Figura 1. Impressive marine vista dominated by a group of hammerhead sharks

Photo: Alex Hearn

Hammerhead sharks of Galapagos: their behavior and migratory patterns

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Hammerhead sharks (*Sphyrna lewini*) are unique among sharks in many ways, most notably in the shape of their head. Their gregarious behavior has always fascinated people, so much so that many tourists spend large amounts of money to travel around the world to observe them. In the Galapagos Islands, hammerhead sharks, along with whale sharks (*Rhincodon typus*), Galapagos sharks (*Carcharhinus galapagensis*), and reef whitetip sharks (*Triaenodon obesus*), constitute an important attraction for dive tourism (Espinoza and Figueroa, 2001), generating substantial income for the local economy. This is due to the fact that the archipelago remains one of the few locations in the world where these animals can still be seen in large groups (Figure 1). This article presents a review of a series of studies carried out under a hammerhead shark tagging and monitoring program in the Galapagos Marine Reserve (GMR) .[1]

Hammerhead sharks are at risk primarily due to overfishing. Strong economic pressure for the commercialization of shark fins worldwide has provoked an increase in the capture of sharks and their fins along the entire western coast of South America (WildAid, 2005). An estimated 1.7 million tons of sharks are captured worldwide annually (Clarke *et al.*, 2006). In the GMR, sharks are protected by law (AIM, Resolution No.011-2000), but unfortunately illegal

[1]The complete analysis of telemetry data of the hammerhead shark will be presented in the doctoral thesis of James Ketchum and in scientific publications currently being prepared by the research team.

fishing continues to threaten their survival. In the last ten years, up to 20,500 fins have been confiscated (GNP, 2009).

Why should we conserve these animals? In addition to their high value as a resource for non-extractive activities such as tourism (WildAid, 2001), sharks play a very important role in marine environments. Most are top-level predators, meaning they feed on many animals but almost no other animal feeds on them. They help to maintain population stability of their prey, preventing disproportionate increases in their numbers and any resulting negative impacts on other marine organisms. However, sharks are very sensitive to any deterioration in their population. Their life history characteristics (low reproductive rate, long-lived, and late sexual maturity) prevent rapid population recuperation following significant reductions in their numbers (Compagno *et al.*, 2005). Examples of direct negative impacts (in shark populations) and indirect impacts (in marine environments as a result of the removal of sharks) are currently reported frequently in the scientific literature (for example: Stewart and Wilson, 2005; Myers and Worm, 2005; Heithaus *et al.*, 2007; Myers *et al.*, 2007).

For these reasons, the authorities of the Galapagos National Park (GNP) implemented a complete ban on the capturing of any sharks within the GMR. Still, protection of sharks requires a better understanding of their distribution, abundance, behavior, and interactions with the marine environment. Baseline information is needed to detect trends in their population status over time. Without this information, conservation efforts will not have a solid scientific foundation. To address these information needs, the Research and Conservation of Sharks Project began over three years ago, as a multi institutional effort of the Charles Darwin Foundation, the GNP, and the University of California-Davis.

The shark tagging project

Since its beginning in 2006, the project has primarily focused on studying the movements of hammerhead sharks, at both macro and micro levels. To date, more than 130 sharks have been tagged and monitored in the northern zone of the archipelago, specifically around Darwin and Wolf Islands, using acoustic and satellite telemetry. Three types of equipment were used: (i) ultrasonic tags for continuous monitoring of individual sharks; (ii) ultrasonic tags for long-term monitoring using monitoring stations, and (iii) satellite tags to permit remote monitoring at a macro scale (Figure 2). Continuous monitoring was done for more than 48 hours at a time around Wolf Island. Monitoring stations were installed in strategic locations throughout the archipelago to be able to detect the acoustic tags, with the greatest density around Darwin and Wolf Islands (Figure 3; for greater detail on the methodology, see Hearn *et al.*, 2008).

