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Records of Great White Shark (*Carcharodon carcharias*) in New Caledonian Waters¹

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Abstract: The occurrence of great white shark (*Carcharodon carcharias*) in New Caledonia is documented from 30 observation events (sightings or captures or forensic examination of wounds) made between 1943 and 2009, involving 34 individual sharks. Nine of the observation events concerned animals caught on lines set for deep-sea fishes, five were encounters with SCUBA divers or snorkelers and one was a fatal attack on a surfer; two other observations included great white sharks feeding on whale carcasses, two were from pop-up archival transmitting tag records that monitored individuals tagged in the Chatham Islands, New Zealand, one was a forensic identification from wounds sustained by another large shark, and seven were fortuitous sightings from boats. Nearly all observations were of solitary sharks.

Observation events were concentrated in the southern lagoon of New Caledonia or along its barrier reef. They occurred from July to March, with most records in September and November, coinciding with a peak of occurrence for large cetaceans.

INFORMATION ABOUT THE DISTRIBUTION, migration and population structure of one of the largest marine predators, the great white shark (*Carcharodon carcharias*), is notoriously poor (Pardini et al. 2001, Bonfil et al. 2005), although recent investigations directed at this species' distribution and migration patterns now make it better known than most other sharks (Boustany et al. 2002, Bonfil et al. 2005, 2010, Bruce et al. 2006, Domeier and Nasby-Lucas 2007, 2008, Weng et al. 2007). The great white shark is globally distributed mainly in temperate waters (Compagno et al. 1997) and investigations on its biology and ecology have traditionally focussed on a few temperate or subtropical populations (e.g. Cliff et al. 1996, Strong et al. 1996, Klimley et al. 2001, Hammerschlag et al. 2006, Domeier and Nasby-Lucas 2008). Great white sharks also occur in the Tropics (Taylor 1985; FishBase point maps: Froese and Pauly 2007), but the question of whether the records from the Tropics reflect permanent distribution or sporadic occurrence has not yet been resolved. Recent tagging experiments using either natural marks or satellite-transmitting archival tags have revealed that great white sharks can make trans-oceanic migrations and regularly undertake large-scale movements from cool-temperate to tropical waters (Boustany et al. 2002, Bonfil et al. 2005, 2010, Bruce et al. 2006, Weng et al. 2007, Domeier and Nasby-Lucas 2007, 2008). For all the tagging data that have been gathered in recent years, further information on behaviour and habitat utilization of great white sharks in tropical waters is nevertheless still required. Bonfil et al.'s (2010) data, from pop-up archival tags successfully attached to three white sharks at the Chatham Islands, suggest that great white sharks may regularly travel from New Zealand to the tropical southwest Pacific, including

New Caledonia and Vanuatu. More data from those tropical islands of the southwest Pacific are desirable to refine hypotheses on seasonal distributions and migration routes.

Great white sharks have previously been reported from New Caledonia by Fourmanoir and Laboute (1976) and S  ret (1994). Here, we review all known records of this species in New Caledonian waters to document eventual seasonal patterns of occurrence and we relate the latter to the availability of potential prey.

METHODS

New Caledonian waters are defined here as the area adjacent to the island of New Caledonia, eastern Coral Sea (South-West Pacific) extending seaward from the mean low water mark to the boundary of the Exclusive Economic Zone (Fig. 1). In the following, the term ‘observation event’ refers to either capture, or sighting, or other documented occurrence. Observations of great white shark in New Caledonian waters were compiled from a variety of sources including local newspapers and accounts and photographs from fishermen and divers.

The Noum  a daily newspaper *Nouvelles Cal  doniennes* reports on events from all across the New Caledonia archipelago, using a network of local correspondents. The publication of this daily started in 1971. For the period 1971–1997, all the titles of articles published in *Nouvelles Cal  doniennes* have been archived on cardboard files which have been sorted according to one main keyword per article. One of us (P.B.) manually browsed through these archives using the keywords ‘p  che’ (fishing), ‘plage’ (beach), ‘poissons’ (fishes), and ‘requins’ (sharks). We consulted either the corresponding original issues of *Nouvelles Cal  doniennes* at Biblioth  que Bernheim, Noum  a, or their copies on microfilms at Service territorial des archives, Noum  a. For the period 1998–2001, we browsed the archives of *Nouvelles Cal  doniennes* then accessible through the Internet (<http://archives-lnc.sdv.fr>) using the same series of keywords. From January 2002 to March 2009, we checked every issue of this newspaper. Additional observations were obtained from fishermen, SCUBA divers, snorkelers, and other water users, and five of the observations events reported here were our own.

