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ORIGINAL PAPER

Habitat use by loggerhead sea turtles *Caretta caretta* off the coast of eastern Spain results in a high vulnerability to neritic fishing gear

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Abstract Previous studies of loggerhead sea turtles have concluded that drifting longlines were the main threat for immature specimens in the western Mediterranean, because immature loggerhead sea turtles mainly inhabit oceanic waters. However, recent aerial surveys have revealed large numbers of immature loggerhead sea turtles over the continental shelf of eastern mainland Spain, where turtles are exposed to neritic fishing gears but not to drifting longlines. We satellite-tracked seven loggerhead sea turtles (minimum straight carapace length (SCLmin) range: 36.5–55.0 cm) to assess whether the turtles in this region are vagrants from the adjoining oceanic regions or whether these loggerheads mostly inhabit the continental shelf. Satellite-tracking revealed that six of the tagged turtles avoided the oceanic realm and made extended use of the continental shelf, whereas only one individual could be considered a true vagrant as it avoided the continental shelf and primarily used the oceanic habitat. These results are in sharp contrast with those previously reported for immature loggerhead sea turtles of similar size from the south-western Mediterranean and fit well a relaxed ontogenic model that was recently proposed for loggerhead sea turtles in the central Mediterranean. Furthermore, these results demonstrate the vulnerability of loggerhead sea turtles of eastern mainland Spain to neritic fishing gears, as three of the seven turtles died and one was bycaught incidentally while being tracked over the continental shelf.

Introduction

Bycatch in drifting longlines has often been considered to be the main threat for immature loggerhead sea turtles *Caretta caretta* (Linnaeus 1758) throughout the Mediterranean, as they experience high rates of bycatch in this fishery (Margaritoulis et al. 2003; Lewison et al. 2004). The highest rates of incidental bycatch are recorded in the south-western Mediterranean (Aguilar et al. 1995; Lewison et al. 2004; Deflorio et al. 2005; Camiñas et al. 2006), probably because immature loggerhead sea turtles inhabiting that region have a preference for oceanic habitats (Cardona et al. 2005; Revelles et al. 2007a; Eckert et al. 2008), and the areas used overlap with the fishing grounds of the Spanish longline fleet (Camiñas and de la Serna 1995; Báez et al. 2007). As a result of this strong interaction, half the turtles stranded in the Balearic Archipelago since 1993 have been bycaught with longlines (Cardona and Fernández, unpublished data), although other fishing gear is also known to capture loggerhead sea turtles off the archipelago incidentally (Carreras et al. 2004). However, capture-tagging-recapture (Casale et al. 2007; Revelles et al. 2008), satellite-tracking (Bentivegna 2002; Hochscheid et al. 2007) and bycatch (Godley et al. 1998; Bertolero

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2003; Casale et al. 2004, 2008; Jribi et al. 2008) data show that immature loggerhead sea turtles make a more extended use of the continental shelf in other regions of the Mediterranean, suggesting lower rates of bycatch in longlines in these regions.

Aerial surveys have revealed the occurrence of a large number of immature loggerhead sea turtles over the continental shelf off the eastern coast of mainland Spain (Gómez de Segura et al. 2003, 2006). Evidence from capture-tagging-recapture studies in the region indicates that loggerhead sea turtles may spend long periods on neritic habitats off the eastern coast of mainland Spain (Bertolero 2003; Revelles et al. 2008). Furthermore, intense satellite-tracking of the loggerhead sea turtles inhabiting the oceanic waters of the south-western Mediterranean has demonstrated that loggerhead sea turtles seldom approach the eastern coast of mainland Spain north of Cape La Nao (Cardona et al. 2005; Revelles et al. 2007a; Eckert et al. 2008). Consequently, we hypothesise that most of the immature loggerhead sea turtles found over the continental shelf of eastern mainland Spain are not vagrants from nearby oceanic areas, but are residents of the continental shelf. This would result in a high risk of loggerhead sea turtle bycatch in neritic fishing gear due to the high fishing effort in comparison with the continental shelf off the Balearic Archipelago (Table 1). This may explain why longlines were involved in only 28% of the turtle strandings recorded in central eastern mainland Spain during the past decade (Tomás et al. 2008), although drifting longliners operate in the area with roughly the same intensity as that off the adjoining Balearic Archipelago (Camiñas and de la Serna 1995; Báez et al. 2007).

This paper aims to provide precise information about habitat use by immature loggerhead sea turtles off the eastern coast of mainland Spain. Specifically, this paper will test the hypothesis that immature loggerhead sea turtles in this region spend most of their time on the continental shelf, thus facing a high risk of incidental capture with neritic fishing gear.