Daily behavior

Much as human beings follow daily routines, the seven hammerhead sharks monitored continuously showed interesting movement patterns (Figure 4). During the day the sharks remained very passive in

Figure 2. Left: Free diving method for attaching ultrasonic tags on the posterior portion of the dorsal fin of the shark (Photo: Eduardo Espinoza). Right: Attaching a satellite tag onboard the Sierra Negra of the GNP. The tag is attached to the dorsal fin of the shark while a constant stream of seawater is poured over the shark to allow respiration (Photo: Peter Oxford).

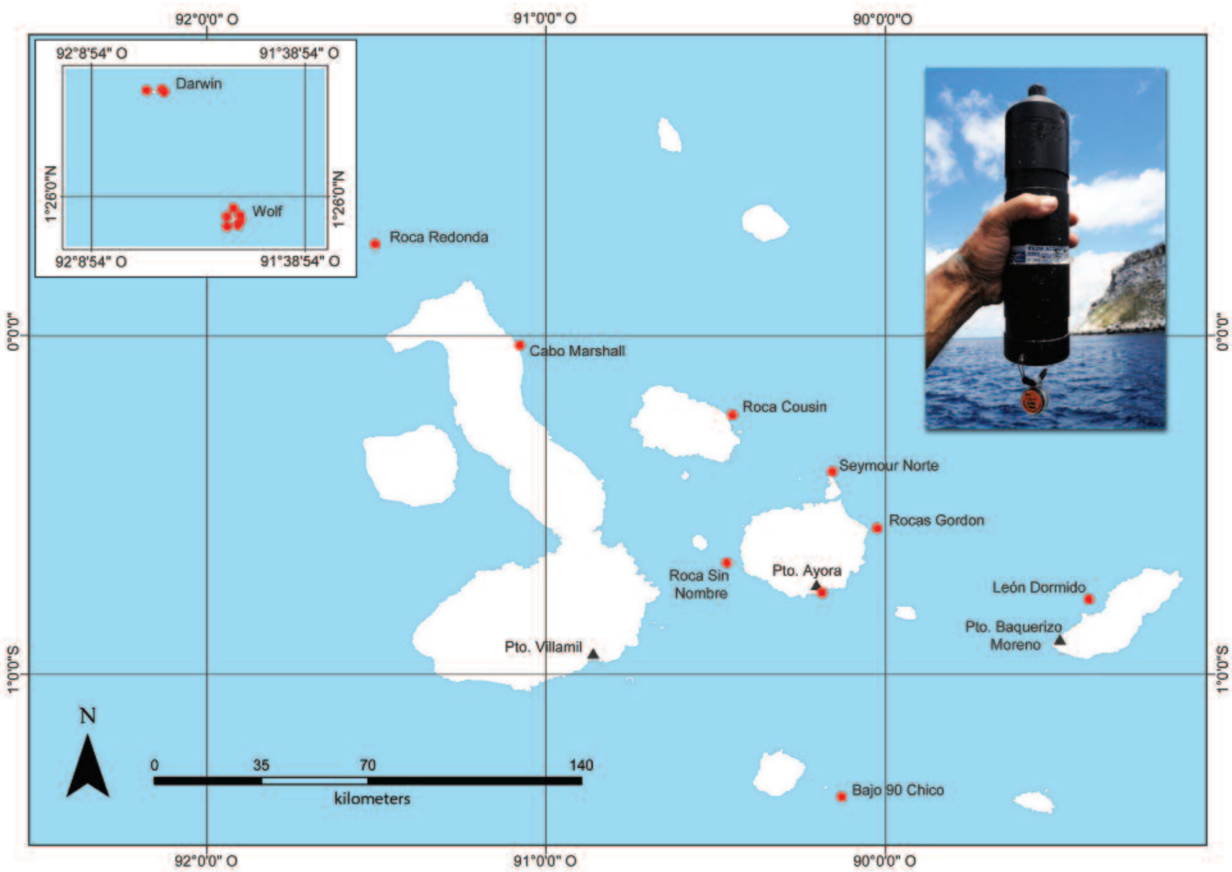

Figure 3. Location of the monitoring stations in the GMR. Upper right hand corner: photo of one of the monitors. Photo: Peter Oxford

zones surrounding the island and then became very active during the night with frequent trips to the open sea.