We also consider the likely spatial and temporal biases in the observation events we have reviewed and present them here. We indirectly measured the seasonal distribution of observation effort as following. One of us (I.J.) undertook aerial surveys of leisure boating and fishing activity in the southern lagoon of New Caledonia from December 2005 to November 2006: during each of 42 aerial surveys

evenly distributed over the year, two observers embarked on a plane noted all boats seen from an altitude of 330 m along a 590-km long transect. The null hypothesis of across-season homogeneity of the number of boats at sea was tested by a chi-square test (Sokal and Rohlf 1995).

RESULTS

Summary of observations

Observations of great white shark in New Caledonian waters are reported in Table 1. Thirty observation events are documented from 1943 to 2009, involving 34 individual sharks. This constitutes the largest dataset on great white shark occurrence in New Caledonian waters collated to date.

The majority (53%) of great white shark captures occurred as bycatch on bottom lines set for deep-sea snappers (*Etelis* spp.) at depths between 150 m and 450 m, where sharks were hooked and died entangled in the mainline. The remaining captures were made on lines deliberately set for large sharks. Bites on a 3-m total length (TL) false catshark (*Pseudotriakis microdon*) caught on a line set at 650 m depth off Jouan Reef, Loyalty archipelago, January 2002, consisted of circular series of deep slits 3-6 cm wide, evenly spaced, with 2-3 cm gaps between consecutive slits; the radius of each bite was about 25 cm. These wounds were examined by B. Séret (IRD, Paris) who concluded they had been inflicted by a great white shark. In one instance, divers photographed two great white sharks from a shark cage off Ugo islet, southern lagoon, using the carcass of a stranded dwarf sperm whale (*Kogia sima*) as bait (Table 1). Great white sharks scavenging a giant sperm whale (*Physeter macrocephalus*) carcass had been previously observed in Sarcelle Pass between New Caledonia and Isle of Pines (November 1997; Table 1). Two records were from pop-up archival transmitting tag releases in New Caledonian waters (Bonfil et al. 2010), from sharks tagged in the Chatham Islands east of New Zealand's southern island in April 2005. Five reports involved encounters with SCUBA divers or snorkelers, and one involved a fatal attack on a surfer on the reef off Nessadiou in March 2009 (Table 1). Nearly all observations were of solitary sharks and the maximum number of sharks seen during the same event was two. All of the events involving two sharks were associated with large windfalls of food: one occurred while beef carcasses were being dumped from a grounded vessel; two were linked to scavenging on whale carcasses; and one was associated with deep-sea fishing.

The smallest individual measured was 2.6 m long. There were several sightings of individuals estimated to be 5 m TL or larger, although the accuracy of these estimates is unknown. Shark sex was seldom recorded, but both males and females were observed (Table 1). Compagno (2001) reports maximum length for great white shark males as between 501-517 cm TL, possibly 550 cm. The observation of an individual larger than this in March 1992 is therefore likely to have been of a female. No neonates or young of the year (i.e. ≤ 165 cm) have been recorded from New Caledonian waters. None of the individuals captured was necropsied.

Most observation events were in the southern lagoon of New Caledonia or along its barrier reef (Fig. 1). Great white sharks were reported from July to March (Fig. 2), with ca. 55% of the records occurring from September to November.

Seasonal variation in observation effort

Results of the aerial survey of leisure boating and fishing activity in the southern lagoon are presented in Table 2. Overall, the highest number of boats observed was in summer (January to March) and the lowest in autumn (April to June). The number of boats at sea in the autumn was about 60% of that in summer, and about 75-80% of that in winter and spring. We have no reason to suspect that the 2005-06 year was not representative of general patterns of use of the lagoon. Two great white shark sightings were reported during the survey period, one in September and the other in December.

DISCUSSION

The failure to collect scientific data from all thirteen great white shark specimens captured in New Caledonia since 1943 (Table 1) is a lost opportunity. If great white sharks are eventually captured again in New Caledonia, for example as bycatch of the deep-sea snapper fishery, the collection of such data should be given high priority.

