CHAPTER 25

Use of Photo Identification to Describe a White Shark Aggregation at Guadalupe Island, Mexico

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ABSTRACT

Photo-identification (photo-ID) techniques have been used to monitor and track northeastern Pacific White Sharks (*Carcharodon carcharias*) at a seasonal adult aggregation site at Guadalupe Island, Mexico. Between 2001 and 2009, 142 sharks have been photographed, 113 of which have been entered into a catalogue that requires both the left and right sides to be photographed. This catalog consists of 67 males (59%) and 46 females (41%). The photo-ID data demonstrated White Sharks to be present at Guadalupe Island between late July and December, although effort past December was minimal. Sharks exhibited seasonal site fidelity, with 83% of the sharks in the catalog sighted in at least 2 yrs. and 28% sighted in at least 5 yrs. of the study. Males were found to return to the island earlier than females, with the sex ratio reaching parity in November. Males were more likely to be sighted in consecutive years, whereas females were more likely to exhibit a non-consecutive year visitation pattern. However, only a small percentage of sexually mature females exhibited a consistent every-other-year pattern, which has been proposed to be associated with an 18-month gestation cycle. The continuation of this photo-ID program will provide important data on life history, migratory patterns, and abundance, which will aid in the management and conservation of this vulnerable species.

INTRODUCTION

Over the past decade, worldwide numbers of large pelagic sharks have been declining because of targeted fishing, trophy hunting, and fishery bycatch (Baum et al., 2003; Myers and Worm, 2003). Included in these statistics are White Sharks (*Carcharodon carcharias*), which are particularly

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vulnerable because of the high market value of their jaws and fins (Shivji et al., 2005; Dulvy et al., 2008). These threats, along with biological characteristics such as low intrinsic rate of population increase (Cailliet et al., 1985; Francis, 1996; Pratt, 1996; Smith et al., 1998; Compagno, 2001), late maturation, and natural rarity, make this species susceptible to overexploitation (Smith et al., 1998; Myers and Worm, 2003). White Sharks are now listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Flora and Fauna and are also listed as vulnerable by the World Conservation Union (IUCN, IUCN Global Red List status VU A1cdþ+2cd) (Hilton-Taylor, 2000).

White Sharks are a global apex predator found in relatively low numbers. In the northeastern Pacific Ocean, adult White Sharks are known to seasonally aggregate at two sites off the coast of North America: Guadalupe Island (GI), Mexico, and Central California (CC), United States. Previous studies have shown that sharks from both of these regions make a seasonal winter/spring migration to an area termed the Shared Offshore Foraging Area (SOFA), centered midway between the Hawaiian Islands and Baja California (Boustany et al., 2002; Weng et al., 2007; Domeier and Nasby-Lucas, 2008). Pop-up satellite tagging and photo-identification (photo-ID) data have shown philopatry in eastern Pacific White Sharks, with individual sharks returning to their specific aggregation site in late summer/early fall (Boustany et al., 2002; Domeier and Nasby-Lucas, 2007, 2008; Weng et al., 2007). The act of seasonally aggregating at a known time and place creates a period of local vulnerability when directed or incidental harvest could lead to local, if not regional, sharp population decline. This presents a serious threat to White Sharks, and the monitoring and management of these aggregation sites are critical for the conservation of eastern Pacific White Sharks.

Photo-ID of individual White Sharks is an important long-term tracking tool that can aid in the monitoring of these aggregation sites. Previous photo-ID studies have provided information on residency patterns (Klimley and Anderson, 1996; Domeier and Nasby-Lucas, 2007) and spatiotemporal differences in sex ratio (Strong et al., 1992; Domeier and Nasby-Lucas, 2007), as well as short- and long-distance movements (Anderson and Goldman, 1996; Bonfil et al., 2005). Recently, two photo-ID databases in the northeastern Pacific were used to estimate the abundance of White Sharks at the GI aggregation site (Chapter 26, this book) and the CC site (Chapple et al., 2011). The long-term use of this information will be an important tool in tracking trends in abundance of White Sharks over time and will be essential for the establishment of management policies.