Materials and methods

Satellite-tracking

Telonics ST-20 satellite transmitters (weight: 188 g, dimensions: 11.5 cm × 6.3 cm × 3 cm, herein referred to as tags) were attached to seven juvenile loggerhead sea turtles collected off the coast of central mainland Spain in 2005. The average minimum straight carapace length (SCLmin, Bolten 2000) of the turtles was 48.37 ± 6.2 SD cm (range: 36.6–55 cm). Turtles use in this study had been bycaught incidentally by professional fishermen and were then transferred to land, where they received veterinary treatment. Only healthy turtles were tagged, and tag weight did not exceed 3% of turtle body weight. Tags were attached to the second central scute with polyester resin and fibreglass. A synthetic polymer was used to make a base for the tag that matched the curved carapace and several layers of resin and fibreglass were applied (Balazs et al. 1996). The whole tagging operation took ∼2 h. After tagging, turtles were placed in 400 l fibreglass containers with seawater for at least 24 h to ensure correct attachment.

Tags were equipped with a salt-switch used to record the time spent underwater. The software was programmed to record the time spent underwater in three time slots: from 8:00 to 12:00 GMT (morning), another from 12:00 to 16:00 GMT (afternoon) and a third one from 19:17 to 4:14 GMT (night). Each transmission showed the time spent underwater at the three time intervals in the last 24 h. Tag duty cycles (hours on/off) were set as 8/96 h, in order to increase the battery life as much as possible. The Service Argos satellites received the information transmitted by the tags and sent this data to the processing centre, where

Table 1 Number of registered fishing vessels and effort density on the continental shelf off the eastern coast of mainland Spain (Girona, Barcelona, Tarragona, Castellón, Valencia, Alicante and Murcia provinces) and the Balearic Archipelago

	Mainland eastern Spain		Balearic Archipelago	
	Vessels	Effort density (vessels km^{-2})	Vessels	Effort density (vessels km^{-2})
Bottom-trawlers	687	0.0376	61	0.0079
Purse-seiners	144	0.0079	11	0.0014
Drifting longliners	23	–	3	–
Bottom longliners	81	0.0044	19	0.0025
Artisanal boats	1,137	0.0623	397	0.0513

Artisanal boats change the gears that they use (bottom longlines, traps, whelk dredges, gillnets, pots and trammel nets) seasonally. The continental shelf covers 18,254 km^2 off the eastern coast of mainland Spain and 7,744 km^2 off the Balearic Archipelago. The effort density of drifting longliners on the continental shelf is not shown, because this gear is used in the oceanic domain positional data were calculated and retransmitted to the user (Argos 2000). Argos assigns a quality index (location class or LC) to each location on the basis of the estimated accuracy in latitude and longitude (Table 2). Argos does not provide an estimation of accuracy for the location classes they identify as LC A, LC B and LC Z, but Hays et al. (2001) demonstrated that LC A is as accurate as LC 1 and is more reliable than LC 0 or LC B. Table 2 shows the performance of the transmitters used, the total number of locations of each of the Argos location classes and the number of locations monitored.

Correlated random walks provided the conceptual framework for quantifying the displacement of individual organisms and for relating movement patterns with the distribution of the organism (Kareiva and Shigesada 1983; Turchin 1991). Correlated random walks assume that move lengths and move angles that describe an animal's movement path are independent. However, moves are considered to be correlated, since movement is directed due to the tendency of animals to move in a preferred direction. Although the turtles may have moved continuously, satellite-tracking supplied only a limited number of fixes, and the paths were reconstructed by connecting the successive fixes with straight lines. This may result in tracks crossing emerged land when turtles quickly turned capes, deltas and other geographical features protruding from the coastline. Positional data were screened to select the "highest quality" fix (a positional accuracy of less than 1 km, i.e., LC 3-1 and A; and a velocity lower than 5 km h^{-1}; Luschi et al. 1998; Argos 2000; Hays et al. 2001). When there were multiple days without "high quality" data (LC 3-1 or A) and the velocity to or from the low-accuracy fix was <5 km h^{-1}, a fix with a lower accuracy was occasionally used (Luschi et al. 1998). Inland locations were never used. After data screening, each path was reconstructed using a GIS to recreate the straight path between successive positions.

