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Residency of the scalloped hammerhead shark (*Sphyrna lewini*) at Malpelo Island and evidence of migration to other islands in the Eastern Tropical Pacific

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Abstract Sixty nine hammerhead sharks, *Sphyrna lewini,* were tagged at Malpelo Island (Colombia) with ultrasonic transmitters during March 2006, 2007 and 2008, as part of a study to understand their residency at the island and their horizontal and vertical movements. Five sharks visited Cocos Island, 627 km distant from Malpelo. One of the sharks that appeared at Cocos Island also visited the Galapagos Islands, 710 km from Cocos, a month later. There is connectivity of *Sphyrna lewini* between Malpelo, Cocos and the Galapagos Islands, but the frequency of movements between the islands appears to be relatively low (<7% of the tagged sharks). The most common depth at which the sharks swam coincided with the thermocline (rs=0.72, p<0.01). The depth of the thermocline varied depending on the time of the year. Nocturnal detections of the sharks were more frequent during the cold season than during the warm season (W=60, p<0.01). We also found that hammerheads spent significantly more time on the up-current side of the island (Kruskal-Wallis=31.1008; p<0.01). This study contributes to the knowledge of hammerhead sharks not only in Malpelo Island but also at a regional level in the Eastern Tropical Pacific.

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Introduction

The Eastern Tropical Pacific Seascape (ETPS) is an area of more than 2 million hectares, spanning the national waters of Panama, Costa Rica, Colombia and Ecuador, and international waters in between. Marine Protected Areas (MPAs) have been designated around some of the oceanic islands in the region, most notably the Galapagos Marine Reserve (138 000 km^2), the Cocos Island National Park (1997 km^2), and the Malpelo Flora and Fauna Sanctuary (9584 km^2). Although the marine reserves were created using the best available knowledge at the time, little was known about the movement and residency patterns of key marine creatures which the

MPAs were designed to protect. Baseline studies were often implemented after their creation (e.g. Danulat and Edgar 2002).

As top predators, sharks are an important group within the ETPS marine ecosystem. In particular, the scalloped hammerhead shark (*Sphyrna lewini*) is known to aggregate in large schools around all these oceanic MPAs. This species has a world-wide distribution from warm temperate waters to the tropics (Ferrari and Ferrari 2001). Its late sexual maturity, low fecundity and low natural mortality results in this species having a low intrinsic rate of population increase (Ferrari and Ferrari 2001). Hence, it is highly vulnerable to overexploitation (Camhi 1998; FAO 2000; Newmark and Santos-Acevedo 2001; Watts 2001; Baum et al. 2003; Simpfendorfer and Heupel 2004; Chapman et al. 2005; Jennings et al. 2005).

Local and regional agreements to limit the capture of sharks as well as the creation of new MPAs are key actions for the protection and conservation of this species. Sharks are also becoming an important source of income for dive ecotourism (Orams 1996; Davis and Banks 1998; Norman 2000; Landmann 2000; Pedersen 2002; Chapman et al. 2005; Dobson 2006; Torres et al. 2007).

Understanding the temporal and spatial scales at which sharks move is of paramount importance to ecologists and conservationists since it gives us a better understanding of habitat use and key sites occupied by these species (Schneider 1994). The tagging of sharks using ultrasonic telemetry is a very useful technique to understand the behavior of these top marine predators (Sciarrotta and Nelson 1977).

In this paper we present information on the movements of the scalloped hammerhead shark at Malpelo Island and evidence of connectivity with other oceanic islands in the Eastern Tropical Pacific (ETP) region. Our main questions are: Do hammerhead sharks display site fidelity at Malpelo Island? What are the diel and seasonal movement patterns of hammerhead sharks at Malpelo Island? Are the populations of hammerhead sharks of Malpelo connected with those of the Galapagos Archipelago and Cocos Island? This study is part of a broader, regional initiative to understand the temporal and spatial relationship between the shark populations of the oceanic MPAs of the ETP.

Material and methods

Study area

Malpelo Island (3°58′N and 81°37′W) is located in the ETP, 490 km from the port of Buenaventura off the Colombian Pacific coast (Fig. 1). The island, 1.2 km^2 in area, is surrounded by eleven pinnacles and its highest point is 300 m above sea level (López-Victoria and Rozo 2006). The waters surrounding Malpelo Island are influenced seasonally by four currents: 1) the North Equatorial Countercurrent, 2) the South Equatorial Current, 3) the Colombia Current and 4) the Panama Cyclonic Current (Rodríguez-Rubio et al. 2007). The extent of mixing of the water masses depends on the interannual migration of the Inter-Tropical Convergence Zone (ITCZ) (Rodríguez-Rubio et al. 2003), and also upon larger scale cycles such as El Niño Southern Oscillation (ENSO) (Devis-Morales et al. 2008). The interactions of currents in Malpelo result in two distinct cold and warm water seasons. During the cold season, from January to April, the waters surrounding the island are high in nutrients and productivity caused by ocean upwelling, which is produced by the interaction between winds originating from Panama and the waters off the Colombian Pacific ocean (Rodríguez-Rubio and Stuardo 2002; Rodríguez-Rubio et al. 2003). The sea surface during the cold season ranges from 20°C to as high as 27°C, however the thermocline can be found relatively shallow (<15 m). Below the thermocline the water temperature can drop as low as 14°C. The water visibility in the top layer (above the thermocline) can be as low as 5 meters due to the high nutrient content water but normally ranges from 10 to 15 m. Below the thermocline the water visibility is up to 50 m. The currents during this period flow from north to south with an average velocity of 100 cm/s (Rodríguez-Rubio et al. 2003; Devis-Morales et al. 2008). During the warm season, from May until the end of December, the average sea surface temperature is around 27°C (Rodríguez-Rubio et al. 2007). At this time, the waters are clear with an average visibility of 25 m, the thermocline is usually >50 m, the currents flow from southwest to northeast with an average velocity of 90 cm/s (Devis-Morales et al. 2008), and there is a higher nutrient and chlorophyll-a content at a depth of 60 m due to the absence of upwelling (Rodríguez-Rubio et al. 2007).

