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Prepared by

Funded by

General Coordination
Linda J. Cayot, Galapagos Conservancy

Editing
Linda J. Cayot
Desirée Cruz
Richard Knab, Galapagos Conservancy

Translation
Spanish to English: Linda Cayot
English to Spanish: Desirée Cruz

Figures and Graphic Design
María Fabiola Álvarez

Photographs
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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.*

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Analysis of the perception of population trends for six shark species in the Galapagos Marine Reserve

César Peñaherrera-Palma[1,2,3], Yasmania Llerena[4], Eduardo Espinoza[3] and Jayson Semmens[1]

[1]University of Tasmania – Institute of Maine and Antarctic Research, [2]CSIRO Marine and Atmospheric Research, [3]Galapagos National Park Directorate [4]Universidad San Francisco de Quito - Galapagos Institute for the Arts and Sciences (GAIAS)

The Galapagos Marine Reserve (GMR) has the potential to be a vital element in the conservation of the marine fauna, especially top predators such as sharks. The GMR is the largest of the Eastern Tropical Pacific marine protected areas, and its management framework has provided protection to sharks since the end of the 1980s through the total prohibition of their capture (SRP, 1989), regulation of fishing practices (DPNG, 1998; Murillo *et al.*, 2004), and the implementation of technologies to control and eliminate illegal fishing (DPNG, 2009). It is hoped that the management framework for the GMR will provide the needed protection to positively influence shark populations. Unfortunately, no monitoring system existed prior to the establishment of the GMR to provide an evaluation of the status and trends of shark populations. This absence of empirical data has made it difficult to determine the extent to which the reserve is protecting shark species.

In other protected areas, the knowledge and experience of users regarding a resource have become a valid and useful source of information to understand resource dynamics and optimize management in the absence of other types of empirical data (Murray *et al.,* 2006). Local ecological knowledge, as it is scientifically known, is based on the accumulated experience of resource users who are constantly in touch with the natural environment (Drew, 2005). In Galapagos, dive guides travel regularly to diving sites, and their constant interaction with the marine environment represents a potential source of information on resource status. Moreover, dive tourism activities began in the mid 1980s, which, if analyzed correctly, provides a time scale much beyond that of any continuous monitoring in the GMR.

This study assessed the perception of dive guides regarding trends in shark populations since the start of dive tours in Galapagos. The species evaluated included: the whale shark (*Rhincodon typus*), hammerhead (*Sphyrna lewini*), blacktip (*Carcharhinus limbatus*), silky (*C. falciformis*), Galapagos (*C. galapagensis*), and whitetip reef shark (*Triaenodon obesus*). It is hoped that the results of this study will provide important information to enhance our understanding of historical trends.

Methods

This project was implemented during the knowledge refresher courses for guides offered by the Galapagos National Park Directorate in the second half of 2013. Dive guides received a self-administered survey designed to evaluate: i) their dive experience; ii) qualitative perceptions of population trends of shark species by decade and region; and, iii) the reasons for the observed changes if applicable. To reduce the number of questions and obtain standardized responses the survey was designed as follows:

1. The time scale used was limited to answers that defined the state of change within each decade in which guides dove. Three decades were used (1980s, 1990s, 2000s), as well as years in the 2010s.

2. The spatial scale was defined in four regions of the Archipelago: north (Darwin, Wolf, and Roca Redonda), south (Floreana, Española, seamounts, and surrounding islets), west (western Isabela and Fernandina), and central (Santa Cruz, San Cristóbal, northeast and southeast of Isabela, seamounts, and surrounding islets).

3. Changes in abundance were limited to five categories: major decrease (MD); decrease (D); stable (S); increase (I), and major increase (MI).

4. Each survey respondent was required to provide the percent change in the population for each response (e.g., MD equal to 50% reduction in population size, D 25% reduction, etc.).

The responses were analyzed using simple statistical analyses and a semi-quantitative analysis of virtual population change (VPC) developed for Galapagos based on the work of Burfield *et al.* (2004), Gregory *et al.* (2004), and Moller *et al.* (2004). Given that the actual population size of each species analyzed is unknown, the initial virtual population size (VPS) was assigned the value of 100%. For each following decade, the model estimates the percentage of population remaining based on the categories and percentages of change indicated by each guide. The model is then adjusted using the values of the previous decade and the degree of experience of the guides to avoid the shifting baseline effect (Saenz-Arroyo *et al.* 2005; Bunce *et al.* 2008).

Experience of the interviewees

A total of 27 dive guides were surveyed, of which only two did not provide useful answers. It is estimated that the completed surveys included ~70% of the guides with extensive experience diving in Galapagos. This percentage was estimated based on answers provided by respondents when asked to enumerate other divers who have experience guiding. The answers often mentioned the same people, few of whom we were unable to contact.