Using a bathymetric dataset with a resolution of 1 × 1 min (latitude × longitude; Smith and Sandwell 1997), a GIS was also used to assess the depth of the water column at each turtle position. A depth scale was used to classify fixes into two general bathymetric domains: neritic represented depths shallower than 200 m, and *oceanic* indicated depths greater than 200 m. The maximum diving depth reported for loggerhead sea turtles is 233 m (Lutcavage and Lutz 1997); therefore, individuals are expected to reach the sea floor only while on the continental shelf (neritic habitat).

Habitat use analysis

Habitat availability was quantified as the percent of areal extent using a GIS. Habitat use was computed as the frequency of fixes from each habitat type (neritic and oceanic), considering only the "highest quality" fix for each duty cycle. The chi-square test (Zar 1999) was used to check whether the use of the bathymetric domains was proportional to habitat availability. When the chi-square test showed that habitat use was not proportional to availability, Ivlev's electivity index (Ivlev 1961, quoted by Crowder 1990) was used to identify the bathymetric domain in which turtle occurrence was higher or lower than expected. Ivlev's index was calculated for each bathymetric domain as:

$$I = (p_o - p_e)/(p_o + p_e) \qquad (1)$$

where p_o is the observed percentage of fixes recorded in a given habitat, and p_e is the proportional coverage of that habitat. Confidence intervals were calculated following Strauss (1979) as:

Table 2 Tracking performance of the seven loggerhead sea turtles tagged off the eastern coast of mainland Spain

Specimen (SCL)	Fixes	Proportion of messages by location class (%)						Tracking period	
		3	2	1	0	A	B	Months	Days
105 (51.0 cm)	128	7.8	5.5	10.2	3.1	25.0	48.4	July 2005–October 2006	442
205 (47.5 cm)	73	4.1	6.8	9.6	5.5	23.3	50.7	January 2006–January 2007	385
305 (45.9 cm)	21	4.8	9.5	9.5	0.0	23.8	52.4	June 2005–December 2005	172
405 (48.6 cm)	63	4.8	12.7	22.2	7.9	22.2	30.2	June 2005–August 2005	57
505 (36.6 cm)	263	14.1	18.6	9.5	14.4	17.9	25.5	July 2005–August 2006	398
605 (55.0 cm)	363	7.7	16.5	17.1	13.2	17.1	28.4	October 2005–August 2006	306
705 (54.0 cm)	143	5.6	22.4	16.8	11.9	16.1	27.3	October 2005–September 2006	337
All	1,054	8.5	15.5	13.9	11.0	19.0	32.1	June 2005–January 2007	579

Argos estimated the accuracy for these location classes as follows: <150 m for LC 3, between 150 and 350 m for LC 2, between 350 and 1,000 m for LC 1 and >1,000 m for LC 0. Hays et al. (2001) demonstrated that LC A is as accurate as LC 1 and is more reliable than LC 0 or LC B

$$E_c = \left(2 - \left(\frac{2p_e}{(p_e + p_0)}\right)\right) \times \left[1 \pm 1.96\sqrt{2n_0 \times p_0 \times (1 - p_e) \times (p_0 + p_e)^2 + p_0 \times (1 - p_0) \times n_e + p_e \times \frac{(1 - p_e)}{n_0 n_e (p_0 + p_e)^2}}\right] - 1 \tag{2}$$

where n_o is the number of fixes, and n_e is the total number of depth points used to generate the bathymetric chart in the GIS (Smith and Sandwell 1997).

Analysis of swimming behaviour

Swimming behaviour was characterised by three parameters: speed of travel, surfacing time and the cosine of the turning angle. To test the existence of preferred turning angles, uniformity of this parameter for each turtle was checked using Rayleigh's test (Zar 1999). The same method was used to test the existence of preferred swimming directions.

Two different analyses were conducted to test whether turtles changed their swimming behaviour in different habitats. First, Spearman's rank correlation coefficient (Zar 1999) was used to examine the correlation between the speed of travel and the mean cosine of turning angles, as the correlated random walk theory predicts that both parameters will increase while animals are in unfavourable patches (Turchin 1991). In a second analysis, the speed of travel and the average cosine of the turning angle in the neritic and oceanic domains were compared, and therefore, whether turtles identified any of them as a preferred habitat. Normality was tested by means of the Lilliefors test, and the Student *t* test or Mann–Whitney test was used to test for differences in sample means between the two environments.

As the surfacing time data were not normally distributed, the Kruskal–Wallis test (Zar 1999) was used to assess differences in the time spent at the surface in three distinct day intervals: morning, afternoon and night.

Data are shown as means ± standard deviation, unless otherwise stated. All statistical analyses were conducted with the SPSS 15 software package.