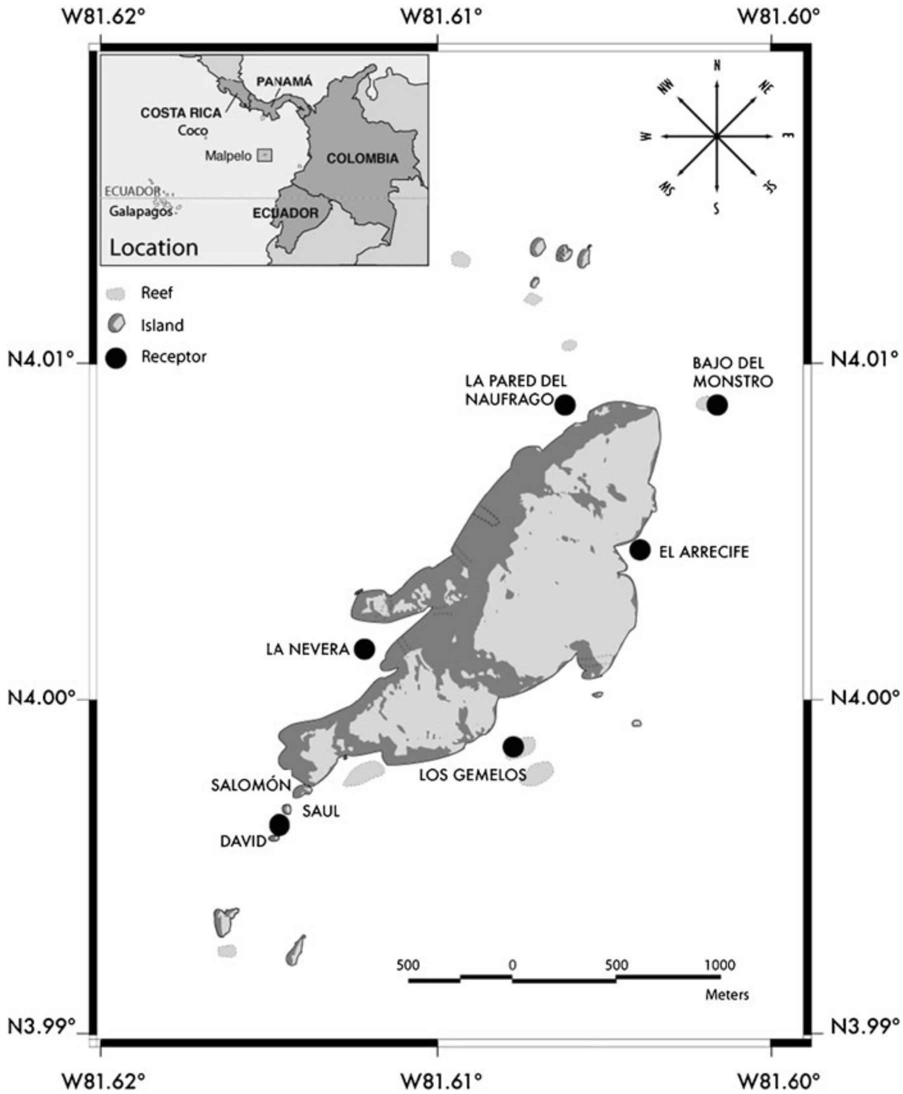

Fig. 1 Malpelo FFS and location of ultrasonic receivers around the island

Ultrasonic telemetry

The tags were affixed to sharks by free divers by inserting a stainless steel barb into the dorsal musculature of the sharks. The tag was attached with a tether to the barb, which was placed in the inset of the tip of a spear gun or pole spear. Sixty nine ultrasonic tags were deployed from 2006-2008 during three expeditions carried out in March; 13, 16 and 40 tags for each of the 3 years, respectively (Table 1). The ultrasonic tags used were of two types: coded transmitters (V16-6H, Vemco Ltd., Halifax, Canada) and sensor tags (V16TP-6H, Vemco Ltd.) that were capable of measuring depth and temperature (16×94 mm, weight in water 14 g, with battery life of approximately 3010 d). The transmitters used in 2006 and 2007 were set to be silent (delay) for a randomized period of 50 to 160 s and the ones used in 2008 were set to be silent for a randomized period of 60 to 190 s between each pulse train and worked in code map R04K and R64K, respectively. The delay for the 2008 transmitters was increased to reduce the collisions between signals since there were 40 tags installed. Both types of tags conveyed an individually specific code for a particular shark which periodically emitted a 'pulse train' of closely spaced 69 kHz 'pings' and were detected by six tag-detecting ultrasonic receivers (VR2,