Three principal types of movement were detected (Ketchum *et al.*, in prep.)[1]:

(i) *Resting* - navigating at low velocity in areas close to the island. Resting occurred primarily during the day, when the sharks stayed close to the rocky areas and coral reefs in the southern, eastern, and northeastern areas of the island. Although hammerhead sharks generally swim in schools or groups, it is unknown whether the monitored sharks stayed in groups or traveled alone.

(ii) *Directional* - when sharks head toward open water or return to the island. Directional navigation was described for this species in Baja California (Klimley *et al.*, 1993), but it was not known if the sharks of Galapagos followed the same movement pattern. The longest directional navigation recorded by this study was more than 40 km, a direct route returning to the island. But how do the sharks find a path and maintain their route? Klimley (1993) suggests that hammerhead sharks use geomagnetism of the sea floor to orient themselves, and that in open water, deep dives allow them to re-orient themselves (one tagged shark descended to 936 m). Hammerhead sharks use electro-receptor organs located at the extremes of their heads to sense the electrical differential in their surrounding environment, including the electric field of other animals (Bennet and Clusin, 1978). This ability is certainly one of the evolutionary reasons responsible for the strange form of their heads, which in addition to geomagnetic-location allows them to better detect and capture their prey.

(iii) *Non-directional or erratic* - primarily in zones away from the shore. Non-directional movements occur during the night. The movements are agile but without direction, with the shark accelerating rapidly for a short time and then moving slowly. Given that the diet of hammerhead sharks is composed almost 90% of squid (Castañeda-Suárez and Sandoval-Londoño, 2007), it is assumed that these movements are a product of feeding behavior. Hammerhead sharks take advantage of the nightly vertical migrations of squid when they move to open waters to feed.