Great white sharks in New Caledonian waters were mostly observed as single individuals, as is usual elsewhere in their range except for known hot spots such as False Bay and Seal Island off the southern coast in South Africa, the Farallon Islands in Southern California, and Guadalupe Island off Baja California (Klimley et al. 2001, Hammerschlag et al. 2006, Domeier and Nasby-Lucas 2008). Most occurrences were in the southern lagoon of New Caledonia or along its barrier reef. However this is also

where observer effort was highest: over half of New Caledonia's population is concentrated on the shores of the southern lagoon; in 2005, about 62% of the approximately 21,000 boats registered in New Caledonia were based in the Noumea area (communicated by Service de la marine marchande et des pêches maritimes, Nouméa).

Fourmanoir and Laboute (1976) have reported that great white sharks seemed to occur in New Caledonian waters only during winter, but Laboute and Grandperrin (2000) have suggested they may be year-round residents offshore. Our data (Fig. 2) indicate that great white sharks occur in New Caledonian waters from, at least, the beginning of the austral winter to the end of the austral summer, with most records occurring during the spring months, i.e. September to November. We consider that the higher reported occurrence of great white sharks in late winter and spring is unlikely to be an artefact of biased observer effort. Similarly, the low number of sightings over summer and absence of observations in autumn appears to reflect either the absence or substantially lower abundance of great white sharks in or near the New Caledonian lagoon at that time of year.

Great white sharks tagged with satellite tags in temperate Australian and New Zealand waters have been observed to migrate to subtropical and tropical regions of the South-West Pacific during the austral winter (Bruce et al. 2006, Bonfil et al. 2010). It has been proposed that great white sharks leave New Zealand waters to follow the northward migration routes of humpback whales (*Megaptera novaeangliae*) to their breeding and presumed calving grounds (Bonfil et al. 2010). Noting that the sharks tagged in April 2005 and monitored by Bonfil et al. (2010) remained until late June up to September in the vicinity of New Zealand fur seals rookeries in the Chatham Islands before embarking in oceanic large-scale movements, it is sensible to propose that factors other than whale migration may trigger the departure of great white sharks from New Zealand waters, such as the seaward dispersal of New Zealand fur seals (*Arctocephalus forsteri*) from their rookeries at the end of their breeding period in the austral autumn. Fur seals have been recorded from New Caledonian waters from July to September (Bonetti 1997, Borsa 2006, Cochin 2008a, Pion 2009), and of the seven fur seals recorded in New Caledonia, all three that were identified to species were New Zealand fur seals. Thus, great white sharks from New Zealand may not only follow the migration routes of humpback whales, but also the movements of New Zealand fur seals and perhaps those of other potential preys.

Great white sharks prey upon a wide variety of marine animals (Long 1991, Stewardson 1999, Fergusson et al. 2000, Klimley et al. 2001, Estes et al. 2003, Curtis et al. 2006, Fitzpatrick et al. 2006, Hammerschlag et al. 2006, Dicken 2008) and probably feed opportunistically on any large marine

vertebrate. It is reasonable to assume that the concentration of breeding humpback whales in New Caledonian waters in the austral winter, from June to October (Garrigue and Gill 1994, Garrigue et al. 2002, P.B. unpublished data) may explain, in part, the apparently higher abundance of great white shark in those areas at the same period. Humpback-whale placentas, still-born calves, cows undergoing problematic parturition, or bulls injured in fights with congeners are all likely to be attractive prey items to great white sharks. Sperm whale abundance in New Caledonian waters is also highest from August to December, with a marked peak in September, as is that of the pygmy sperm whale (Borsa 2006) and that of fur seals (as mentioned in the preceding paragraph). While the occurrence of great white sharks in the winter and spring may be related to that of those highly energetic food sources, other explanations have to be sought for the extension of great white shark occurrence in New Caledonian waters up to the end of summer. Other potential prey of great white sharks in New Caledonia are dugong (*Dugong dugon*) and other marine mammals, sea turtles, and deep-sea snappers, tunas and other large fishes, all of which occur year-round in New Caledonian waters. It is also possible that a proportion of the great white sharks observed in New Caledonian waters are resident year-round or most of the year, with transient sharks from around New Zealand or possibly elsewhere additionally occurring in the austral winter and spring.