Table 1 Details of tags, serial number, type, accuracy, date implanted, tagging location in the island, sex and size of the 69 hammerhead sharks tagged in Malpelo during March 2006, 2007 and 2008 with ultrasonic transmitters

TAG #	Type	Range of accuracy	Code	Date implanted	Location
1	V16TP	from—5 to 35°C / 0 to 1020 m	168/169	3/2/2006	Pared del Aguila
2	V16TP	from—5 to 35°C / 0 to 1020 m	170/171	3/1/2006	Arrecife
3	V16TP	from—5 to 35°C / 0 to 1020 m	172/173	3/1/2006	Bajo de Junior
4 to 13	V16		128 to 137	2/28/2006 to 03/02/2006	Los Gemelos, Nevera, Pared del Aguila, Bajo de Junior
14 to 29	V16		1933 to 1942 and 3459 to 3464	3/8/2007	Arrecife
30 to 69	V16		6922 to 6965 [a]	03/08/2008 to 03/12/2008	Arrecife

[a] some codes were not used. Sharks ranged in size from 1.3 to 2.5 m

36 females, 23 males and 10 sharks of unknown sex were tagged

Vemco Ltd.) situated around the island at locations where sharks are normally seen (Fig. 1, Table 2). Each successfully decoded pulse train was recorded as a single detection by a VR2 receiver and stored in the receiver memory as the unique transmitter number, date and time of detection. The information of the receivers was downloaded nine times during the 3 year period (every 4 to 5 months). If a shark was not registered in any receiver it was assumed that the shark was absent from the island, the tag was shed, or the animal was dead. Similar arrays of receivers were also deployed by other research teams in the Galapagos Islands (Hearn et al. 2010), and at Cocos Island (Arauz, *personal communication*).

Table 2 Location of the receivers placed in Malpelo, depth where they were installed and general configuration of the surrounding environment

Receiver location	Depth (m)	Bottom configuaration
Arrecife	28	Sand and ruble
Monstruo	60	Rock
Naufrago	40	Sand and ruble
Nevera	22	Rock
David	40	Sand and ruble
Gemelos	27	Rock

Range tests

We conducted range tests to determine the maximum distance of detection of the ultrasonic transmitters by the receivers. These range tests were conducted in three different locations (Arrecife, David and Gemelos) around Malpelo Island, which differ in their general environmental conditions and water current. These tests were performed at a maximum distance of 400 m from the VR2 receivers using an inflatable boat. Five V16 transmitters were lowered to 10 m depth and waited for at least two pulses or a 10 min interval every 50 m until the 400 m distance was reached. In the three places where the range test was performed, the receivers were able to listen to the transmissions in a range of 300 to 350 m or less, however 50% detections occurred between 200 to 250 m.

Environmental variables and depth of sharks

Monthly environmental variables (sea surface and altimetry data) were obtained from the DIVERSITY Project (Themis) at a resolution of 4 km. At each site, where ultrasonic receivers were deployed, scuba divers determined the depth of the thermocline (see ultrasonic telemetry section). During each dive, two or more scuba divers recorded abrupt changes in water temperature at depth using their dive computers

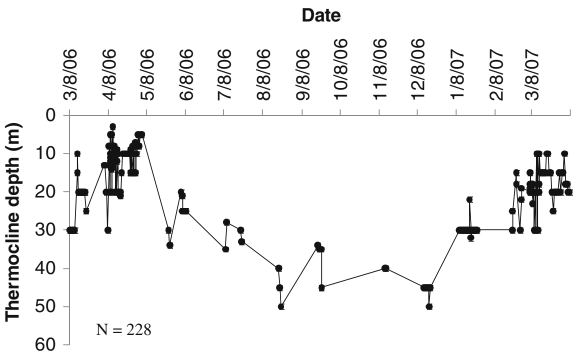

Fig. 2 Mean (+/−Standard Error) thermocline depth per month around Malpelo, from March 2006 until March 2007. N=228 was the number of dives where the thermocline was determined

(Fig. 2). This activity was carried out during tagging cruises and other research cruises to the island. The thermocline was defined as the depth at which the rate of temperature change was greatest. The depth of the sharks was recorded by the ultrasonic receivers. The correlation depth of sharks vs. depth of thermocline was compared only for days with information for both variables. Furthermore, visual censuses were also conducted and the approximate depth of the sharks was estimated in relation to the depth of the divers. During these censuses, experienced divers were asked to record the presence, size and depth of individual sharks, and to estimate the school size where appropriate. Census results were normalized by dividing the abundance by the time spent underwater.

Data analysis

We compared the number of days present per shark at each receiver with the direction and intensity of currents (DIVERSITY project, Themis) from March 2007 to April 2009. For this comparison, we used 42 sharks for the cold season and 27 sharks for the warm season, and altimetry measurements from satellite data sources (JASON-1 and ENVISAT). There were two predominant current conditions: southerly direction during the cold season and northeasterly during the warm season. We used a multiple comparison test among medians (Fisher—Least Significant Difference) to determine whether certain sites showed similarities or differences.

