GALAPAGOS REPORT 2015-2016

MARINE MANAGEMENT

REPORT ON THE POPULATION STATUS OF HAMMERHEAD SHARKS IN THE GALAPAGOS MARINE RESERVE

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How to cite this article:


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The Galapagos National Park Directorate has its headquarters in Puerto Ayora, Santa Cruz Island, Galapagos and is the Ecuadorian governmental institution responsible for the administration and management of the protected areas of Galapagos.

The Governing Council of Galapagos has its headquarters in Puerto Baquerizo Moreno, San Cristóbal Island, and is the Ecuadorian governmental institution responsible for planning and the administration of the province.

The Charles Darwin Foundation, an international non-profit organization registered in Belgium, operates the Charles Darwin Research Station in Puerto Ayora, Santa Cruz Island, Galapagos.

Galapagos Conservancy, based in Fairfax, Virginia USA, is the only US non-profit organization focused exclusively on the long-term protection of the Galapagos Archipelago.
The hammerhead shark (*Sphyrna lewini*) is in danger of extinction throughout its worldwide distribution, primarily due to overfishing (Baum et al., 2007). Several studies have reported population reductions of up to a 90% (e.g., Baum & Myers, 2004; Ferretti et al., 2008) in areas within the marine protected areas of the Eastern Tropical Pacific (ETP). On Cocos Island, ~700 km from the Galapagos Marine Reserve (GMR), this species' abundance has declined by 50% since the 1990s (White et al., 2015). Similarly, in Malpelo Island, ~1000 km from the GMR, hammerhead sharks have declined by 45% since the beginning of the 2000s (Soler et al., 2013).

The gregarious behavior and singular body form of this species have transformed it into one of the most important marine tourist attractions in the GMR (Danulat et al., 2003). It is one of the dominant reasons that Galapagos is listed as one of the best dive destinations in the world (Scuba-Diving, 2000; 2008; 2012). This species is distributed throughout the Archipelago, but can be observed in higher numbers at Wolf and Darwin Islands, especially during the cold season (Hearn et al., 2014). Despite the economic importance of this species for both tourism and commerce in Galapagos (Peñaherrera et al., 2013), little is known about its population status and its use of the GMR (Hearn et al., 2014). This document supports the recently adopted zoning system by summarizing published information and expanding that knowledge with new details about the population status of hammerhead sharks.

**Methods**

This study employed several analytical tools used in social sciences, population ecology, and behavioral ecology. For example, to understand how hammerhead sharks use the GMR, we studied their migratory behavior and site fidelity using acoustic and satellite telemetry (methodology described in Hearn et al., 2014). Telemetry provides remote tracking of animals to determine their presence, position, or physiological state (Cooke et al., 2004), and was used to estimate probable range (Bullard, 1999). Due to a lack of information, the historical population trend was assessed using a semi-quantitative tool that models virtual abundance change (VAC) based on local ecological knowledge (methodology described in Peñaherrera et al., 2015). Relative abundance (total number of sharks observed during a one-hour dive) has been measured since 2007. This is done by...
visual censuses during autonomous dives in several dive sites of the GMR (methodology described in Hearn et al., 2014). Finally, population size of hammerhead sharks at Darwin Island was estimated using a combination of visual counts with acoustic telemetry (methodology described in Peñaherrera-Palma, 2016). Unlike other underwater census methodologies (such as visual censuses or stereo-cameras), assessment of population size provides information on the number of unique individuals that exist in an area. This in turn makes it possible to determine with greater certainty the number of individuals that can co-exist in the same place during a defined period of time and thus calculate the true existing biomass with greater accuracy.

**Use of the GMR**

Studies carried out since 2006 show that hammerhead sharks have a high preference for the areas around Darwin and Wolf Islands, and on a smaller scale around Roca Redonda (Ketchum et al., 2014b). Although sharks have been marked in the northern and central-southern regions of the GMR, only one shark was observed migrating from the north to the south, and another from south to north (Ketchum, 2011). This has raised doubts about the connectivity and use of the two regions for this species. Hearn et al. (2014) suggested the existence of possible differences in the use of the GMR depending on whether individuals are adult or juvenile. His hypothesis is based on two points: 1) the differences in the average size of the individuals marked in the north (181 +/-24 cm) and those marked in the south (141 +/-11 cm); and 2) records of juvenile hammerhead sharks in some breeding areas of blacktip reef sharks (Llerena, 2009; Jaenig, 2010). Although data are not yet sufficient to verify this hypothesis (for example, breeding areas not yet identified), studies in the Ecuadorian oceanic territory have shown that there are differences in the type of food consumed by adult and juvenile hammerhead sharks (Loor-Andrade et al., 2015).