Results

The seven turtles with satellite tags were released between 23 June 2005 and 3 January 2006 (Table 2). The turtles were tracked for between 57 and 442 days, with an average tracking time of 299.6 ± 137.7 days. Good quality fixes were obtained from all of the animals (Table 2), although only about half of the duty cycles produced good quality fixes (50.0% for turtle #105; 33.9% for turtle #205; 35.0% for turtle #305; 91.7% for turtle #405; 59.6% for turtle #505; 87.0% for turtle #605 and 64.0% for turtle #705).

The tracked turtles moved throughout most of the western Mediterranean, from south-eastern Spain to the Sicilian channel and from southern France to northern Africa (Figs. 1, 2). Bearing angles were randomly distributed for all turtles (Table 3), so the turtles were not just moving away from the release point during tracking but were involved in a habitat search. Furthermore, the cosine of the turning angle and the speed of travel were positively correlated with four turtles (Table 4), thus revealing that they alternated between periods of slow, convoluted swimming and periods of much faster, straight swimming (Figs. 1, 2), probably in response to the patchy distribution of suitable habitats. The location of areas of slow, convoluted swimming, which were likely foraging areas, was variable, but most of these areas were located on the continental shelf, often off the Ebro Delta. Conversely, no correlation existed between the cosine of the turning angle and the speed of travel of the remaining three turtles (Table 4), because they had homogenously convoluted (#205 and #605) or rectilinear (#305) routes (Figs. 1, 2), despite extended tracking for all them (Table 2). Turning angles were also randomly distributed for four turtles, but three turtles turned left more frequently than would be expected from a random distribution (Table 3).

Turtles #105, #305, #505 and #705 moved south throughout the late autumn and winter, but turtles #205 and #605 did not (Figs. 1, 2). Turtle #205 spent a whole year off the Ebro Delta (Fig. 1), whereas turtle #605 spent 11 months wandering between northern Africa and the permanent salinity front than runs between Minorca and Corsica islands latitude of roughly 40°N (Fig. 2). Turtle #105 is remarkable, because it was the only turtle that moved northward in the spring, returning to the same area (Ebro Delta) where it had spent the previous summer (Fig. 1). The track for turtle #405 was too short to analyse seasonal patterns in habitat use.

Although the routes were highly variable, most turtles (#105, #205, #303, #405, #505 and #705) avoided the oceanic domain and spent most of their time in the neritic domain (Table 5). Conversely, turtle #605 avoided the