Results

Tagged hammerhead sharks were detected by receivers at each of the six sites around the island (Fig. 3). Some of the sharks remained within the

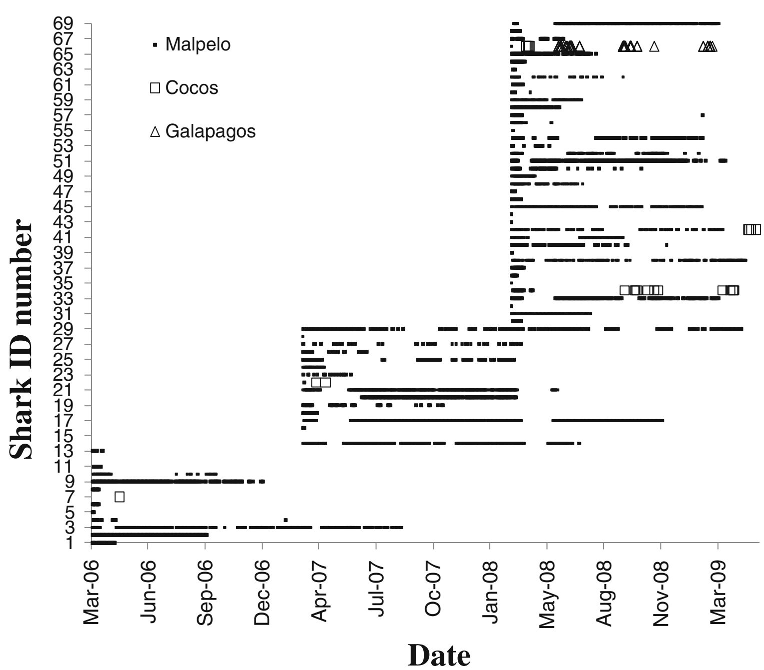

Fig. 3 Presence of tagged sharks at Malpelo from 2006–2009. 69 tags deployed were detected by the receivers. Note there were five sharks tagged in Malpelo detected in Coco's Island (□). One of these sharks was also detected in the Galapagos archipelago (Δ)

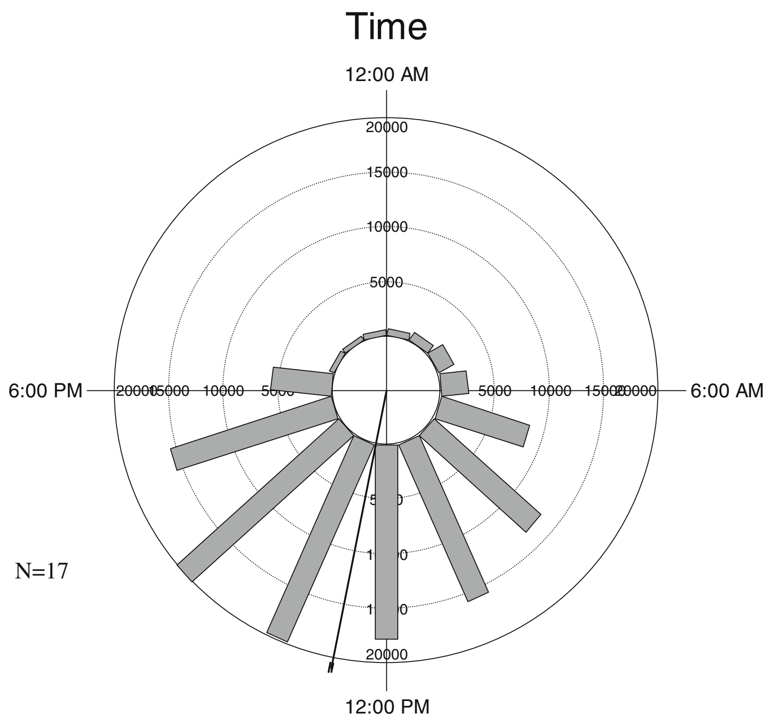

Fig. 4 Number of transmissions received for each hour for *Sphyrna lewini* in Malpelo during the 3 years of study. Seventeen sharks which held their tags for 10 months or longer were used for this graph. The mean vector was 12:45 pm and r was equal to 0.636—r is a measurement of the concentration of sharks. The Rao's Spacing Test ($p<0.01$) shows that the data was not evenly spread (uniform) throughout the day

range of the receivers for less than a week before departing (Fig. 3). Other sharks remained at the island for periods ranging from two weeks to several months, whereas others left the island and returned after periods ranging from two weeks to several months (Fig. 3). It is worth noting that some of the tagged hammerhead sharks left the island and returned back to Malpelo with only some days of difference between each other, please see Fig. 3 (ID: 14, 15, 20, 21, 25). Five of the sharks tagged in