The GI, Mexico White Shark population has been monitored via photo-ID since 2001 (Domeier and Nasby-Lucas, 2007). GI is 407 km south-southwest of San Diego, California and 260 km offshore of Baja California, Mexico and is both a Mexican nature preserve (dedicated in 1925) and a pinniped sanctuary (1975). The island serves as a haulout and pupping site for the Northern Elephant Seal (*Mirounga angustirostris*), the Guadalupe Fur Seal (*Arctocephalus townsendi*), and the California Sea Lion (*Zalophus californianus*). The photo-ID project at GI uses pigment patterns to identify individual White Sharks, and as of 2005, Domeier and Nasby-Lucas (2007) had collected 5 yrs. of data resulting in a catalog of 73 individual White Sharks. These data showed repeat patterns in seasonal visitation, with 78% of the sharks being resighted at the island in multiple years. Through both photo-ID tracking and previous satellite tagging studies (Domeier and Nasby-Lucas, 2008), it has been shown that male White Sharks return to GI every year in late summer, whereas sexually mature females may return in alternate years (Domeier and Nasby-Lucas, 2007; Chapter 16, this book). The 2-yr. migration pattern for females is proposed to be associated with a presumed 18-month gestation cycle (Mollet et al., 2000).

This paper provides a valuable update of the photo-ID database from GI. The goals for the continuation of the GI photo-ID database include the following:

1. Continue to monitor the visitation patterns of previously identified White Sharks at GI, as well as add new sharks to the database.
2. Monitor the visitation pattern of sexually mature females to examine the hypothesized every-other-year visitation pattern.

3. Examine the observed sex ratio for GI White Sharks.
4. Provide mark-recapture type data that can be used for annual population estimates (Chapter 26, this book).

MATERIALS AND METHODS

Between 2001 and 2009, photographic images of White Sharks at GI, Mexico, were obtained from video and still cameras operated by caged divers or through the use of a camera mounted on a hand-held pole. Images were taken by the authors and divers who volunteered images after visiting the site on commercial cage-dive operations that began in 2002. Photographer, date, and location were logged for each photograph. Pigment patterns from three regions of the body were used to identify sharks: the gill flaps (extension of the interbrachial septum), pelvic fin region, and caudal fin region. Two nonpigment characters were also recorded to aid reidentification: the sex of the fish and permanent trauma-induced markings (i.e., major scars, damage and notches on the trailing edge of the dorsal fin, and any mutilations) (Figure 25.1) (see Domeier and Nasby-Lucas (2007) for a detailed description of pigment pattern identification methods).

A catalog of identified sharks was maintained, and sharks were assigned numbers in the order they were identified. Only sharks with photos from both the left and right side were added to the catalog, because pigment patterns are not bilaterally symmetrical. Length data were added when available either using actual measurements from captured sharks (Chapter 11, this book), calculated using a paired-laser system, or estimated while the shark was next to a boat or shark cage of known length. Length values are reported as total length. Sexual maturity was based on total length and was designated for males of at least 3.6 m and females of at least 4.5 m in length (Francis, 1996; Pratt, 1996). A summary sighting log was kept to track the years and months the individual sharks were sighted at the island, and the complete database was compiled indicating each date that each individual shark was sighted at the island.

Sighting data were analyzed to determine number of sharks per week, month, and year as well as to calculate the sex ratio and examine repeat-visitation patterns of individual sharks. The number of sharks sighted per week was adjusted for effort by dividing the number of sharks by the effort for that particular week. Effort was dependent upon the number of days that dive boats were present at the island and was determined by counting the number of individual days in which photos were taken. The year 2001 was omitted from the analysis of sightings by week because of very little effort. Sex ratio was calculated from the total number of sharks in the database and by sharks sighted each year. Sex ratio was also calculated by month from the average number of male and female sightings from 2002 to 2009. Repeat-visitation patterns were examined to determine whether sharks were sighted in consecutive years, nonconsecutive years, or only once. Any gap between years of sighting was considered nonconsecutive.