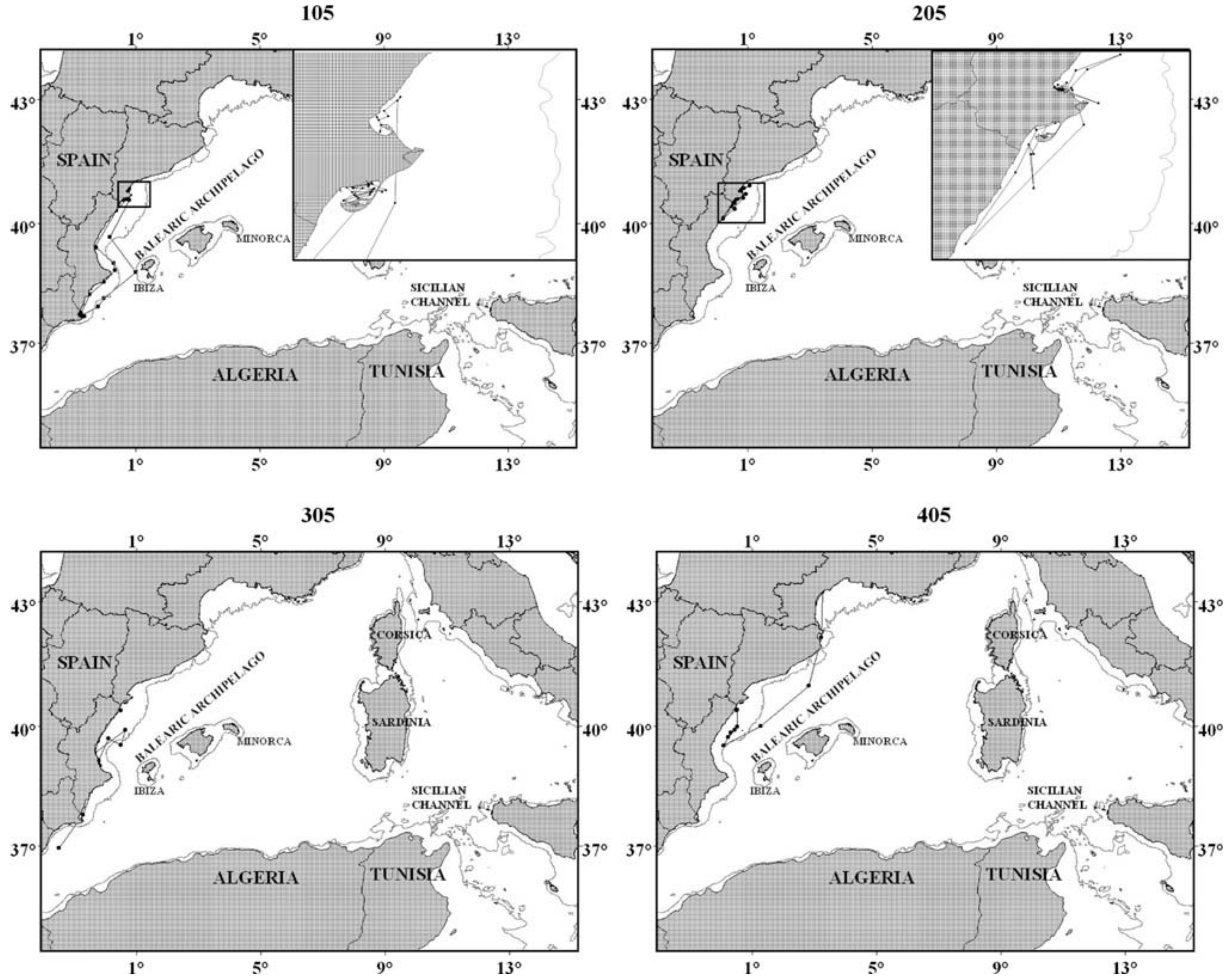
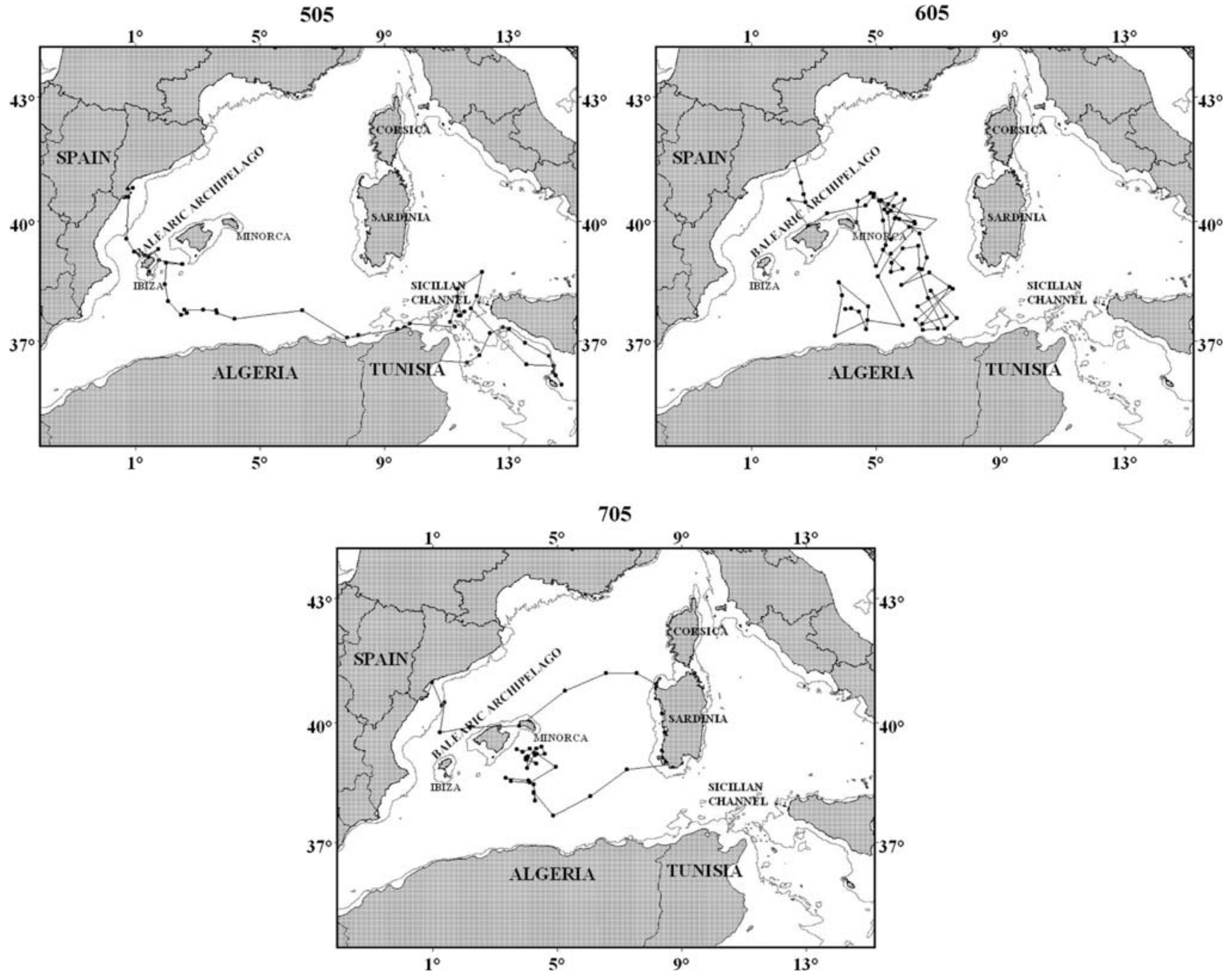