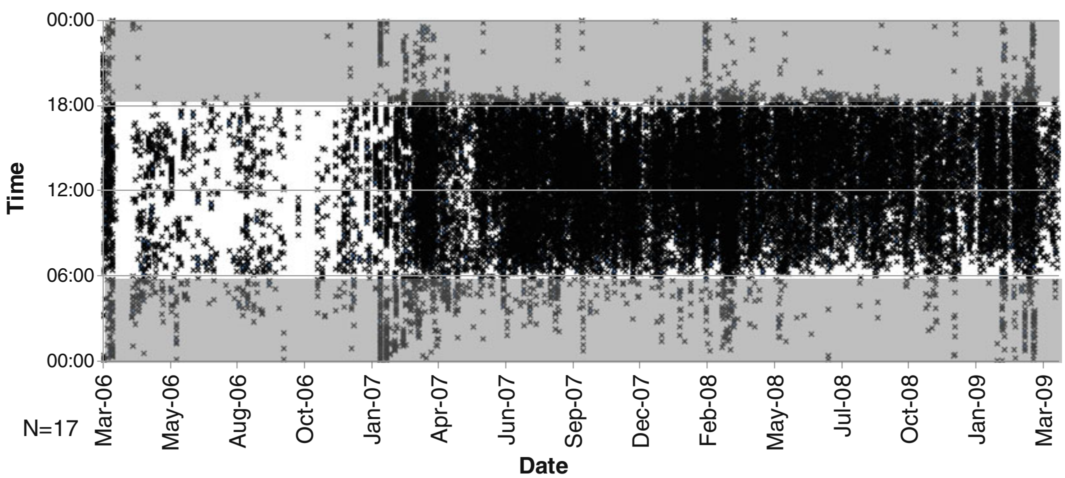

Fig. 5 Hour of detections received by all receivers during the 3 year study period for 17 (N) sharks which held their tags for 10 months or longer. As seen in the graph day detections were far more common than night detections. Grey areas are showing approximate night time

Malpelo Island with ultrasonic transmitters were recorded at Cocos Island, 627 km from Malpelo, during 2006, 2007, 2008 and 2009. Moreover, one of the sharks (ID 63) detected in April 2008 at Cocos Island was also recorded at the Galapagos Islands, 710 km from Cocos Island, from the end of May 2008 until March 2009 (Fig. 3).

There were many more transmissions recorded during daytime than at nighttime throughout the study period ($p<0.05$) (Fig. 4; Fig. 5). This was consistent with the sharks remaining close to the island during the day and moving into the surrounding waters away from the detection range of the receivers at nighttime. The sharks were detected more often at nighttime during the cold season compared with the warm season (Fig. 6). For this comparison we used information from 17 sharks which held their tags for 10 months or longer and we compared 14 months corresponding to the Cold seasons of 2006 to 2009 vs. 14 months corresponding to the Warm seasons of 2006 to 2008. There were significant differences between the medians at 99% significance (Mann-Whitney–Wilcoxon=60.0, $p<0.01$), suggesting that the hammerhead sharks stayed closer to the island and for longer periods at night during the cold part of the year, and remained away from the island at night during the warm season.

The depths registered by the ultrasonic tags near the receivers show that there is a relationship between the depth at which the sharks swam and the depth of the thermocline as measured by divers near the receivers ($rs=0.72$, $R^2=0.44$, $p<0.01$). For example,

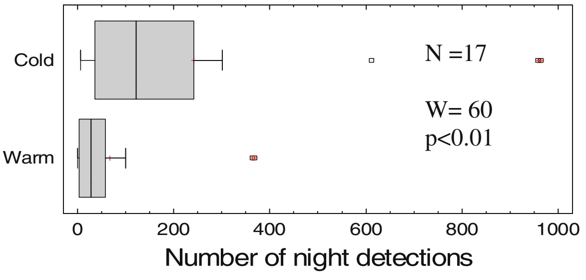

Fig. 6 Comparison of number of detections at night for the 3 year period for 17 sharks (*Sphyrna lewini*) which held their tags for 10 months or longer. In order to make this comparison 14 months of the cold season (January to April) were compared against 14 months of the warm season (May to December) for the 3 years of study. As seen the number of night detections during the cold season were significantly greater than the night detections during the warm season

the recorded depths of the sharks ranged from five to 15 m when the thermocline was at 10 m; conversely, their depths varied from 10 to 50 m when the thermocline was at a depth of 30 m (Fig. 7a). Thus, when the thermocline was shallow, hammerhead sharks swam mainly near the surface, and when the thermocline was deeper the sharks swam not only at the surface, but also at greater depth within the mixed layer. This same trend was observed by visual census conducted by divers with significant relationship between the depth of the hammerhead sharks and the thermocline (Fig. 7b).

The depth of sharks did not always correlate with a particular temperature. For example, a particular shark (code 172/173) swam at greater depths as the temperature decreased from August to September, but continued to swim at similar depths as the temperatures rose from October to November. We used this shark (172/173) as an example since it was one out of three sharks carrying temperature and depth sensors, which remained affixed to the sharks for over 15 months. The deepest average depth registered by this shark carrying an ultrasonic transmitter was 49 m during December when the mixed layer was at its deepest (50 m) as measured by a dive computer (Fig. 2). The depths at which the shark swam near Malpelo were relatively shallow, ranging from 14 to 50 m, depending on the time of the year. However, the maximum depth recorded might be an artifact of the range of detections of the receivers (±300 m), determined from range tests performed and the depth of the island shelf at that distance (<100 m). Hammerhead shark schools sighted by divers were found fairly deep during the warm water season (around 25 m), and shallower during the cold season, around 18 m ($W=5533.5$, $p<0.01$) (Fig. 8).

