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The occurrence of white sharks, *Carcharodon carcharias*, around the Balearic Islands (western Mediterranean Sea)

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Synopsis

The regular presence of the white shark, *Carcharodon carcharias*, off the Balearic Islands (western Mediterranean) is shown from 27 captures carried out with trap nets between the 1920s and 1970s and from eight attacks on cetaceans and marine turtles from the 1990s to the present. The geographic distribution, seasonality and population structure of the species in the area are analysed and discussed in relation to environmental conditions and to the proposed distribution of this species in the Mediterranean Sea.

Introduction

The white shark, *Carcharodon carcharias*, is widely distributed in the temperate and subtropical seas throughout the world (Compagno 1984). The status of this species in the Mediterranean Sea has been considered as an occasional transient from Atlantic waters rather than a resident. Fergusson (1996) compiled around 90 records of white sharks in the western and central Mediterranean, from 1852 to 1993, and hypothesized about the permanent population of the white shark in the area. More recently, the same author has postulated that the Sicilian Channel, and its adjoining environs in the central Mediterranean are reproductive and nursery areas for white sharks (Fergusson 2002). In recent years, Mojetta et al. (1997) concerning Italian waters and Soldo & Jardas (2002) the eastern Adriatic have demonstrated that the records of this species in the area are more numerous than previously reported.

Barrull (1993–1994) carried out a review of ancient records of white sharks off the north-eastern Iberian coast, reporting several captures during the 19th and 20th centuries, some of them with only information about its presence and others with more complete information (site and date of capture, and length of the specimens). In the Balearic Islands, the white shark has been scarcely recorded since ancient times, and recently only two specimens captured by a commercial fisherman have been reported in 1992 off south-western Mallorca (Fergusson 1996), although they should be treated as unconfirmed (I.K. Fergusson pers. comm.). The present paper aims to estimate the presence of the white shark off Balearic Islands and to contribute to the knowledge of its population in the area.

Compiled information and data analysis

From 1995 to 2001, we obtained data on white sharks catches in Mallorca (Balearic Islands) from interviews with fishermen. In each record we required the following information: date, location, fishing method, total length (TL; from Bigelow & Schroeder 1948), weight and sex of the specimen. Whenever possible, we also

obtained a photograph of the specimen. In some cases, data were incomplete and we used additional information. Since in most cases the fishes were sold for human consumption, we estimated their length from their known weight by applying the weight–length relationship from Mollet & Cailliet (1996). Another method to complete the information of reports was the morphometric measurements developed from photographs (Figure 1), using image analysis programs (Cad 14, Corel Draw 8.0 and Optimas 6.1) to compare the length of the shark with known lengths of objects, which appear in the photographs. In some cases we also applied morphometric relationships from Mollet & Cailliet (1996). To validate the information obtained from fishermen, we analysed the reported TL in two ways: (i) by comparing reported TL with TL derived from analyses of photographs; and (ii) by comparing reported TL with TL derived from reported weight.