Ketchum et al. (2014a) determined that during the day, hammerhead sharks use areas of strong currents around Darwin and Wolf, possibly as resting zones. During the night they move a considerable distance away from the islands, potentially towards feeding areas in open water. The extent of hammerhead shark movements in open water is greatly influenced by oceanographic conditions (Peñaherrera-Palma, 2016). For example, during the cold season (June-October), 90% of the area used by hammerhead sharks fell within the GMR, though most was concentrated around Darwin and Wolf. However, the amount of time spent in the GMR during the transition months was reduced to 65%, and to only 30% during the warm season (Figure 1). These movements differ considerably with other shark species, such as the blacktip reef shark (Peñaherrera-Palma, 2016) and the Galapagos shark (Hearn et al., 2014), whose movements are restricted primarily to coastal areas within the limits of the GMR.

**Population trends**

The population analysis using the VAC model shows a perceived reduction of 50% in hammerhead shark abundance since the 1980s (Peñaherrera-Palma et al., 2015; Figure 2). These data suggest that in the early 1980s a diver could observe on average ~100 hammerhead sharks per dive throughout the GMR. From 2010 to 2013, the average relative abundance was 50.6 ind/dive-hour (Peñaherrera-Palma, 2016). The greatest reduction in the abundance of this species was perceived in the central and southern areas of the Archipelago. Divers also indicated that in the past, the southern-central regions of the GMR had significant aggregations of hammerhead sharks, in numbers close to those seen today at Darwin and Wolf (Peñaherrera-Palma et al., 2015). Although it is unknown what the relative abundance of hammerhead sharks was in the central and southern areas of the Archipelago prior
to 1980, current visual census data indicate an annual average of 25 ind/dive-hour.

In Darwin and Wolf the annual average has been recorded up to 128 ind/dive-hour, indicating that these are the only sites in the GMR where you can still see hammerhead sharks in large numbers. However, since 2007, the areas around these islands show a negative trend in the relative abundance of this species. Trends in the rest of the GMR show an apparent increase, although the magnitude represents less than a quarter of what is observed in Darwin and Wolf.

**Population size**

Despite the abundance of individuals seen at Darwin and Wolf, the study of the size of the resident population at Darwin Island suggests that there are limitations to the number of unique individuals that can frequent the island at the same time (Peñaherrera-Palma, 2016). This analysis estimated that the average size of the resident population of hammerhead sharks fluctuates between 400 to 600 individuals (Figure 3). These results suggest that Darwin, and quite possibly Wolf, could represent areas with a limited carrying capacity in terms of the abundance of unique individuals of hammerhead sharks. This is of great interest for conservation, as at Darwin the resident population consists of individuals with an average total length of 238 cm, with a majority of females (85-90%; Peñaherrera-Palma, 2016; Figure 3).
Conclusions and recommendations

This research highlights the following points:

1. The susceptibility of this species when it migrates out of the GMR, especially during the hot season. Although sharks are protected within the GMR by the current management framework, we recommend expanding conservation efforts to improve fishing regulations outside the GMR. This could help: 1) reduce the susceptibility of this species to both national and international fishing fleets in open water; and 2) slow down the population decline observed in the north of the GMR. All research and management efforts should be coordinated with neighboring countries that share the stock of hammerhead sharks in the Eastern Tropical Pacific, such as Colombia, Costa Rica, and Panama.

2. The possible existence of breeding areas of this species in the south-central region of the GMR and the connection with areas of aggregation in the north. It is critical to assess the existence of these breeding areas to understand the role of the GMR in the protection of other key life stages of hammerhead sharks.

3. The apparent increase in the relative abundance of hammerhead sharks in some historical aggregation sites (e.g., Floreana, North Seymour, Genovesa, Marchena). We recommend a more detailed evaluation of the causes that generated the decline in abundance, as well as the biological and management factors that could optimize the increase in abundance in these areas. The recovery of these aggregation sites will: 1) improve the conservation status of this species in danger of extinction; 2) provide new dive sites with characteristics similar to Darwin and Wolf; and 3) reduce the intensity of use of the dive sites at Darwin and Wolf Islands.

4. The possible existence of a limit on the number of sharks that can co-habit the areas around Darwin and (potentially) Wolf. We need to evaluate in greater detail what factors limit the presence of hammerhead sharks at these aggregation sites. Determining these factors is critical to: 1) ensure habitat quality for resting and for aggregations of hammerhead sharks in the north of the GMR; 2) provide conservation indicators to assess historical aggregation areas; and 3) promote the recovery of hammerhead sharks to historical levels in the central-southern areas of the GMR.

Acknowledgments

The shark project has received funding from many institutions, among which the following stand out: the National Secretariat for Higher Education, Science, Technology and Innovation (formerly SENESCYT); Galapagos Conservation Trust; WWF - Galapagos program; WWF Prince Bernard; Conservation International; Holsworth Wildlife Research Endowment; Blake, Kimberly and George Rapier Charitable Trust; Linblad Expeditions; National Geographic Society, and the Swiss Friends of Galapagos. We also thank all of the volunteers and others who helped during field data collection, including GMR guides, the ships Agressor and Humboldt, and the crews of the Sierra Negra and the Guadalupe River, and park rangers of the Galapagos National Park Directorate.

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