Significant differences were found between the number of days present per shark at each site (Kruskal-Wallis=31.101 $p<0.0001$). Using a multiple comparison test among medians (Fisher LSD) of number of sharks detected per day during the cold season with south current at the six receivers showed that Arrecife, Monstruo and Naufrago (receiver stations in the northern part of the island) formed a separate group, whereas David, Nevera and Gemelos (stations in the opposite side of the island) constituted a second group (see upper graph –a- and map, Fig. 9 and Table 3).

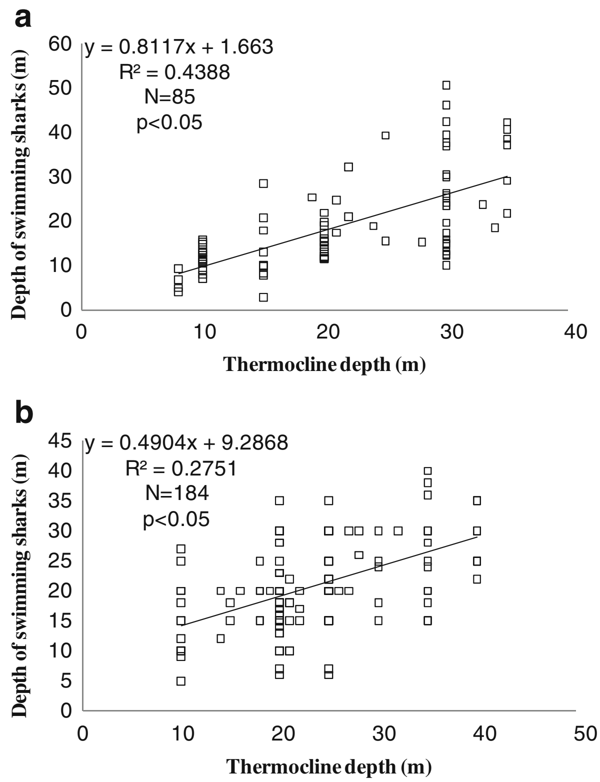

Fig. 7 **a** Linear regression of depth of the three hammerhead sharks (168/169, 170/171, 172/173), equipped with V16TP (Temperature depth sensors), determined by ultrasonic transmitters and depth of thermocline. In N=85 cases there was comparable information for thermocline and depth of the three sharks with depth temperature transmitters. The information presented is from March 2006 until July 2007 period in which these three tags were active. **b** Linear regression of depth of sharks estimated by divers vs depth of thermocline. N=Number of independent dives where sharks were sighted and thermocline determined. The information presented is from January 2007 until November 2009

Similarly, using a multiple comparison test among medians (Fisher LSD) of number of sharks detected per day during the warm season with northeasterly current at the six receivers, hammerheads spent more days at the receivers situated at David, Nevera, Naufrago on the southwestern side and Monstruo located on the northwestern side of the island (see lower graph –b- and map, Fig. 9 and Table 4). Although, Naufrago and Monstruo are located at the northern end of the island, both of these places were subject to strong currents, which correlates with the higher number of days per shark detected at these sites. Nevertheless, the only significant difference in the number of days per shark between sites was with Gemelos located in the southeastern side of the island. Gemelos is only exposed to weaker current conditions during the warm water period presumably being the cause for fewer numbers of days detected per shark.

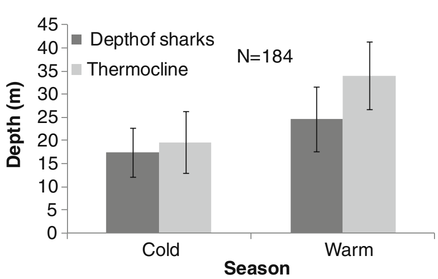

Fig. 8 Depth of hammerhead schools vs thermocline in Malpelo Island determine by visual census during the cold and warm season, from January 2007 until November 2009. N=Number of dives where sharks were sighted

Discussion

The results obtained during this study cast new light on the understanding of the behavior and local and regional movements of hammerhead sharks at Malpelo Island. The sharks tagged at Malpelo and detected in Cocos and Galapagos support our hypothesis that the local population of hammerheads present in Malpelo are not exclusive of this island but move widely within the region. Some individuals left the area for long periods of time, for over a month, and some did not return. However, it is very possible that some of the tags were shed or that several sharks were fished, accounting for the diminishing of detections in time (Fig. 3). This was the case for the 3 years of study.

