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Illegal shark fishing in the Galápagos Marine Reserve

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ABSTRACT

Illegal shark fishing is thought to occur globally, including within so-called "shark sanctuaries", marine reserves and even inside UNESCO World Heritage sites, such as the Galápagos Islands. Presumably, this is due to poor local enforcement coupled with the growing international demand (and high economic incentives) for shark and other wildlife products. Understanding illegal shark fishing practices, and specifically catch composition, is important as poaching is identified as a causal factor of global declines in shark populations. Unfortunately, reliable quantitative data on illegal shark fishing are scarce. Here, the catch onboard an illegal shark fishing vessel seized within the borders of the Galápagos Marine Reserve was documented. A total of 379 sharks from seven shark species were found onboard the vessel. A large fraction of the illegal catch was comprised of both female and juvenile sharks (64% and 89%, respectively). Despite numerous recent advances in shark conservation worldwide, this study demonstrates illegal shark fishing is an ongoing concern and that stricter enforcement and legislation is urgently needed, particularly in areas of high biodiversity.

1. Introduction

Shark populations are declining globally due to a combination of anthropogenic stressors, such as habitat degradation, fishing and poaching [1–4]. Apex predators are particularly vulnerable to these stressors due to their low natural abundances and life-history characteristics (e.g., slow growth, late age of maturity, and low fecundity) [5]. Thus, even with increased fisheries regulations and improved management practices preservation and restoration of top predator populations is inherently challenging.

The global loss of sharks has intensified in recent decades as a result of incidental catch (or bycatch) in other economically valuable fisheries (i.e., tuna and billfish), and targeted shark fishing [6]. Fishermen target sharks in part due to a growing demand for shark fins in Asian markets and, on a smaller scale, for the meat [7,8]. Shark finning involves catching and removing the dorsal, pelvic and pectoral fins from a live shark, which is then thrown back into the ocean to perish. The resulting fins are dried and exported to Asian markets and other trade "hubs" for their eventual use in shark fin soup [8–10]. Both shark finning and catching sharks for the shark fin trade are lucrative practices for fishermen due to the rapid economic growth in China [8], whereby the recent growth of the middle-class has increased demand for shark fin soup because more people can afford the dish [11]. Recent estimates suggest that the total shark biomass in the global shark fin trade could be up to ~1.70 million tons, ranging between ~26–73 million sharks annually [8]. The high economic incentives coupled with a lack of enforcement in restricted areas due to limited personnel and high costs associated with patrolling large geographic expanses result in unregulated shark fishing globally [12]. Illegal shark fishing has been documented in areas of high biodiversity, and within marine protected areas and no-take zones [11,13,14].

1.1. Background on Galápagos Marine Reserve and shark fishing

The Galápagos Islands were designated a marine reserve, the Galápagos Marine Reserve (GMR), in 1986. There are over 40

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shark species documented in Ecuadorian waters (including the GMR), and ~30 of these species are frequently caught by fishermen [11]. All of the most commonly caught species are on the International Union for Conservation of Nature (IUCN) Red List, a comprehensive inventory of the global conservation status of biological species, and are considered as Near Threatened or Vulnerable. Near Threatened refers to species likely to become endangered in the near future, and Vulnerable describes species with a high risk of endangerment in the wild [15].

While some sharks in Ecuador are caught and sold for meat, most are targeted for their fins [11]. Shark fins are exported from mainland Ecuador to Hong Kong, Taiwan and Singapore [11]. While the shark fin trade has existed on mainland Ecuador since the early 1960s, large-scale industrial shark finning in the Galápagos Islands began in the early 1950s [11]. Although the Galápagos Islands were designated as a marine reserve in 1986 this decree did not carry national protected area status, making management and enforcement of exploitation impossible.

The concern that sharks landed on mainland Ecuador were caught within the borders of the protected GMR prompted governmental concern. In response to these concerns, a law was passed in 1993 that required all 'incidental' sharks to be landed with fins intact. The result is that while Ecuadorian fishermen are not allowed to target sharks specifically, it is still legal (and common) to sell and export the fins from "incidental catch". This regulation enables mass quantities of shark fins to be exported from the Ecuadorian mainland to the Asian markets.