All respondents were between 30 and 60 years old, and their dive experience in Galapagos ranged from 5 to 30 years. Three age groups were defined: i) 30-39 years; ii) 40-49 years; and iii) 50-60 years. Of these groups, the second and third (72% of the total) reported having extensive experience diving in the GMR (average of 19 and 17 years, respectively; Table 1). All interviewees dove in the last two decades. The presence of divers during the 1980s and 1990s was, in contrast, variable, with fewer diving in the 1980s. Finally, the experience reported by region showed that 85-100% of the guides dove in the north, south, and central areas. Few guides reported experience in the western region of the Archipelago.

Perception of spatial and temporal trends

Of the guides surveyed, 82% indicated observed changes in the size of shark populations; 7% said that they had observed no changes, and the remaining 11% declined to answer. Of the guides who responded that there were changes, 64% observed declines in shark population sizes, 27% indicated having observed increases, and the remaining 9% indicated that changes varied depending on the species (some increased and some decreased). The guides pointed to fishing as the main factor influencing the decrease in shark populations (70% of responses). It was not clear if they were referring to artisanal, industrial, or illegal fishing, although illegal fishing was noted on several occasions. Climate change, together with strong environmental events such as El Niño, was the second most often mentioned factor influencing the observed decreases (26% of responses).

The apparent agreement on negative trends in shark populations observed in this study is consistent with the study by Hearn *et al.* (2008), who reported that guides expressed concern for the reduction in the abundance of sharks at dive sites. However, this generalized perception does not apply for all species (Figure 1):

Table 1. Description of the experience of dive guides interviewed by age group.

Age group	N	Years of dive experience			Percentage of guides by decade				Percentage of guides by region			
		Ave.	Max.	Mín.	1980	1990	2000	2010	North	South	West	Central
30 - 39	7	10	13	5	--	--	100	100	100	100	43	100
40 - 49	11	19	30	8	18	91	100	100	100	91	73	91
50 - 60	7	17	25	5	29	57	100	100	86	100	71	86

Whale shark. Most guides indicated that the population has been stable (S). With regard to the regions of the Archipelago, there was some consensus of a decrease (D) in the northern region, a stable population in the south and central regions, and interestingly, an increase (I) in the population in the west of the Archipelago.

Hammerhead shark. This is the only species for which most guides consistently agreed on a decline in the population by both decade and region. The categories for a decreasing population (D and MD) dominated the responses for all decades and regions studied. The decade with the greatest decrease was the 1990s, while the areas with the most marked decrease were the south and central regions.

Blacktip shark. Most guides categorized this population as stable (S) during the 1990s. However, for the 2000s and 2010s, guides reported an increase (I and MI) in the population, especially in the northern (45% of responses) and central (56% of responses) regions.

Galapagos shark. Responses related to this species varied, revealing an increase in the categories stable (S) and increase (I) over the last two decades. In regards to regions, the guides observed negative trends in the south (62%), central (67%), and north (40%) regions, while the western region was generally categorized as stable (50%).

Whitetip reef shark. Guides generally agreed that there has been a decrease in the population in the 2000s and 2010s. As for regions, there was a general consensus on the stability of the population in all except the central region, where the categories of decrease (D & MD) dominated the responses.

Silky shark. 60% of guides reported negative trends in the 1980s, while 70% observed a stable population in the 1990s. For the 2000s, 50% responded that the population remained stable and 50% indicated a decline (D and MD). The perception of population trends by region was dominated by the stable category for all regions (50-75%).

Virtual population change model

Unlike previous analyses, the use of this model makes it possible to clearly discern population trends of shark species over the last four decades, showing some interesting patterns in the last two decades (Figure 2).

Whale shark. This is the only species in this study that showed stable conditions during the four decades. The model shows that the variation of the virtual population size (VPS) ranged between 95 and 102% in comparison with the initial population size.

Hammerhead shark. According to the perception of the guides, this species suffered the greatest population decline, with a sustained reduction that reached a VPS of 50% in this decade. This suggests that the population that we see today is approximately half what it was prior to 1980.

Blacktip shark. The model suggests that this is the only species for which guides observed a population recovery. During the 1980s and 1990s, the population declined to 65%, and then rebounded to reach 80% in 2010.

Galapagos shark. For this species guide perceptions also suggests a negative trend. According to the model, the population reached an average VPS of 60% of the initial size in the last three decades.

Whitetip reef shark. In the 1980s and 1990s, this species remained relatively stable, but the perception of the guides suggests a reduction in population size during the 2000s and 2010s with a current VPS of 70% of its initial size.

Silky shark. The model indicated a negative trend similar to that of the Galapagos shark, but its trend curve only reached a VPS of 75%.

The model also suggests that the populations of at least three species have remained stable throughout the last two decades. Hammerhead, Galapagos, and silky sharks have maintained very similar values for their VPS during the 2000s, and so far in the 2010s. There is also a perceived increase in the population of blacktip sharks, while whitetip reef sharks have experienced a major decline in the last decade.