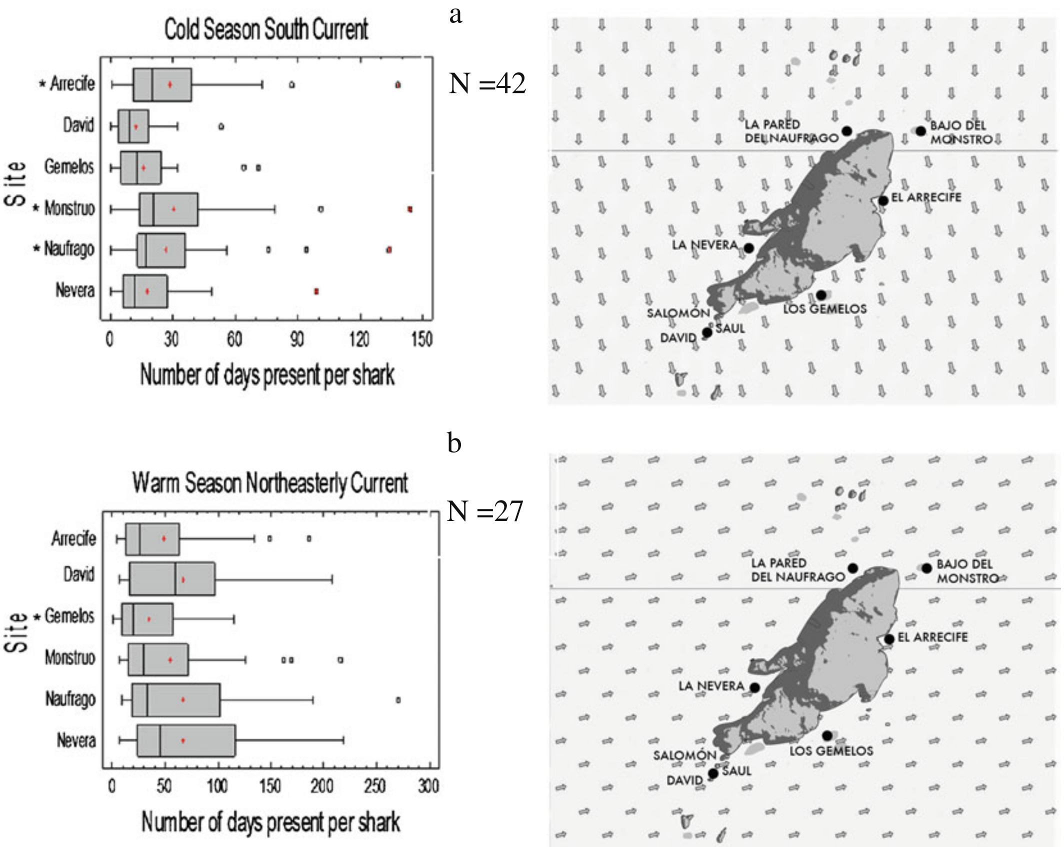

Fig. 9 Comparison of number of sharks present per day at each of the receivers around the island during **a** Cold (North current) and **b** Warm season (Southwester current). N=number of sharks used for each season. The graphs on the right show a typical current condition for each period, the arrows show where the current was coming from. The *asterisk* denotes similarity (cold) or difference (warm) within each group

Our results show that many of the tagged sharks left the area between March and beginning of April in the 3 years of study (Fig. 3). Many individuals were seen apparently pregnant during the first months of the year. This was determined by the size of the abdominal area compared to other females in the schools and females observed with well developed pups in their wombs fished illegally inside the marine

Table 3 Multiple comparison test among medians (Fisher LSD) of number of sharks detected per day during the Cold season with south current at the six receivers. Arrecife, Monstruo, Naufrago (located in the north part of the island) and Nevera grouped homogeneously while David, Nevera, Gemelos (located in the south part of the island) and Naufrago form a second homogeneous group

	Freq.	Mean	Homogeneous groups	
David	42	12.4048	X	
Gemelos	41	15.5366	X	
Nevera	42	17.8333	X	X
Naufrago	42	26.5476	X	X
Arrecife	42	28.5952		X
Monstruo	42	30.5		X

Table 4 Multiple comparison test among medians (Fisher LSD) of number of sharks detected per day during the Warm season with northeasterly current at the six receivers. Gemelos, Arrecife and Monstruo grouped together while Arrrecife, Monstruo, David, Nevera and Naufrago formed a second group. The only significant difference was Gemelos against David, Naufrago and Nevera

	Freq.	Mean	Homogeneous groups	
Gemelos	27	34.7037	X	
Arrecife	27	48.7037	X	X
Monstruo	27	55	X	X
Naufrago	27	66.7407		X
David	27	67.1852		X
Nevera	27	67.4444		X

protected area during the same period in previous years. Out of 125 female hammerhead sharks fished illegally in February 2002 inside the Malpelo's Marine Protected Area, 84 were pregnant (Bessudo *personal observation*). These observations and our results support the idea that sharks are leaving the island in March and April to move to pupping areas away from Malpelo and returning to the island at a later time. Hearn et al. (2010) also found that the abundance of hammerheads at the Galapagos Islands declined from March to June. Other studies in different areas found that sharks move widely. Kohler and Turner (2001) summarize maximum known travel distances for a number of shark species, based on tagging studies. They found that the maximum recorded distance moved by a scalloped hammerhead shark was 1671 km. Our results show that the total distance covered by a hammerhead that travelled from Malpelo through Cocos to Galapagos, and around Galapagos was at least 1941 km. Extensive movements have also been reported in other species, such as tiger sharks (*Galeocerdo cuvier)* in Hawaii (Holland et al. 1999; Meyer et al. 2010), white sharks (Bonfil et al. 2005), and whale sharks, *Rhincodon typus* (Eckert and Stewart 2001).