The present records of great white shark from New Caledonia, together with the pop-up archival tag data of Bonfil et al. (2010) should be compared to the data recently gathered on the groups of sharks studied off central California and around Guadalupe Island, Mexico (Domeier and Nasby-Lucas 2007, 2008, Weng et al. 2007). Sharks from the North-East Pacific move from their temperate California and Guadalupe Island concentration areas to tropical waters on a seasonally predictable pattern, and individual sharks show extreme philopatry for the temperate portion of their geographic range, but the extent of the fidelity to their tropical destinations is still unknown (Domeier and Nasby-Lucas 2008). Bonfil et al.'s (2010) and our data suggest that the large-scale movement routes and timing in the South-West Pacific may be symmetrical to those uncovered in the North-East Pacific. Future research programs should consider tagging individuals in New Caledonia to determine whether great white sharks make return migrations to temperate waters and if so, at which time of the year. Whether the large-scale movements from temperate to tropical waters in the South-West Pacific are related to offshore parturition and mating, and not only foraging as assumed so far (Bonfil et al. 2010), also remains to be investigated.

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TABLE 1. Observations of great white shark (*Carcharhinus carcharias*) in New Caledonian waters, 1943-2009. *Source* includes published material and persons interviewed.

Date	Site	Coordinates	Depth	N	Observation	Voucher	Source
19 Mar. 1943	Nogumatiugi Reef	22°59'S; 166°56'E	surface	2	observed from ship <i>Pawnee</i> among many other sharks attracted by beef carcasses dumped overboard from grounded vessel <i>Delphinus</i> ; one individual "at least 15 feet long" captured using a fishing line	-	Mason 1990
-- --- 1960	Touho Pass	20°47'S; 165°16'E	sub-surface	1	captured on fishing line set for sharks	jaws	Fourmanoir and Laboute 1976
-- --- 1971	Touho Pass	20°47'S; 165°16'E	sub-surface	1	(4.2 m), captured on fishing line set for sharks	jaws	Fourmanoir and Laboute 1976
04 Sep. 1979	Saint Vincent Pass	22°01'S; 165°58'E	420 m	1	(3.8 m), captured by boat <i>Djeve</i> on fishing line set for deep-sea snapper	photos; teeth	Anonymous 1979; PT, pers. obs.
-- Jan. 1986	Bourail Pass	21°39'S; 165°26'E	50-60 m	1	(~3.0 m), captured on fishing line set for sharks	photo	Anonymous 1986; J.-C. Cazères pers. comm.
-- Nov. 1989	-	-	-	1	captured by boat <i>Thalassa</i> on fishing line set for deep-sea snapper	-	Anonymous 1990
Nov. 1989-Jan. 1990	-	-	-	1	captured by boat <i>Thalassa</i> on fishing line set for deep-sea snapper	-	Anonymous 1990
31 Jan. 1990	Grand Coude	23°01'S; 167°10'E	450 m	1	(4.5 m), captured by boat <i>Thalassa</i> on fishing line set for deep-sea snapper	photos, jaws	Anonymous 1990
22 Mar. 1992	off Isle of Pines	22°53'S; 167°35'E	400 m	1	(>5.5 m), captured by boat <i>Yasmin II</i> on fishing line set for deep-sea snapper	photos	Le Pêchoux 1992; J.-P. Garcia, pers. comm.
30 Sep. 1992	Ua islet	22°43'S; 166°48'E	6 m	1	(female, ca. 4 m), observed by SCUBA divers	photos	Marmy 1992; Laboute and Grandperrin 2000
16 Oct. 1994	Boulari Pass	22°30'S; 166°27'E	surface	1	observed by SCUBA divers	-	B. Andreani, pers. comm..
04 Jan. 1997	Walpole island	22°36'S; 168°56'E	450 m	1	(4.5 m), captured on fishing line set for deep-sea snapper	photo	Martin 1997
-- Jul. 1997	off Isle of Pines	22°37'S; 167°38'E	surface	2	observed from boat <i>Thalassa</i> ; one individual (2.6 m), then captured using a fishing line	photo	Anonymous 1997; J.-P. Garcia, pers. comm.
29 Nov. 1997	Sarcelle Pass	22°28'S; 167°12'E	surface	2	(including 1 male), observed from boat, feeding on the carcass of a giant sperm whale drifting at the surface	photos	Bonetti et al. 1998
15 Nov. 1998	Grand Coude	23°04'S; 167°08'E	150-300 m	1	(4.5 m), captured on fishing line set for deep-sea snapper	jaws	Antoine and Le Pêchoux 1998
16 Nov. 1998	Grand Coude	23°04'S; 167°08'E	150-300 m	1	(4.1 m), captured on fishing line set for deep-sea snapper	jaws	Antoine and Le Pêchoux 1998
27 Jan. 2002	off Jouan Reef	20°35'S; 166°58'E	650 m	1	fresh remains of <i>Pseudotriakis microdon</i> entangled on fishing line set for alfoncino, from RV <i>Alis</i>	wounds	Girard 2002; B. Séret pers. comm.; PB, pers. obs.
-- Aug. 2002	Boulari Pass	22°30'S; 166°27'E	15 m	1	observed by SCUBA divers	-	R. Monthouel pers. comm..
22 Sep. 2002	off Redika Islet	22°29'S ; 166°30'E	surface	1	observed from boat	-	Gavelle 2002
-- Sep. 2003	off Toombo reef	22°33'S; 166°26'E	surface	1	observed from boat	-	F. Larue and P. Larue pers. comm..
-- Aug. 2005	Sarcelle Pass	22°28'S; 167°12'E	surface	1	observed from boat	photos	Frédière 2005a
05 Sep. 2005	Grand Coude	22°44'S; 167°09'E	-	1	(female, 4.0 m TL) tagged in the Chatham Islands in April 2005 by M. Francis; last known position indicated here	electronic records	Frédière 2005a; Bonfil et al. in press
05 Oct. 2005	off Maré Island	21°11'S; 169°42'E	-	1	(male, 3.2-3.5 m TL) tagged in the Chatham Islands in April 2005 by R. Bonfil; last known position indicated here	electronic records	Frédière 2005b; Bonfil et al. in press
11 Nov. 2005	Redika Islet	22°30'S; 166°38'E	surface	1	observed from boats	-	Frédière 2005c
14 Dec. 2005	Tiotibagi Reef	22°36'S; 166°56'E	surface	1	observed from boat	-	Ribot 2005; J.-J. Raban pers. comm..
11 Sep 2006	Ugo Islet	22°27'S; 166°56'E	surface	2	attracted by the carcass of a dwarf sperm whale used as bait	photos	Frédière 2006
08 Sep. 2007	Dumbea Pass	22°22'S; 166°15'E	18 m	1	male, observed by SCUBA divers	photos	Chatel and Bourdil 2007
07 Nov. 2007	M'Ba islet	22°13'S; 166°13'E	surface	1	observed from boat	photos	Anonymous 2007
23 Aug. 2008	Mato Pass	22°39'S; 166°38'E	surface	1	female, observed by snorkelers	photos	Cochin 2008b
06 Mar. 2009	off Nessadiou	21°42'S; 165°28'E	surface	1	fatal attack on surfer	wounds	Chatel 2009; A. Lafage pers. comm.; PT, pers. obs.