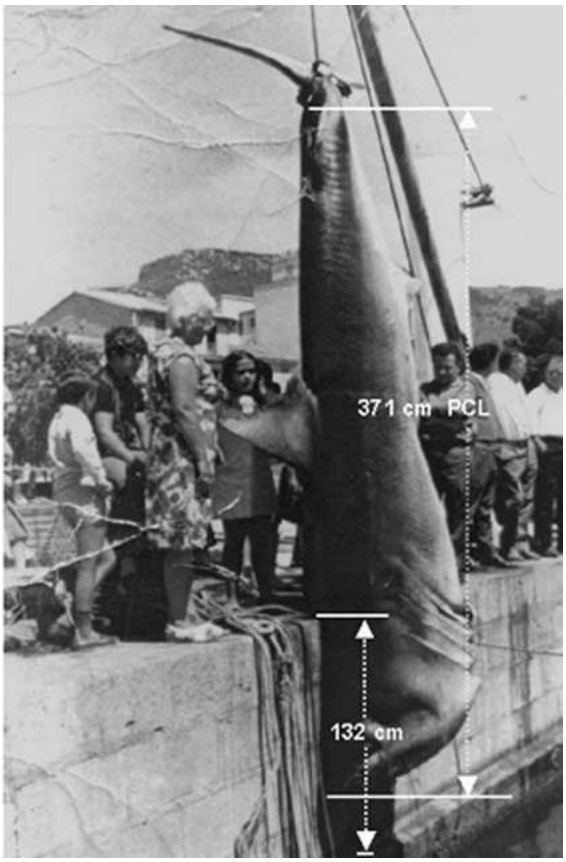

Figure 1. A male white shark, 415 cm TL, captured in Mallorca with trap net on 1.10.1967, and its precaudal length (posteriorly converted to TL from Mollet & Cailliet, 1996) developed with image analysis system from the known height of the pier (Photograph by J. Rullan).

We also compiled additional information from a monitoring program of cetaceans and marine turtles strandings, carried out from 1993 to 2001 along the whole coast of the Balearic Islands. Some of these specimens showed clear evidences of shark-inflicted injuries. Since no tooth fragments were recovered from the carcasses, we used the size and shape of bites and number of tooth punctures to identify, to the lowest possible taxa, the responsible species, as previously done by other authors (e.g. Long 1991, 1996, Fergusson 1994, Long & Jones 1996). Long & Jones (1996) listed 18 taxa that are known to include cetaceans in their diet. Eight of them have been reported in Balearic waters: white shark, *Hexanchus griseus*, *Isurus oxyrinchus*, *Prionace glauca*, *Carcharhinus brachyurus*, *Carcharhinus plumbeus*, *Sphyrna* spp. and *Centroscymnus coelolepis*, although *Carcharhinus limbatus* and *Carcharhinus obscurus* have also been reported from adjacent Mediterranean areas (Fergusson & Compagno 2000). Nevertheless, only the white shark has been confirmed as a chelonian predator in the Mediterranean Sea (Fergusson et al. 2000). We examined both jaws and teeth of these sharks and compared them to bite marks on the stranded cetaceans and turtles to determine the responsible species. Information on the bite location on the cetaceans' bodies was also reported, following criteria from Long and Jones (1996): (i) caudal peduncle; (ii) urogenital region; (iii) abdominal area; (iv) dorsal region; (v) head; (vi) flanks. Bite location on the turtle bodies was determined as: (i) head; (ii) front flippers; (iii) hind flippers; (iv) carapace; (v) plastron.

For the analysis of the length distribution of the sharks, we established three length categories according to Fergusson (1996): juveniles (TL $\leq$ 250 cm), subadults (TL 251–450 cm) and adults (TL $>$ 450 cm). This adult class agrees with Francis' (1996) values for females which reach maturity at lengths between 450 and 500 cm TL. This also applied to the specimens whose sex could not been determined (Fergusson 2002). Size at maturity for males was established at TL $>$ 379 cm (Pratt 1996). The length distribution was constructed using TL values obtained from the weight–length relationship, but whenever TL values from photographs were available these were used instead. White shark specimens without verified TL (from weight–length relationship or photographs) and

records of this species from ancient bibliography or without verified and complete information (i.e. doubtful captures or sightings) were not taken into account for our analyses.

Records of white sharks off Balearic Islands

Catches

A total of 27 reliable captures of white sharks were reported in Mallorca (Table 1), all of them caught with trap nets targeted to the capture of bluefin tuna, *Thunnus thynnus*. Dates of recorded captures ranged between the 1920s and 1976. Most of catches (79%) were in the north-eastern coast of Mallorca, between Formentor and Capdepera (Figure 2). The percentage of catches in the remaining sectors of Mallorca was 15% in the south-western coast, between Dragonera and Cape Salines and 3% both in the north-western (between Formentor and Dragonera) and south-eastern (between Cape Salines and Capdepera) coasts. Some differences in the seasonal distribution of these catches can be observed in Figure 3, ranging from early autumn to early spring. Taking into account the additional information only on the season of capture (Table 1), 76% of them took place during winter, 24% during spring and autumn and no captures were made during summer.