Sharks were found to school around the island, but they displayed a specific diel pattern, a seasonal signal, and spent more time in particular sites at the island—mainly those facing the impinging current. Hammerhead sharks at Malpelo spent significantly more time near the receivers during daytime than at nighttime. This same pattern has been reported by Klimley and Nelson (1984) in Bajo de Espiritu Santo and by Hearn et al. (2010) in the Galapagos Islands. A higher proportion of nighttime detections were observed at Malpelo for the first months of the year compared with the second half of the year. This could be related with the high nutrient and clorophyll-a content (Rodríguez-Rubio et al. 2007) and, consequently, the high abundance of food at the island during this period of the year, based on fish census (Malpelo Foundation unpubl.). Increased food abundance close to the island would imply that sharks need to spend less time foraging in search of food and would probably move away for lesser distances and spend more time schooling at the island. From May to December hammerhead sharks apparently moved away from the island at night, perhaps to forage in the pelagic environment, which may explain why there were less detections—during the night for this period.

The largest schools of hammerhead sharks in Malpelo were found from January to March, and these groups started to diminish in size by April and once more peaked in size in May and diminishing towards the end of the year. A similar trend but for different times of the year has been observed in Cocos Island, with peaks of abundance during May to July, and for Wolf and Darwin islands in the Galapagos, with a peak from January to February and a second peak in August to October (Randall and Gherinich, pers. comm.; Hearn et al. 2010). In El Bajo de Espiritu Santo, large schools of hammerhead sharks were seen during the summer (July to October) and fish assemblages changed depending on the season (summer or winter; Klimley et al. 2005).

In Malpelo, hammerheads were found below, but also within and above the thermocline, thus not restricted to thermal gradients. The correlation between the depth at which the sharks swim and the depth of the thermocline has also been observed for hammerheads in the Galapagos Islands (Ketchum, pers. comm.) and on other species of sharks like *Galeocerdo cuvier (*Holland et al. 1999). It was suggested by Holland et al. (1999) that tiger sharks could be using the thermocline as a reference point, and Klimley et al. (1993) found that the hammerhead sharks around El Bajo de Espiritu Santo swam most of the time below the thermocline; however their vertical movements were not restricted by strong thermal gradients (Klimley 1993), similar to the hammerheads at Malpelo and Galapagos (Ketchum et al. in prep).

Our results indicate that the scalloped hammerhead sharks around Malpelo Island were more common on the side of the island where the current was strongest. However, Klimley and Nelson (1984) found that the hammerhead sharks at El Bajo de Espiritu Santo, Mexico, did not change their position in relation to tidal currents. These differences in behavior in relation to the current can probably be related with the disparity in the bottom topography and oceanographic dynamics of each site. El Bajo de Espiritu Santo is a seamount relatively near–shore bound by the oceanographic conditions of the Gulf of California (Trasviña et al. 2003), while Malpelo Island is an oceanic island of larger size subject to the oceanography of the equatorial ETP (Rodríguez-Rubio et al.

2007). In the Galapagos Archipelago, particularly in Wolf and Darwin islands, hammerhead sharks seem to show a similar behavior as in Malpelo, with the largest aggregations of hammerhead sharks found up-current in the side of the island where the current flows into (Hearn et al. 2010).

Most hammerhead sharks are present at Malpelo for extended periods of time throughout the year, then leaving and returning to the island after a couple of days or several months. Sharks moved in and out of the island during the three study seasons, and some of them coinciding in their movements by leaving the island with some days of difference and being away for similar periods (see Fig. 3). This could suggest that hammerhead seasonal movements in Malpelo are linked to the different oceanographic conditions present at the island. Thus, seasonal environmental signals may trigger migratory movements from Malpelo to pupping areas near the coast and homing back to the island several months later. Individuals tagged with color-coded spaghetti tags were observed at the Espiritu Santo Seamount one and 2 years after tagging (Klimley and Nelson 1984) a clear example of homing as observed in Malpelo, but in a different time scale.

Our work demonstrates the importance of telemetric studies for the management and conservation of hammerhead sharks in Malpelo and other islands of the ETP. We showed that hammerheads move widely in the ETP, therefore multinational efforts are crucial for their conservation. Similar studies should be conducted in potential Marine Protected Areas to gather information on the behavior of this and other species of sharks. Furthermore, stock assessments need to be carried out at a national level and then integrated by taking into account the connectivity between islands. Also, periods of open ocean movements need to be defined; perhaps special fishing restrictions might operate during these times throughout the region. This needs to be addressed within a framework of international cooperation. Currently a joint effort between regional scientists in the ETP is underway known as Migramar (www.migramar.org). This group should work in the near future to answer questions still remaining such as the where, spatial patterns of movements throughout the ETP, why, the causes underlying their movement (e.g., reproduction, feeding), and how, the environmental cues that control movement (e.g., temperature, geomagnetism, *sensu* Klimley 1993). Finally, protected areas need to take into account shark movements in full diel cycles to be able to protect the total expanse of their habitat, and future work aimed at defining nightly foraging areas as well as nursery and pupping will be of great priority.

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