermore, it is included in the so-called Golfo de Vera, where the influence of Atlantic currents is present (Diaz del Rio, 1991), which could increase the productivity of the area. Future studies on the habitat use of loggerheads in this area could help to understand this distribution pattern.

Conservation implications

These results have important applications for the conservation of loggerhead sea turtles in Spanish waters. The absolute abundance presented here will allow to evaluate the effect of different threats to this endangered species, for instance incidental catches. Aguilar *et al.* (1995) estimated that around 20 000 loggerhead turtles are being captured every year by the Spanish long-line fishery, but this figure is based on data from 1990–1991. More recent studies (Camiñas, 2002) suggested that, in 2000, more than 29 000 loggerheads were captured by the Spanish long-line fishery (but this information is quite imprecise). We have estimated an absolute abundance of around 19 000 loggerheads in waters of the Valencia and Murcia communities. This zone is approximately a fifth of the Spanish fishing area. Although we cannot extrapolate this density to the rest of the Spanish waters, it allow us to get an idea of the abundance and the impact of fisheries; we estimate that between a third and a fifth of the Spanish loggerhead stock is accidentally captured annually by long-line fisheries. Of the animals captured, only a small portion dies directly (0.4%) but mortality increases to at least 34% after release as a result of the injuries caused (Aguilar *et al.*, 1995). Furthermore, Carreras *et al.* (2004) showed that other fishing gears, like lobster trammel, could also have a significant impact on Spanish loggerheads because of the high capture rate and the high direct mortality (100% in onboard observer reports). There is an urgent need for a recent and precise estimation of the number of turtles captured by every fishing gears in the Spanish waters in order to assess the impact of fisheries on this stock accurately. Nevertheless, the results of this study suggest that the loggerhead stock present in Spanish waters seems unable to sustain such high numbers of accidental captures. Thus, urgent conservation measures must be adopted in order to avoid a non-sustainable situation.

Although we estimated the abundance of turtles during 2 years in this study, the information is not enough to detect population trends and to estimate whether or not loggerheads are increasing, decreasing or are stable in numbers. However, the present study provides a baseline that can serve as a reference point for a future framework to improve the management and monitoring of this species. In addition, this study supplies important biological information about seasonal density and distribution for use in future management plans. For example, abundance estimates indicate that the southern zone would be an important area for the conservation of this species because of the higher density of turtles observed in both years.

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