Analysis of the regression between reported TL and calculated TL showed a high correspondence level. In six cases, comparison of calculated TL from photographs with communicated TL was feasible, showing close agreement, with a mean difference of 0.48 m (SE = 0.28 m). In 14 cases, reported

Table 1. Compiled data of white shark captures in Mallorca, showing their capture sector (NE: northeastern; NW: northwestern; SE: southeastern and SW: southwestern coasts), date, communicated TL (m), TL calculated from photographs (TL–PH, m) and from weight–length relationship (TL–WLR, m; Mollet and Cailliet, 1996), communicated TW (kg), sex (F: female; M: male) and the reporter.

No	Sector	Date	TL	TL–PH	TL–WLR	TW	Sex	Reporter
1[a]	NE	1920s		3.9				G. Blanc
2	NE	1920s			5.13	2000		F. Riera
3	SE	Winter 1920s	7					L. Vadell
4	SW	3.9.1927	7					J. Morey
5	SW	Winter 1935	7					B. Ginard
6	NE	Winter 1940s	>4.0		4.44	800		M. Cerdà
7	NE	Winter 1940s	>4.0		4.77	1000		M. Cerdà
8	NE	1.2.1942	4		4.44	800		J. Borràs
9	NE	12.2.1944	5.35		5.26	1350		J. Borràs
10[a]	NE	3.1962	3.5		3.82	500		J. Borràs
11[a]	NE	3.1962	3		3.24	300		J. Borràs
12	NE	Winter 1963	5		3.82	500		A. Salas
13[a]	NE	26.12.1963	6.15		6.16	2200	F	J. Borràs
14	NE	Winter 1965	7		4.77	1000		S. Bisbal
15	NE	1.1964	5.35	5.1	5.45	1400	F	J. Borràs
16	NE	1966			4.92	1100	F	J. Borràs
17	NE	1966			5.06	1200	F	J. Borràs
18[a]	NE	1.1967	5.5	5.5	5.67	1700	F	O. Pinet
19[a]	NW	1.10.1967	5.15	4.5	5.67	1700	M	J. Rullan
20[a]	NE	1967	5.35		5.26	1350	F	F. Pérez
21[a]	NE	2.1969[b]	5.5	5.35	5.13	2000	F	J. Domingo
22[a]	NE	2.1969[b]		5.5	5.97	1250		A. Vera
23	NE	2.1969[b]			4.77	1000		F. Vera
24[a]	SW	3.1969	8	6.2	6.42	2500	F	G. Ferragut
25	NE	1.1970			5.26	1350		M. Albertí
26	NE	1972			6.42	2500		M. Albertí
27[a]	NE	5.2.1976	6.15	6.1	6.42	2500	F	F. Pérez

[a]Indicates those specimens from which the authors obtained photographs.
[b]These three specimens were captured at the same point within 5 days.