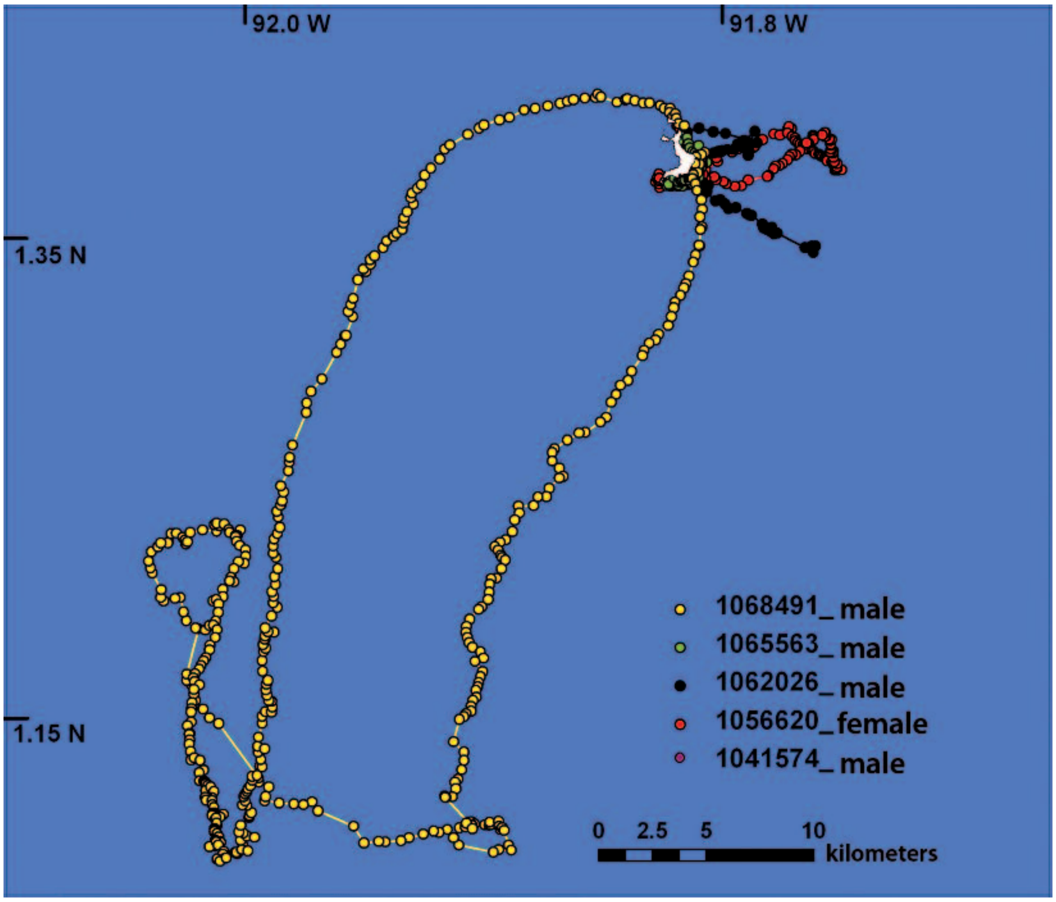

Figure 4. Navigation routes of hammerhead sharks followed continuously for 48 to 72 hours around Wolf Island. (Source: Ketchum *et al.*, in prep.).

Hammerhead sharks were also observed to have high site fidelity. One hundred percent of the monitored sharks used the southeastern and northeastern faces of Wolf Island exclusively during the daytime. This preferential behavior was confirmed by information obtained from the monitoring stations around Wolf Island, where the majority of ultrasonic tag detections were on the eastern side of the island (Figure 5). Visual censuses of sharks carried out on both sides of the island suggest that the behavior of schools of sharks differ on the two sides of the island. On the western side, their movements are rapid and directed, while on the eastern side sharks move about slowly and cover the same areas over and over. Hearn *et al.* (in prep.) suggest that this behavior could result from a variety of interacting factors. The southeastern side of the island is constantly bathed by currents that import nutrients, creating a large concentration of organisms in a protected area where sharks can feed without moving great distances. Hammerhead sharks also take advantage of these areas in the center of their range for resting and for the "cleaning services" provided by the local fauna. Important cleaning zones have been recorded in this area, with angel fish (*Holocanthus passer*) and blacknosed butterflyfish (*Johnrandallia nigrirostris*) the most important species filling this role (Ketchum *et al.*, in prep.).

Connectivity and migratory behavior

Large-scale movements observed were surprising. Monitoring station data indicate that the connectivity within the archipelago is limited to the islands of Darwin, Wolf, and Roca Redonda, while outside the GMR hammerhead sharks have been recorded in areas of the Pacific far from where they were tagged. Three hammerhead sharks tagged at Darwin and Wolf Islands were detected at Cocos Island (Costa Rica), a distance of nearly 500 km. One, tagged at Malpelo Island (Colombia), resided in the northern part of Galapagos for nearly one year (this shark made its first stop at Cocos Island before heading on to Galapagos). Satellite monitoring of seven sharks also shows an intensive use of the areas around Darwin and Wolf Islands as well as open waters outside of the GMR (Figure 6; for more details, see Ketchum *et al.*, 2009).

These results confirm that the hammerhead shark is a highly migratory species and that there exists connectivity between the northern waters of the GMR and