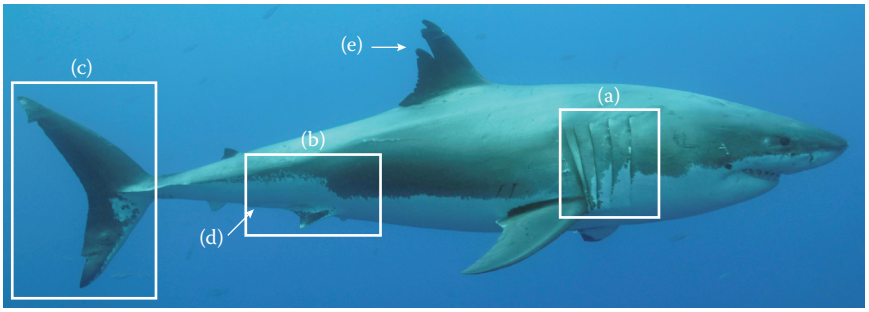

Figure 25.1 Characters used in identification of White Sharks include pigment pattern at the gill flaps (a), pelvic fin (b), caudal fin (c), the sex of the shark (d), and dorsal fin notches or any additional mutilations (e). (Courtesy of Stephen McCulloch, Harbor Branch Oceanographic Institute.)

RESULTS

The photographic and video records collected from 2001 to 2009 led to the identification of 113 individual White Sharks from GI consisting of 67 males (59%) and 46 females (41%) (Table 25.1). Ninety-four (83%) individuals were sighted in more than 1 yr. (females $n = 38$, males $n = 56$), and of these, 12 were identified in at least 7 yrs. (all male), 7 in 6 of the 9 yrs. (4 males, 3 female), 13 in 5 of the 9 yrs. (8 males, 5 females), 18 in 4 of the 9 yrs. (12 males, 6 females), 26 in 3 of the 9 yrs. (15 males, 11 females), and 18 in 2 of the 9 yrs. (5 males, 13 females) (Figure 25.2). Effort varied by year, but the maximum number of sharks sighted in a single year was 62 in 2005 (39 males, 23 females). The maximum number of individual sharks sighted in one month was 40 in September 2005 (29 males, 11 females) (Table 25.2), and the maximum effort was also in September 2005, with 23 d (Table 25.3). Twenty-one sharks have not been sighted since 2005 or earlier. This includes 12 females and 9 males (Table 25.1). The longest gap between sightings was 6 yrs. for a female (#6) and 4 yrs. for males (#17, #71, #73, and #96; Table 25.1).

Between 2006 and 2009, 40 new sharks were added to the database. Eight of the new sharks included a corresponding length resulting in the determination of two sexually immature males, two sexually mature females, and four sexually mature males added to the database. Ten of the new sharks were found to previously exist in our records as orphans. Orphans are defined as sharks for which there are photographs of only one side and therefore cannot be entered into the catalogue (Domeier and Nasby-Lucas, 2007). Once an orphan is matched with images of the opposing side, years worth of data can be recovered for that individual. In this case, all 10 recovered orphans allowed for data for these new sharks to be entered from 2005 or earlier (Table 25.1). To date, we have 27 left-side and 29 right-side orphans remaining, representing a minimum of 29 additional individual sharks. Adding the 29 orphans to the 113 fully identified individual sharks results in a minimum of 142 sharks photographed at GI since 2001.

Male White Sharks seasonally arrived at GI earlier than females. The earliest male sighting was July 14, whereas the earliest female sighting was August 20. August sightings of females were quite rare (maximum of two in any given year), but males were commonly observed in August (maximum of 25 in any given year) (Table 25.2). The rate (number of individuals sighted per day of effort) of female sightings increased as the season progressed, peaking in November. Male sightings peaked in late August to early September and decreased thereafter, but peaked again in December (note that there were very few days of effort in December, and most photos taken in December were by the authors on scientific expeditions) (Figure 25.3).

The overall sex ratio for the GI White Shark photo-ID catalog was 1.5:1 (male:female) and was significantly different than 1:1 (chi-squared $P = 0.05$). The sex ratio by year from 2002 to 2009 ranged from 1.4:1 to 2.9:1 (Figure 25.4). The ratio of males to females by month for all years combined (Table 25.2) was significantly different in August and September (ratios 18.8:1 and 3.1:1, t-test $P = 0.0001$, 0.0008). The overall sex ratio was more uniform in October, November, and December (ratios 1.6:1, 0.9:1, and 2.7:1, respectively; t-test $P = 0.08$, 0.88, and 0.16, respectively).