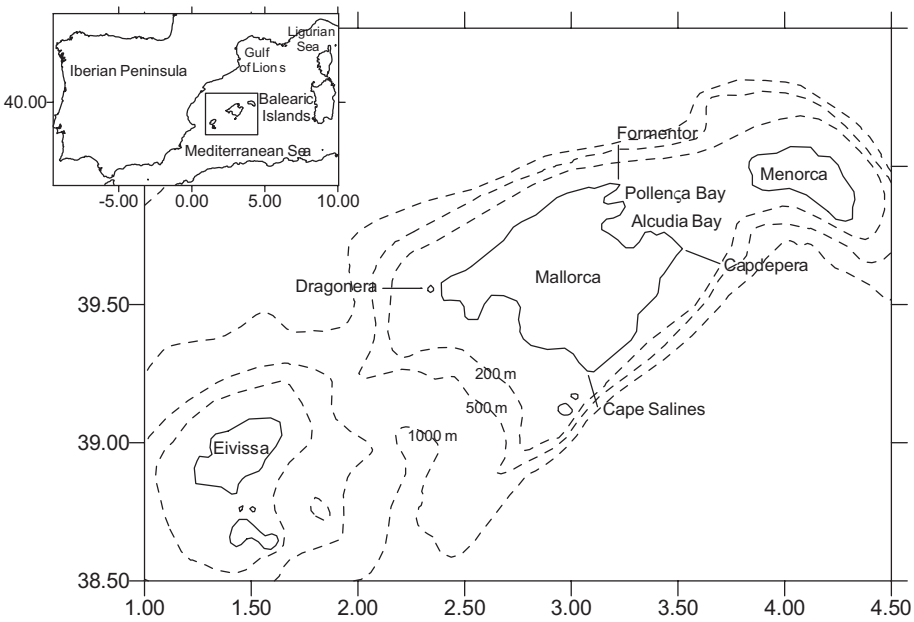

Figure 2. Map of the study area (Balearic Islands, western Mediterranean), showing the sectors considered in the analysis of the geographical distribution of white shark catches in Mallorca and strandings of cetaceans and turtles. The names cited in the text are also included.

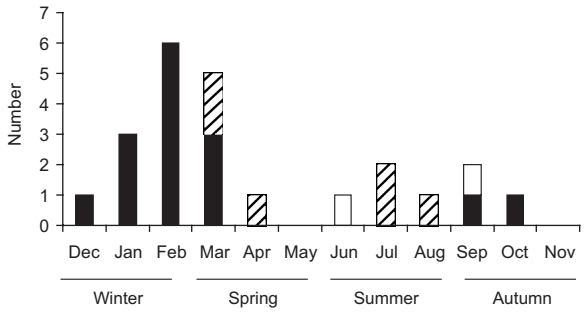

Figure 3. Monthly distribution of white shark catches (black bars) in Mallorca, and attacks of this species upon cetaceans (striped bars) and turtles (white bars) off Balearic Islands (western Mediterranean).

TL with TL derived from weight–length relationship could be compared, with a mean difference of 0.55 m (SE = 0.18 m). Thus, reported lengths of specimens greater than 7 m (numbers 14 and 24 in Table 1) can be considered as overestimated.

Length-frequency distribution of the specimens whose TL could be verified (n = 24) showed that 71% of them (17 fish) corresponded to individuals larger than 450 cm and only in seven cases (29%) was TL between 250 and 450 cm. No juveniles (TL $\leq$ 250 cm) were recorded. Sex was reported for only 10 specimens, nine females and one male. These 10 specimens together with eight unsexed were mature, while only six (all of them unsexed) were considered immature, representing a ratio of 3 : 1 in favour of mature individuals.

Strandings of cetaceans and marine turtles

Data from 26 cetaceans, belonging to the species *Physeter macrocephalus*, *Grampus griseus*, *Stenella coeruleoalba* and *Tursiops truncatus*, and seven turtles of the species *Caretta caretta* presented evidence of shark predation or scavenging, showing the incidence upon these groups of, at least, three taxa of sharks in the Balearic waters (Table 2). White shark was considered to be responsible in eight cases and *H. griseus* was considered involved in four cases. Carcharhinid species (i.e. *P. glauca* and *Carcharhinus* spp.) were grouped under the category Carcharhinidae because the responsible species for the wounds could not be determined in a total of eleven cases. Three of the cases in which the white shark was identified as the responsible species happened during March–April (Figure 3), whereas five cases occurred during June–September.

Table 2. Shark incidence upon cetaceans and marine turtles in the Balearic Sea, showing the stranded species, their TL (m) or carapace length (CL, centimeters), sex (F: females; M: males), date of stranding, bite location on their bodies (see compiled information and data analysis) and the shark species considered responsible for the bites.