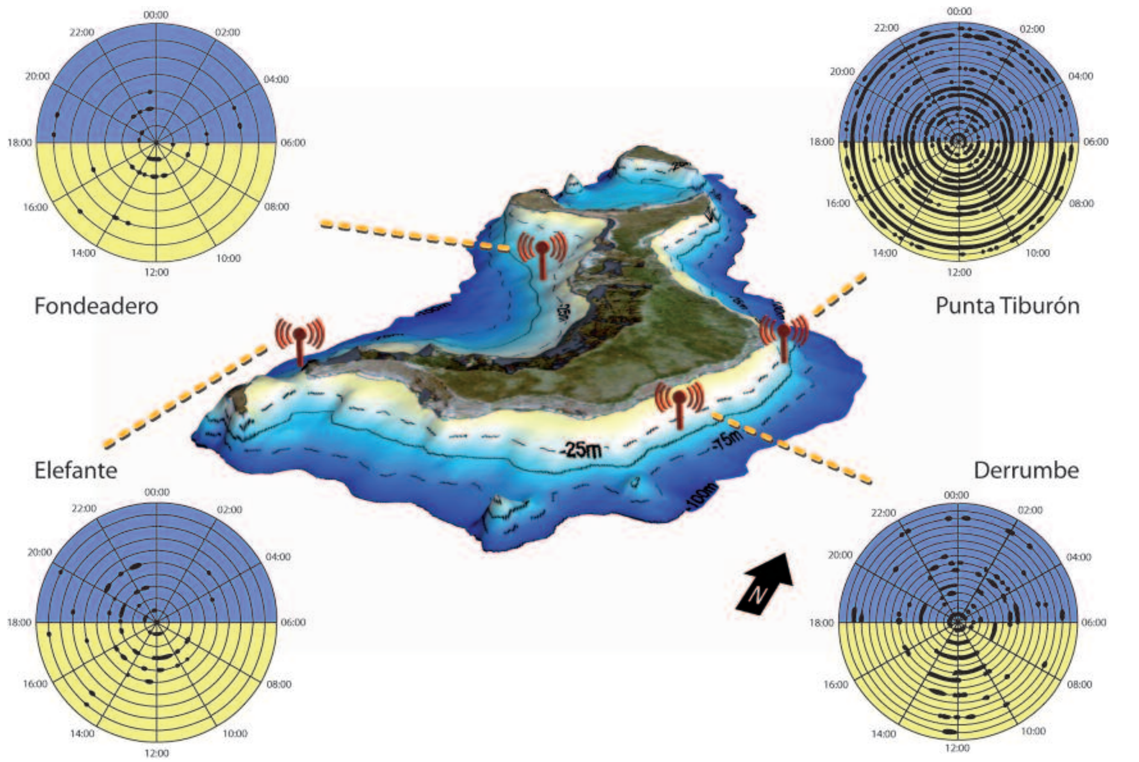

Figure 5. Differences in the number of recorded detections of sharks by the four monitoring stations in Wolf Island in August 2007 indicate the preference of different areas by hammerhead sharks. The circular graphs indicate the nighttime detections (blue) and the daytime detections (cream); the concentric circles correspond to the number of tags recorded by the monitoring stations.

other protected areas of the Eastern Pacific. However, a major question remains: Why were no individuals detected in the central-southern regions of the GMR? Satellite tracking of seven sharks showed that only one individual traveled to the center of the archipelago. Historical data provided by divers with a long history in the GMR indicate that more than 20 years ago large schools of hammerhead sharks were observed in the central part of the islands, at sites such as North Seymour (Fernando Ortiz, pers. comm.). Today only small schools of hammerhead sharks are observed at North Seymour and other sites where they were frequently observed in the past (such as Gordon Rocks, Devil's Crown, and Kicker Rock).

The historical presence and importance of hammerhead sharks in the south-central portion of the archipelago is indisputable. However, the absence of connectivity between this region and the north generates many questions. To explain the current situation, two hypotheses are currently being discussed. The first explains the lack of connectivity by the migratory response of hammerhead sharks as they become adults. The southern zones are probably used as birthing and rearing areas, while the northern zones are used as feeding grounds for adults. Evidence for this hypothesis is based on observations and recording of the presence of neonate and juvenile hammerhead sharks in the mangrove areas and bays of the southern and central archipelago, such as San Cristóbal (Llerena, 2010). In the northern zones only adults and subadults more than 1.5 m long are sighted. The second hypothesis presents the possibility that there has been a considerable decline in the population in the south resulting from over-fishing. In any case, more studies are required before the true reasons for this difference in abundance of hammerhead sharks throughout the GMR can be determined.

Conclusions and recommendations

Based on the results of this study, it is evident that the hammerhead shark is a resident species of Galapagos but at the same time highly migratory. Its site and habitat preferences at both macro and micro scales are beginning to be revealed but there are still many questions that need answers. What are the environmental conditions that make hammerhead sharks prefer specific sites? What drives the major migrations to other areas of the Pacific? Why has no connection been detected between the northern and southern areas of the GMR? What is the abundance of hammerhead sharks in the different regions of the GMR? Where are the rearing areas for this species? Given these questions, additional