The return visitation patterns exhibited in the GI photo-ID database were examined for all sharks. A similar percentage of males and females were sighted in only 1 yr. (males 16.4%, females 17.4%), but they differed for sharks that were sighted in consecutive years (males 53.7%, females 26.1%) with females having a higher percentage of sightings in nonconsecutive years (males 29.9%, females 56.5%) (Figure 25.5). Six females with nonconsecutive visitation patterns exhibited a consistent every-other-year pattern. Two of the females exhibited a pattern of every other year for 5 yrs. and then returned in the following consecutive year (both of these sharks were over 5.1 m and presumed sexually mature), seven females were present in consecutive years and then began an every-other-year pattern (length was unknown), three females were present every third year (one

Table 25.1 **Sighting Log of All Sharks by Year**

		2001	2002	2003	2004	2005	2006	2007	2008	2009
1	F			■	■	■	■	■		■
2	F		■	■	■	■				
3	F			■	■			■		
4	F		■	■	■		■			■
5	F			■	■	■				
6	F			■						■
7	M		■	■	■	■	■	■	■	■
8	M			■	■	■	■	■		
9	M	■	■	■	■	■	■	■	■	
10	M			■	■	■				
11	M			■	■	■	■	■	■	■
12	M			■	■	■				
13	M	■	■	■	■	■	■	■	■	■
14	M		■	■	■	■	■	■	■	■
15	M	■	■	■	■	■	■	■		■
16	M	■	■	■		■				
17	M	■	■	■		■				■
18	M			■	■	■		■		■
19	M	■	■	■	■	■	■	■	■	■
20	F			■	■	■	■		■	
21	M				■	■	■	■	■	■
22	M		■		■	■	■			■
23	M	■	■	■	■	■	■	■	■	■
24	M				■	■	■	■		
25	M			■	■	■	■	■		
26	M			■	■	■	■			
27	M				■		■	■	■	■
28	F			■	■			■	■	■
29	F				■	■				
30	F				■	■	■	■		■
31	F				■	■			■	
32	M			■	■	■	■	■	■	■
33	M			■	■	■			■	
34	M				■	■	■	■	■	
35	F			■	■	■	■	■	■	
36	F		■	■	■		■		■	
37	F		■		■		■			
38	F				■			■		
39	F				■		■		■	■
40	F		■		■		■			
41	F				■	■				
42	F		■		■		■		■	
43	F	■	■		■	■				
44	F				■	■				
45	M		■	■	■			■		■
46	M	■		■	■	■	■	■	■	■
47	F				■	■	■	■	■	■

continued

Table 25.1 **(Continued) Sighting Log of All Sharks by Year**

		2001	2002	2003	2004	2005	2006	2007	2008	2009
48	M									
49	M									
50	M									
51	F									
52	M									
53	F									
54	F									
55	M									
56	M									
57	F									
58	F									
59	M									
60	F									
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84	F									
85	M									
86	M									
87	F									
88	M									
89	M									
90	M									
91	F									
92	M									
93	M									
94	M									
95	M									

Table 25.1 (Continued) Sighting Log of All Sharks by Year

		2001	2002	2003	2004	2005	2006	2007	2008	2009
96	M		■			■				■
97	M							■	■	■
98	F								■	
99	M							■	■	■
100	F									■
101	M									■
102	M									■
103	M									■
104	F									■
105	M							■	■	■
106	F								■	■
107	M							■	■	■
108	F					■		■		■
109	F								■	■
110	M									■
111	M									■
112	F					■		■		■
113	M									■

This table lists all sharks by year and indicates the number of the shark and whether it is a male or a female. Gray shading indicates that the shark was sighted at Guadalupe Island in that year.