No.	Cetacean species	TL	Sex	Date	Bite location	Shark species
1	*Globicephala melas*	>3		1.1.1993	1,2,3,4,5,6	Carcharhinidae
2	*Tursiops truncatus*	1.3		8.10.1996	2	Unidentified
3	*Physeter macrocephalus*	8		5.7.1997	1,2,3,4	Carcharhinidae, *Hexanchus griseus*, *Carcharodon carcharias*
4	Delphinidae		M	2.2.1998	Body sectioned behind dorsal fin	Unidentified
5	*Globicephala melas*	5.1	M	6.2.1998	1,3,4	Carcharhinidae, *Hexanchus griseus*
6	*Stenella coeruleoalba*	1.9	M	28.2.1998	3	Carcharhinidae
7	*Stenella coeruleoalba*	2.2	M	21.3.1998	2	*Carcharodon carcharias*
8	Delphinidae			9.5.1998	Body sectioned behind dorsal fin/ 3,4,5	Unidentified
9	*Tursiops truncatus*		F	29.8.1998	Body sectioned behind dorsal fin	Unidentified
10	*Stenella coeruleoalba*	1.6		25.2.1999	2,3,4	Carcharhinidae
11	*Stenella coeruleoalba*	1.2		5.6.1999	1,2,4,5,6	*Hexanchus griseus*
12	Unidentified	5		1.2.2000	1,2,3,5	Unidentified
13	Delphinidae	1.9	F	2.3.2000	3,6	Carcharhinidae
14	*Stenella coeruleoalba*	2.1	M	24.4.2000	1,2	Unidentified
15	*Tursiops truncatus*			2.5.2000	1,2,3,4,5,6	Unidentified
16	*Tursiops truncatus*	2.8		3.7.2000	1,2,3	Carcharhinidae
17	Delphinidae			8.7.2000	1,2,3	Carcharhinidae, *Hexanchus griseus*
18	*Tursiops truncatus*	3.3	F	23.7.2000	2	*Carcharodon carcharias*
19	*Tursiops truncatus*	2.6		26.7.2000	2	Unidentified
20	*Tursiops truncatus*	3.5		9.8.2000	2	*Carcharodon carcharias*
21	*Stenella coeruleoalba*	2.2	M	12.8.2000	2	Carcharhinidae
22	*Tursiops truncatus*	3.5		5.9.2000	1,2,3,4,5,6	Unidentified
23	*Grampus griseus*			3.3.2001	1,2,3,4	Carcharhinidae, *Carcharodon carcharias*
24	*Grampus griseus*			10.3.2001	2	Unidentified
25	*Stenella coeruleoalba*	1.9		19.4.2001	2	*Carcharodon carcharias*
26	*Tursiops truncatus*	2.9		9.5.2001	1,2,5	Unidentified
	Turtle species	CL				
27	*Caretta caretta*	53		26.9.1997	4	Unidentified
28	*Caretta caretta*			13.6.1998	3,4,5	*Carcharodon carcharias*
29	*Caretta caretta*			8.9.1998	5	*Carcharodon carcharias*
30	*Caretta caretta*	36.5		24.1.1999	2,3,4	Unidentified
31	*Caretta caretta*	52.5		20.6.1999	5	Unidentified
32	*Caretta caretta*			10.7.1999	5	Carcharhinidae
33	*Caretta caretta*	62.5		21.10.1999	4	Unidentified

Discussion

This study reports the presence of white sharks in the Balearic Islands since the 1920s. The two methods used to verify it can be considered as complementary. From the 1920s to the 1970s, its presence can be inferred from accidental captures in trap nets for bluefin tuna, *T. thynnus*, a fishing gear commonly used in the study area but not in use since the late 1970s, due to decline of the tuna stock and to the introduction of other fishing

methods (e.g. purse-seine nets). From the 1990s to the present, its presence can be inferred from strandings of cetaceans and turtles. The compiled reliable information from these two methods shows that occurrences of the white shark in the Balearic Islands during the 20th century are greater than those previously reported in the area (Fergusson 1996). These occurrences are also relatively higher than those reported in other Mediterranean areas: e.g. 150 specimens sighted or captured from the 17th to 20th century along the whole Italian coast (Mojetta et al. 1997) and 61 records since 1868 in the eastern Adriatic (Soldo & Jardas 2002).