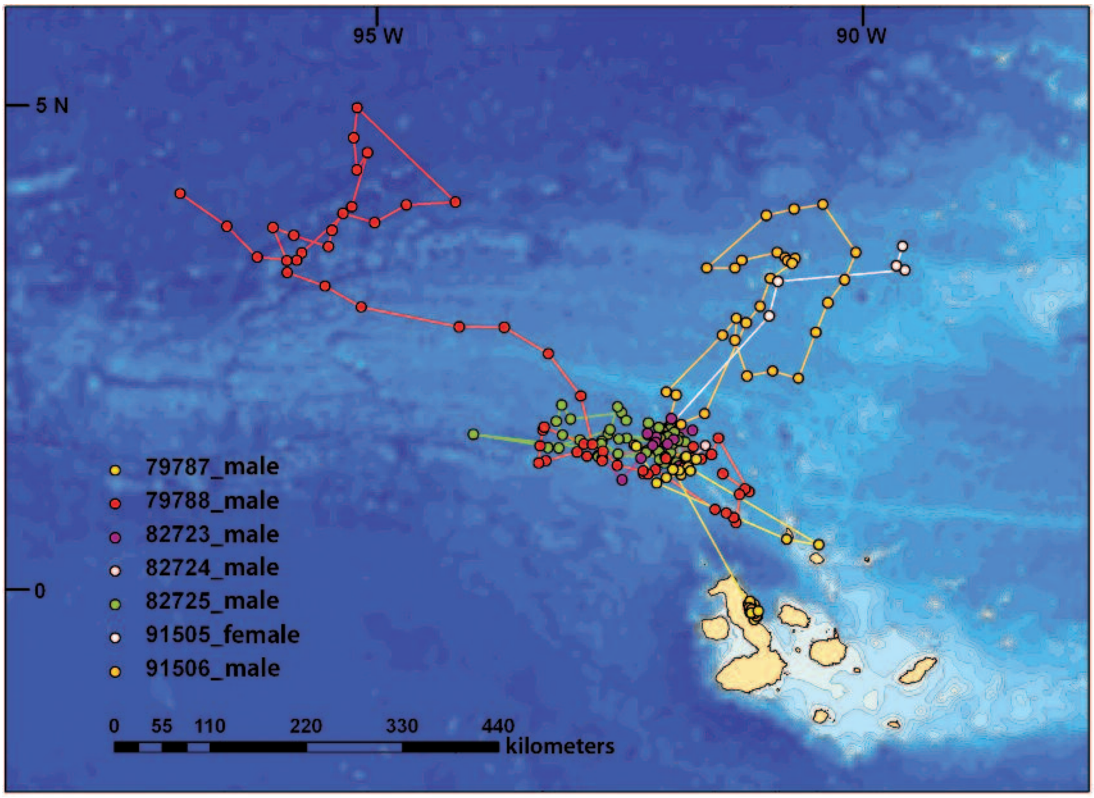

Figure 6. Navigation routes of seven hammerhead sharks tagged with satellite devices in Darwin and Wolf Islands from November 2007 to May 2009. Source: Ketchum *et al.*, in prep).

population, oceanographic, and geologic data, and environmental modeling is needed to increase our understanding of the conditions and environmental forces that mold the behavior of this species.

Studies of this type for hammerhead and other sharks, such as whale sharks, Galapagos sharks, and reef whitetip sharks, are very important for understanding their behavior and use of the various zones of the GMR. In terms of management, identifying the areas of greatest use can result in improved and more effective control and patrolling to combat illegal fishing. Research will also determine rearing and resting patterns in the coastal zones, which would help the authorities to evaluate current zoning of the GMR and incorporate measures for greater protection in critical areas. The protection of sharks will result in greater protection of some of the less charismatic species that are of great ecological value for marine environments. Finally, understanding migratory patterns for these species helps to identify priority conservation zones in open water, which could serve as a basis for the possible zoning of the open waters of the GMR. Cooperation with other countries, such as Costa Rica and Columbia, is essential for adopting management measures that will protect hammerhead sharks in international waters. These efforts are advancing and scientists in the Eastern Pacific are cooperating in the production of regional information critical to achieving this goal *(for more information on international cooperation visit the webpage: www.migramar.org*).

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