Fig. 1 Routes of the tracked loggerhead sea turtles that were mostly observed within the neritic domain. The *grey* contour represents the 200-m bathymetric line

neritic domain and made a slightly positive use of the oceanic domain (Fig. 2; Table 5). Swimming behaviour did not shift between bathymetric domains, as differences were not statistically significant for the average speed of travel (Student's $t = 0.898$; $df = 10$; $P = 0.390$; Table 6) and the mean cosine of the turning angles (Mann–Whitney U; $P = 0.078$; Table 6). However, the turtles spent less time at the surface in the neritic domain (8.4%) than in the oceanic domain (58.3%; Mann–Whitney U; $P < 0.001$). Furthermore, day period had no effect on the time spent at the surface, while in the neritic realm (morning: 8.5 ± 18.2; afternoon: 8.3 ± 16.9; night: 8.4 ± 15.9; Kruskal–Wallis test; Hstat = 10.957; $df = 2$; $P = 0.004$), although turtles in the oceanic domain reduced the time they spent at the surface at night (morning: 67.5 ± 35.1; afternoon: 68.8 ± 35.4; night: 38.5 ± 33.1; Kruskal–Wallis test; Hstat = 72.208; $df = 2$; $P < 0.001$).

Vulnerability to neritic fishing gears was high, as three of the five turtles that were primarily tracked on the shelf stranded dead (#105, #205 and #405). The underwater time sensor of two of these dead turtles (#105 and #205) recorded permanent emersion during the last duty cycle, a pattern that was never observed before. Then, the transmission ceased, and the turtle stranded after a few weeks. The last transmission of turtle #405 was not unusual, but the animal stranded dead a few days later. None of the dead stranded turtles had any hook in their mouth/throat or any visible fishing line entanglements, so an interaction with a longline was considered unlikely to be the cause for the death of these animals. Collision can also be discarded as a cause, as none of the turtles had any injury in the head or back. Furthermore, turtle #305 was incidentally caught by an angler while being tracked. It was released alive and was tracked for four more months.



505

605

705

Fig. 2 Routes of the tracked loggerhead sea turtles that were mostly observed within the oceanic domain. The *grey* contour represents the 200-m bathymetric line

Table 3 Average bearing and turning angles of the seven loggerhead sea turtles tracked

Specimen	Number of moves	Average bearing of move	Direction	Rayleigh's *z*	Average turning angle	Rayleigh's *z*
105	48	332.834	NW	0.919	342.478	0.210
205	32	349.391	NW	0.326	216.924	3.767*
305	8	207.325	SW	3.773	346.191	0.169
405	10	200.072	SW	0.005	289.425	0.563
505	56	236.027	SW	1.819	339.452	4.543*
605	66	185.661	SW	0.168	353.769	0.491
705	45	205.325	SW	1.314	316.821	9.343***

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Discussion

The turtles tagged in previous studies in the south-western Mediterranean made an extended use of the oceanic realm, avoided the continental shelf, spent long periods at the surface of the ocean, did not change their distribution seasonally and had a broad scale of habitat selection (Cardona et al. 2005; Revelles et al. 2007a, b; Eckert et al.