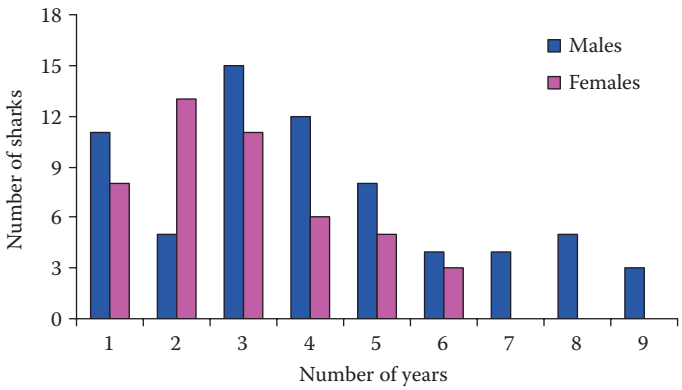

Figure 25.2 Number of annual visitations documented for individual male and female White Sharks at Guadalupe Island (*n* = 113).

shark was 4.8 m and two were of unknown length), one female was sighted every fourth year (length unknown), and one was sighted every sixth year (4.6 m).

DISCUSSION

The long-term photo-ID monitoring of White Sharks at GI has resulted in a 9-yr. data set that tracks the seasonal presence of individual White Sharks. Forty sharks have been added to the database since 2007 (Domeier and Nasby-Lucas, 2007), bringing the total to 113 identified sharks. An additional 29 discrete orphan records exist for a minimum total of 142 photographed individuals. Eighty-three percent of the sharks in the database were sighted in more than 1 yr., with 11% of

Table 25.2 Sighting Log of All Sharks by Month

	July	August	September	October	November	December	Total
2001	0/0	0/0	4/0	6/1	1/1	0/0	11/2
2002	2/0	4/0	6/3	5/2	8/8	0/1	17/11
2003	0/0	13/1	11/1	9/4	15/11	10/3	27/13
2004	0/0	11/0	20/8	19/11	11/16	12/6	33/24
2005	0/0	10/1	29/11	16/10	10/11	11/3	39/23
2006	0/0	15/1	17/5	9/11	3/8	0/0	28/12
2007	0/0	25/1	29/4	25/10	7/7	3/1	43/15
2008	0/0	18/2	20/7	14/11	1/1	7/5	34/17
2009	2/0	17/0	22/10	15/14	9/9	0/0	40/18

The total number of individual sharks (male/female) sighted for each month and year of sampling. Annual totals reflect the fact that many individuals were sighted in more than one month.

Table 25.3 Days of Effort by Month and Year

	July	August	September	October	November	December	Total
2001	0	0	1	1	1	0	3
2002	2	2	6	6	5	1	22
2003	0	9	5	6	15	2	37
2004	0	3	10	13	19	5	50
2005	0	6	23	12	13	3	57
2006	0	11	16	12	11	0	50
2007	0	6	18	21	6	2	53
2008	0	13	17	12	2	5	49
2009	2	10	20	20	12	0	64

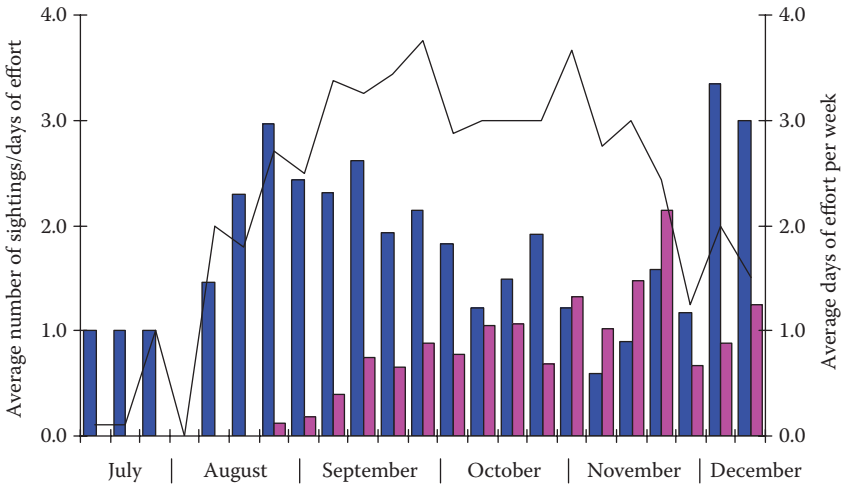

Figure 25.3 Average number of sharks sighted by week adjusted by weekly sighting effort. Blue indicates male, pink indicates female, and the black line shows average days of effort for that week over all years of data.