The population structure of the white shark off the Balearic Islands is only made up of subadult and adult specimens. The occurrence of juvenile specimens has not been reported in the area. Although this fact can be due to misidentification of young individuals, which could be identified as *I. oxyrinchus* or *Lamna nasus* specimens (Casey & Pratt 1985, Bruce 1992), it could also be related to ontogenetic changes in feeding habits and to the different distribution of the species in the Mediterranean. Juveniles prey mostly on demersal fishes (Casey & Pratt 1985) and, therefore, are not likely to enter into the trap nets following tuna schools. In fact, only two white sharks of TL $<$ 250 cm have been reported in trap nets along the Mediterranean Sea (Fergusson 1996, Mojetta et al. 1997). In the Mediterranean Sea, large white sharks could prey or scavenge mainly upon large prey items such as cetaceans, chelonians, other elasmobranchs and large teleosts (e.g. tunas and swordfish). Moreover, it must be taken into account that Fergusson (1996, 2002) has hypothesized that parturition occurs during late spring to late summer in the central Mediterranean and that juveniles depart the Mediterranean into Atlantic waters before reaching maturity.

White sharks seem to be present around the Balearic Islands all year around, although some seasonal differences in the spatio-temporal occurrence of the species can be observed, with the highest percentage during winter off the north-eastern coast of Mallorca. This area presents a wider insular shelf (Pollença and Alcúdia bays and the channel between Mallorca and Menorca, with maximum depths over 100 m), which have been considered as preferred habitat for the species (Compagno 1984, Bruce 1992). Although seasonal changes in the use of trap nets cannot be rejected, these differences could also be due to oceanographic conditions and availability of food resources in the area. The major occurrence in winter also agrees with the hypothesized migration patterns of the white shark in the Mediterranean, with an apparent northwards displacement of the population during summer due to rising seawater temperature (Fergusson 1996), which agrees with its regular occurrence in the Gulf of Lyon during summer (Quignard & Raibaut 1993). Moreover, as it has been pointed out for other white shark populations (Ainley et al. 1981, 1985, Cliff et al. 1989, Bruce 1992, Ferreira & Ferreira 1996), the apparent seasonal distribution of white shark catches in the Balearic Islands can also be related to trophic migrations. Thus, some of its prey species show well-known northwards displacements in the western Mediterranean during the summer. This is the case for bluefin tuna (Cort 1990) and for cetaceans, which are concentrated in the Ligurian Sea during this season (Forcada et al. 1995, Marsili et al. 2001).

According to Brasseur et al. (1996), winter sea surface temperature off the Balearic Islands is around 15°C, tending to uniformity throughout the water column, which agrees with the white sharks' preference (12–22°C; Casey & Pratt 1985, Bruce 1992) and also with their greater occurrence in the area. During summer, sea surface temperatures usually range between 21.5°C and 24°C, with a thermocline at about 50 m depth. Below this surface layer, the water mass temperature is not very different from that of the winter, which should allow for white sharks' presence at greater depths or associated with the thermocline, as indicated by Carey et al. (1982). Although Fergusson (1996) reported catches of the species in the Mediterranean between 7.5°C and 25°C, he also proposed the above-mentioned displacement. But the evidence of attacks by the species upon stranded cetaceans and turtles shows the occurrence of the species during the summer off the Balearic Islands. However, this presence could be explained in terms of individual white shark patrolling offshore and deeper waters, from which they could rise into warm sea surface waters, presumably to forage. In this sense, although the usual depth range of this species has been commonly established over continental or insular shelves, Boustany et al. (2002) have recently demonstrated that it has a wider ecological niche, with a broader thermal and depth range, and more pelagic habits. Therefore, concerning the residency patterns of the white shark in the area, we can not ascribe to it the status of resident, since any evidence of the continuous or regular presence of the same individuals were obtained, in contrast to other

studies for other populations (e.g. Strong et al. 1996, Klimley & Anderson 1996).

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