Table 4 Correlations between the average speed of travel and the mean cosine of turning angle (ψ) of the seven loggerhead sea turtles throughout the tracking period

Specimen	Spearman Rho	*n*	Areas of convoluted swimming
105	0.302*	47	Shelf off Ebro Delta and SE Spain
205	−0.058	31	All the track
305	0.179	7	None
405	0.867**	9	Shelf off E Spain and S France
505	0.290*	55	Shelf of Ebro Delta, Ibiza and Sicilian Channel
605	−0.188	65	All the track
705	0.322*	44	Shelf off W Corsica and oceanic domain off S Minorca

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Table 5 Habitat use by the seven loggerhead sea turtles tracked and the associated Ivlev's electivity index

Specimen	Chi-square statistic	Specimen and habitat type	Number of fixes	Ivlev's electivity	95% CI
105	260.859***	Oceanic	3	−0.869	−0.879, −0.859
		Neritic	47	0.737	0.619, 0.856
205	205.069***	Oceanic	0	−1.000	−1.000, −1.000
		Neritic	34	0.751	0.697, 0.805
305	35.468***	Oceanic	2	−0.622	−0.711, −0.532
		Neritic	8	0.698	0.248, 1.000
405	46.984***	Oceanic	2	−0.674	−0.742, −0.607
		Neritic	10	0.708	0.335, 1.000
505	10.824**	Oceanic	41	−0.096	−0.170, −0.023
		Neritic	17	0.347	−0.018, 0.711
605	5.364*	Oceanic	65	0.054	0.011, 0.097
		Neritic	3	−0.526	−0.652, −0.401
705	9.334**	Oceanic	33	−0.100	−0.180, −0.019
		Neritic	14	0.354	−0.051, 0.758

Habitat availability within the regions frequented by the turtles (Figs. 1, 2) was as follows: 402,546.5 km^2 in the oceanic realm and 66,741.2 km^2 on the continental shelf (* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; degrees of freedom = 2 for all the turtles)

Table 6 Average speed of travel and mean cosine of turning angle (ψ) of the seven loggerhead sea turtles tracked in the two bathymetric domains

Specimen	Habitat type	Speed of travel (m s^{-1})	ψ
105	Oceanic	0.295	0.473
	Neritic	0.107	0.036
205	Neritic	0.114	−0.279
305	Oceanic	0.206	0.959
	Neritic	0.225	0.016
405	Oceanic	1.365	0.071
	Neritic	0.509	0.087
505	Oceanic	0.529	0.335
	Neritic	0.196	0.077
605	Oceanic	0.622	0.091
	Neritic	0.691	−0.062
705	Oceanic	0.164	0.168
	Neritic	0.360	0.840

2008). Only one of the seven turtles tagged in the present study exhibited a similar pattern of habitat use, as the other six turtles used the continental shelf extensively, spent most of the time underwater, had a much finer scale of habitat selection with a strong preference for Ebro Delta, and several turtles also moved southward in late fall and winter.

The turtles tracked in this study were comparable in body size to those tagged by Cardona et al. (2005) and Revelles et al. (2007a) in the south-western Mediterranean (36.6–55.0 cm SCL versus 37.1–63.0 cm SCL) and were within the size range of the turtles tagged by Eckert et al. (2008) in this basin. Therefore, the above-reported differences in the pattern of habitat use cannot be attributed to differences in size. Tags are known to influence animal behaviour (e.g., Gauthier-Clerc et al. 2004; Dugger et al. 2006), but this is an unlikely reason for the contrasting results reported earlier, as the tags used in the present study were extremely similar in shape and size to those used by

Cardona et al. (2005) and Revelles et al. (2007a). A third potential confounding factor is the origin of the turtles used in each study. Most of the turtles used in the previous studies in the south-western Mediterranean had been captured intentionally by the researchers and kept in captivity for only a few hours (Cardona et al. 2005; Revelles et al. 2007a; Eckert et al. 2008). Conversely, the turtles used in the present study had been captured incidentally by fishermen and spent several days or weeks in captivity before being released. This may have influenced their postrelease behaviour, although to our knowledge, the influence of captivity on the behaviour of sea turtles has not been addressed experimentally.

There are three reasons to suggest that the extended use of the continental shelf off the coast of eastern Spain reported here is not an artefact caused by the origin of the individual turtles. First, aerial surveys have shown a much higher density of loggerhead sea turtles on the continental shelf of eastern mainland Spain (Gómez de Segura et al. 2006) than on the continental shelf off the Balearic Archipelago (Cardona et al. 2005), a result consistent with the differences in the patterns of habitat use reported earlier. Secondly, the extended use of the continental shelf off the eastern coast of mainland Spain and the strong preference for particular areas such as the Ebro Delta is consistent with the strong area fidelity already indicated by capture-tagging-recapture studies off the coasts of Italy (Casale et al. 2007) and Spain (Revelles et al. 2008). Thirdly, the contrasting patterns of habitat use revealed by satellite telemetry off the mainland Spain and the south-western Mediterranean are consistent with the contrasting diets reported for those areas, with a high prevalence of neritic prey off the coast of eastern mainland Spain (Tomás et al. 2001) and the dominance of oceanic prey off the Balearic Archipelago (Revelles et al. 2007c).