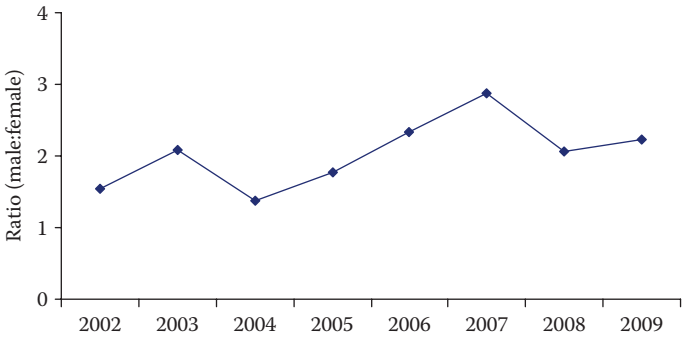

Figure 25.4 Sex ratio of sharks sighted by year.

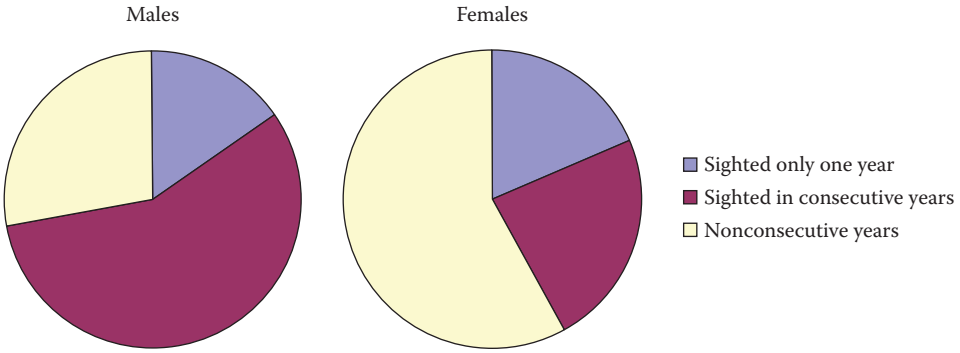

Figure 25.5 Repeat sighting pattern for all sharks in the catalog; males were more frequently sighted in consecutive years than females.

the identified sharks recorded in 7 yrs. or more, providing clear evidence of long-term, seasonal philopatry of White Sharks around GI.

The aggregation of White Sharks at GI consists of adults and subadults; small juveniles have not been recorded by our program. The majority of the sharks added to our database since 2005 have no length estimate, but two were known to be subadult males, perhaps an indication of new recruitment to GI. Young-of-the-year, juvenile, and subadult White Sharks are believed to inhabit coastal regions year round (Klimley, 1985; Chapter 16, this book), but it is not known how or when subadults recruit to the adult aggregations found at GI and CC.

Six of the newly catalogued individuals were large enough to be considered sexually mature. One of these mature sharks was a 5.4-m male, possibly the largest male recorded anywhere in the world (Chapter 16, this book); it is unlikely that this shark could have been present at GI for each of the previous 9 yrs. without being sighted, leading to the possibility that some sharks may recruit to GI from elsewhere, as fully mature adults. It is also possible that the absence of this large male in previous years is an artifact of different behavioral responses between individual sharks; however, larger sharks are typically dominant in the presence of a bait source, which would increase the probability of sighting a large individual (Laroche et al., 2007).

Sex-Specific Differences

The overall sex ratio of White Sharks at GI was biased toward males (1.5:1). This may be a genuine male bias but is likely to be an artifact of sampling. Females arrive later in the season when

photographic effort declines. Furthermore, effort ceases prior to the seasonal dissolution of the aggregation, so the entire aggregation period is never sampled. For any given year, we would expect a male-biased sex ratio because of the fact that mature females have a 2-yr. migratory pattern that causes a large portion of the female population to be absent from the adult aggregation (Chapters 11 and 16, this book). Over the course of this study, the male bias in the sex ratio has increased over time. There are several factors that could contribute to this observation:

1. Beginning around 2005, effort increased in the early part of the season and decreased in the latter part, which is when the females are most prevalent at the island.
2. Mature females are not present at the island each year making it easier to "miss" individual females.
3. Males travel back and forth from the middle of the Pacific Ocean (SOFA) to GI, where there are few interactions with fisheries, but it is assumed that mature females travel to areas along the coast of Southern California and Baja California, Mexico to give birth (Chapter 16, this book). Females are then more likely to have an incidental fatal encounter with fishing activities that are concentrated along the coast of North America.