As indicated, there is no empirical information in Galapagos to validate these results for the time-scale studied. However, in the last two decades population trends of several species of sharks in the Cocos and Malpelo Islands corroborate the perceptions on shark trends by guides in Galapagos. Friedlander *et al.* (2012) and Soler *et al.* (2013) reported that the abundance of whitetip reef sharks and hammerhead sharks declined significantly in the 1990s and 2000s in both Cocos and Malpelo, respectively. In addition, Sibaja-Cordero (2008) reported a decline in the occurrence of silky sharks towards the end of the 1990s around Cocos Island, and an increase in the occurrence of blacktip sharks in the 2000s. The perceived increase in the blacktip shark population reported consistently by fishermen and guides was an important result obtained in this study. The growth of this population in Galapagos could be a response to the existence of favorable conditions for reproduction of this species in the Archipelago (Llerena *et al.*, 2014).

A theoretical analysis based on food webs of the pelagic ecosystem of the GMR suggests some degree

Figure 1. Summary of changes in shark populations by decade (left column) and bioregion (right column) for each species as perceived by dive guides. Scales of change: MI = major increase; I = increase; S = stable; D = decline; MD = major decline.

of congruence with the results of this study. Wolff *et al.* (2012) suggested that populations of hammerhead and bentho-pelagic sharks (blacktip, Galapagos, and silky, among others) experienced a substantial increase in the biomass of their populations in the 2000s, while others, such as smaller-sized sharks (like whitetip reef sharks), suffered a population decline. In the case of hammerhead, Galapagos, and silky sharks, the perception of the Galapagos guides and studies in Cocos and Malpelo suggest that their stocks did not change after 2000, but rather stabilized. These differences could result from biological and physiological processes that were not analyzed in detail in the study of Wolff *et al.*, whether related to the nature of the trophic study and/or the clustering of species into functional groups. However, the study by Wolff *et al.* and this report suggest a change from negative trends for all shark populations, to a decline of whitetip reef sharks and an increase in blacktip sharks, after the establishment of the GMR.

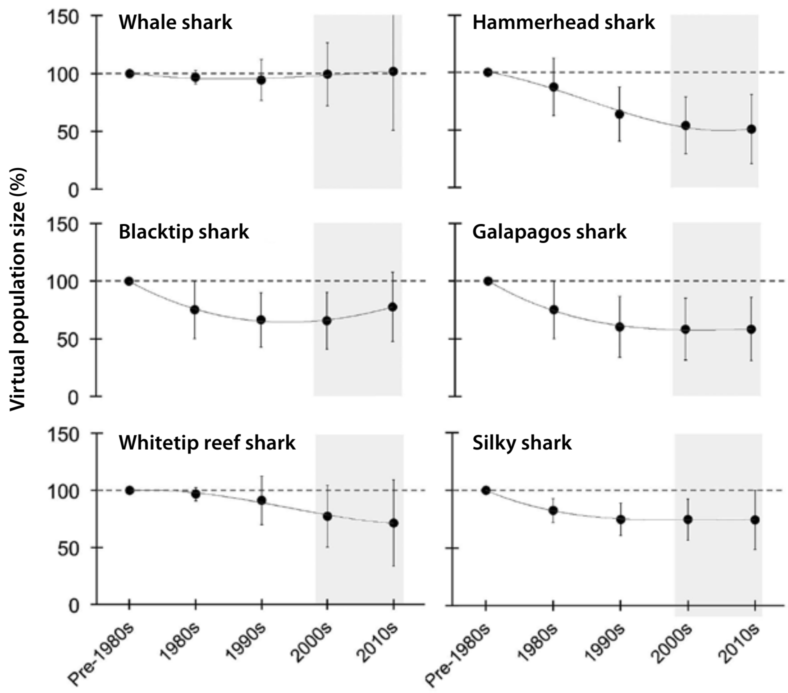

Figure 2. Variation in the virtual population size (VPS) of the six evaluated shark species. Vertical bars show the standard deviation as a measure of variability in responses, and the gray area the decades following the establishment of the GMR.

Discussion and conclusions

While most guides generally agree that all shark species have experienced negative population trends, this study shows that perception varies by species, and that there is an apparent change in trends after 2000. In regards to spatial analysis, the central and southern regions of the Archipelago were categorized as having suffered a significant population decline in the shark species studied. Fishing was identified as the primary cause of the decline of shark populations in the GMR.

It should be noted that this study, as well as any study of perceptions and opinions, carries with it a degree of uncertainty related to the knowledge and belief of each individual (Poizat & Baran, 1997). However, these types of studies are considered valid when the experience of resource users highlights coherent patterns about resource knowledge and status, especially in cases where empirical information is absent or scarce (Berkes *et al.*, 2000; Davis & Wagner, 2003).

The analysis of the collective memory and experience of dive guides examined in this study provides new information on possible population trends of six shark species in the GMR. The three scenarios (stable, decline, and increase) obtained from the ecological knowledge of the guides has identified important population trends, which are supported by studies in Cocos and Malpelo Islands, and partially corroborate results published by Wolff *et al.* (2012). We recommend that additional, more in-depth studies be carried out at the species level to determine what factors are influencing these changes and what role the establishment and management of the GMR have played in providing greater protection for the conservation of these species. In addition, it is hoped that the methodology used in this study will continue to be used by those who manage the GMR to evaluate charismatic species for which little or no information on population trends is available.

Photo: © Paul Schmeider

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