TABLE 2. Evaluation of temporal bias in observation effort of great white shark (*Carcharodon carcharias*), assumed to be proportional to the number of boats at sea. A total of 42 aerial surveys (each of 3 hours, in the morning, 590 km long, over the southwest lagoon of New Caledonia) was undertaken from December 2005 to November 2006 to count boats. *Number of boats* is the number spotted by two observers on the plane along the 590-km transect; *Autumn* from 21 March to 21 June; *Winter* from 21 June to 21 September; *Spring* from 21 September to 21 December; *Summer* from 21 December to 21 March. Significant heterogeneity was present in each of the datasets (chi-square test: $P < 0.001$)

<i>Day of week, Variable</i>	Season			
	Autumn	Winter	Spring	Summer
<i>Holiday or weekend</i>				
Total number of boats	1437	2103	1209	2086
(Number of aerial surveys)	(5)	(5)	(5)	(7)
Average per aerial survey	287.4	420.6	241.8	298.0
<i>Working day</i>				
Total number of boats	517	611	1159	1255
(Number of aerial surveys)	(5)	(5)	(6)	(5)
Average per aerial survey	103.4	122.2	193.2	251.0
<i>Any (2 working days for 1 holiday)</i>				
Average per aerial survey	164.7	221.7	209.4	266.7

FIGURE 1. Great white shark (*Carcharodon carcharias*). Spatial distribution of the individuals ($N=31$) reported from New Caledonian waters over the period 1943-2009. The individual that released its satellite archival tag on 06 October 2005 does not appear on this map as its last known position was off limits. The precise location of two other individuals was not available (see Table 1). *Thin circle*: one individual observed; *thicker circle*: two individuals; *cross*: Noumea city. *Light-grey areas* represent New Caledonia and surrounding islands; *darker-grey contours* delineate the barrier reef.

FIGURE 2. Great white shark (*Carcharodon carcharias*). Distribution of observations ($N=31$ individuals) in New Caledonian waters, by month, over the period 1943-2009.