Analysis of sex ratio by month illustrates the changing sex ratio as the season progresses. Males arrived late July or early August, whereas females arrived in September with the number of females increasing through September and October. Over the entire history of the program, we have a 0.9:1 sex ratio for the month of November, a time when there is still reasonable sampling effort, and females are present. Spatial and temporal sexual segregation is not uncommon in sharks (Klimley, 1987; Sims, 2005; Robbins, 2007; Chapter 11, this book). Seasonal segregation of White Sharks may be due to prey availability, differing physiological needs, or reproductive habits. The diminishing rate of male White Shark sightings after the return of females could also be an artifact of intraspecific behavior. Larger sharks are often observed chasing smaller sharks away, and females are typically larger than males, possibly contributing to the apparent decline of the rate of male sightings until December.

Differences in visitation patterns between the sexes were noted, with the females more likely to be sighted in nonconsecutive years. This pattern has been observed at the White Shark aggregation in CC (Anderson and Pyle, 2003), as well as in other species of sharks. Pratt and Carrier (2001) found that in Nurse Sharks (*Ginglymostoma cirratum*), the adult males visit every year whereas adult females visit the study area to mate in alternate years. This corresponds with patterns observed in eastern Pacific White Sharks using satellite telemetry data (Chapter 11, this book), and in light of newly emerging reproductive data (Chapters 16 and 30, this book), the eastern Pacific adult White Shark aggregation sites may be mating sites.

Although prior studies have suggested that mature females have a strong every-other-year pattern of visitation to the adult aggregation sites (Anderson and Pyle, 2003; Domeier and Nasby-Lucas, 2007), the longer time series presented in this study revealed that established individual female visitation patterns are malleable. While females were more likely to exhibit a nonconsecutive year visitation pattern, only a small percentage exhibited a consistent every-other-year pattern. Two sexually mature females appeared in consecutive years after a history of appearing every-other-year, whereas another mature female was sighted every third year. This variation in mature female visitation patterns could indicate that mating is not always successful or that females may sometimes skip a reproductive cycle. There is much to learn regarding reproduction in White Sharks. Continued monitoring via photo-ID combined with multiyear tracking via electronic tagging will help to answer these important life history questions.

CONCLUSIONS

The GI White Shark photo-ID project is an important monitoring tool for the GI White Shark aggregation. This database has allowed us to produce the first ever index of abundance for the GI

White Shark aggregation (Chapter 16, this book). Although we do not know the absolute number of adult and subadult White Sharks that visit GI, clearly it is a relatively low number of individuals, which indicates the importance of managing and protecting this population. It is currently prohibited to kill White Sharks in U.S. and Mexican waters, but there is evidence of incidental catch on juveniles along both coasts that will have an effect on the adult population (Galván-Magaña et al., 2010; Chapters 14 and 15, this book). This study is important for monitoring the size and stability of the GI White Shark population and is critical for long-term management. Learning more about the multiyear migration patterns and where female White Sharks go to give birth is important in protecting this vulnerable shark, which travels great distances and is known to cross international boundaries.

ACKNOWLEDGMENTS

We would like to thank T. Pfleger, J. Harper, M. Graf, P. Douglas, L. Groth, and S. Drogin for their assistance in taking and collecting photographs. We also thank all cage divers who allowed us to view their photos. This project was funded through the George T. Pfleger Foundation, the Offield Family Foundation, and the Guadalupe Island Conservation Fund. We thank F. Galván-Magaña, M. Hoyos-Padilla, and O. Sosa-Nishizaki for Mexican permitting support. Research was conducted in accordance with permits through the Comisión Nacional de Áreas Naturales Protegidas.

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