Based on dietary information, Casale et al. (2008) proposed a relaxed ontogenic model for loggerhead sea turtles in the central Mediterranean, with an early short obligate epipelagic stage, followed by the main opportunistic amphi-habitat stage, with an increasing preference for benthic prey as turtles grow, although association or fidelity to specific oceanic or neritic zones would vary among individuals under this model. This model fits with both the results of capture-tagging-recapture (Casale et al. 2008) and satellite-tracking studies (Bentivegna 2002) from the central Mediterranean as well as the results from aerial surveys (Gómez de Segura et al. 2006), capture-tagging-recapture studies (Revelles et al. 2008) and satellite-tracking research (this study) conducted off the eastern coast of mainland Spain. Nevertheless, the model does not explain why loggerhead sea turtles in the south-western Mediterranean remain in the oceanic stage for so long. This observation might be related to the prevalence of individuals from the Atlantic rookeries in this region (Carreras et al. 2006), who are thought to have an extended oceanic stage (Casale et al. 2007).

Regardless of the causes for the contrasting patterns of habitat use discussed earlier, the data reported here demonstrate that drifting longlines are unlikely to be the most important threat for immature loggerhead sea turtles off the eastern coast of mainland Spain, as most turtles strongly avoided the oceanic domain, where drifting longlines are set (Báez et al. 2007). Conversely, bottom nets, bottom trawling and other neritic fishing gears might be a much more relevant threat in this region, as already suggested based on strandings (Tomás et al. 2008) and informal interviews with fishermen (Bertolero 2003). The high rate of bycatch and dead-stranding affecting the turtles tracked here supports this hypothesis, as necropsies did not reveal interactions with longlines and boat collisions.

A final point that merits discussion is the strong preference for the Ebro Delta shown by some of the tracked turtles, a result that confirms previous findings from capture-tagging-recapture studies (Bertolero 2003; Revelles et al. 2008). Similar patterns of fidelity to feeding grounds a few tens of square kilometres in size have also been reported for late immature individuals off the North America (Avens et al. 2003) and for adult females in the eastern Mediterranean (Broderick et al. 2007). A strong preference for the Ebro Delta seems logical when considering the enhanced productivity of the area influenced by the plume of the Ebro River (Estrada 1996), but aerial surveys failed to detect a higher abundance of loggerhead sea turtles off the Ebro Delta than elsewhere off the eastern coast of mainland Spain south to a latitude of 40°41′N (Gómez de Segura et al. 2006). This might be an artefact of the study design, because the oceanic loggerhead sea turtles inhabiting the southern part of the western Mediterranean often approach the surveyed area south to Cape la Nao, but seldom visit the area north to a latitude of 39°30′N, which has also been covered by aerial surveys (Cardona et al. 2005; Revelles et al. 2007a). Furthermore, the continental shelf is much narrower south to Cape la Nao; and hence, most of the surveyed area was oceanic, whereas the opposite was true off the Ebro Delta (Gómez de Segura et al. 2003, 2006). As immature loggerhead sea turtles spend much more time at the surface while in the oceanic realm than while over the shelf (Cardona et al. 2005; Revelles et al. 2007a, this study), turtle sightability is expected to be much higher south to Cape la Nao. As Gómez de Segura et al. (2006) did not account for these sources of bias, their conclusion that turtle density is the highest south to Cape la Nao should be considered to be premature, and further research is needed to test the hypothesis that Ebro Delta is a hot spot for loggerhead sea turtles off the eastern coast of mainland Spain.

Furthermore, the estimation of 6,653 turtles reported for the surveyed area (Gómez de Segura et al. 2006) is certainly an underestimate of the actual stock size in the region; this study used the percentage of surface time reported by Cardona et al. (2005) for oceanic turtles, and most of the turtles found north to Cape la Nao were observed over the continental shelf.

In summary, the overall evidence indicates that a large fraction of the immature loggerhead sea turtles found off the eastern coast of mainland Spain used the continental shelf extensively and exhibited strong fidelity to some neritic feeding grounds where they are exposed to incidental bycatch in neritic fishing gears.

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