National protected area status for the GMR was granted in 1998, commercial fishing (including shark finning) was prohibited and the Galápagos National Park was able to enforce Reserve regulations. But it was not until 2003 that the Ecuadorian Ministry of the Environment prohibited shark fishing, landing and trading (including the "incidental catch" of sharks) inside the GMR. Despite the active legislation to preserve shark populations within the protected 40-mile radius around the Galápagos Islands, illegal shark fishing and finning continues throughout the archipelago (Table 1) [11].

Illegal shark fishing within the GMR occurs via national and foreign industrial fishing vessels. From 2001–2007 the Ecuadorian authorities have seized 29 illegal shark catches within the boundaries of the GMR (Table 1) [11]. Seizures ranged from raids on illegal campsites to the capture of fishing vessels, with catch size ranging from two dead sharks to >1800 shark fins. While Ecuadorian authorities and various non-governmental organizations have caught, seized and impounded several illegal shark catches in recent years (Table 1) [11], illegal activities continue as evidenced by the apprehension of three shark-fishing vessels within the GMR boundaries during the latter half of 2011.

On July 19, 2011 the Galápagos National Park, along with the Ecuadorian Navy, seized the *Fer Mary I* (a long line fishing vessel from Manta, Ecuador) and crew of 30 on the southeast side of Genovesa. The boat was equipped with 1 long line fishing set with 369 hooks, and 6 "lanchas", or 8 m outboard powered fiber-glass boats, for patrolling long lines. 379 shark carcasses were onboard the boat. The *Fer Mary I* was boarded on July 23rd, and each shark was identified to species, the condition of each body was determined, and body size and sex were recorded for each of the sharks prior to the mandatory disposal of the bodies, as required by Ecuadorian law (to ensure that no profit is earned whatsoever from illegally fished animals).

2. Methods

Shark length was measured as precaudal length (PCL) in mm, and converted to cm, for all sharks with heads attached. Determination of total length (TL) of *Alopias superciliosus* was impossible because the top lobe of the caudal fin from these sharks had been removed. PCL was used to estimate TL based on allometric equations [16]. However, raw PCL was unobtainable on 64% of all big-eye threshers, *A. superciliosus*, as heads had been removed. Therefore, on these sharks ($n=194$), the dorsal standard length DSL, a distance from the beginning of the dorsal fin to the precaudal pit was measured. To determine PCL for these specimens a relationship between PCL and DSL was calculated from a subsample of headed *A. superciliosus* ($n=76$), and a linear model was developed to describe the length allometry of *A. superciliosus*. PCL was quantified using the equation: $PCL=(0.88)\ DSL+0.73$ and determined TL from PCL using the approach previously described. The R^2 for the developed linear model is 0.53. The observed range of the explanatory variable (i.e., DSL) is 0.6 to 0.96. And the intercept and slope parameters are 0.73 ± 0.07 and 0.88 ± 0.09 (mean ± 1 SE), respectively.

Logistical constraints restricted the ability to measure shark biomass; therefore, all shark lengths (TL) were converted to biomass (g) using species-specific, and when available sex-specific, conversion constants [16–19]. Individual shark biomass was estimated using the allometric length-weight conversion: $W=aL^b_{(T)}$, where W is weight in grams, parameters a and b are length–weight conversion parameters obtained from www.fishbase.org. Shark biomass was then pooled by sex and species and converted from grams to metric tons. Four individual sharks were excluded from analyses as one shark carcass was too degraded to identify and the others could not be measured because key anatomical features (i.e. heads, dorsal fins, precaudal pits) were missing. Sex was determined by the presence/absence of external reproductive organs.

Chi-square tests were conducted to determine if the sex ratio of the three most common shark species departed from the 1:1 ratio. Chi-square tests were also conducted on juvenile to adult ratios for male thresher sharks, female and male silky sharks and the total juvenile to adult ratios for the three most common shark species caught (big-eye thresher sharks, silky sharks and blue sharks). All statistical analyses were performed in R (v. 2.10.1).

3. Results

Shark species composition was as follows: 303 pelagic thresher sharks (*A. superciliosus*), 42 silky sharks (*Carcharhinus falciformis*), 24 blue sharks (*Prionace glauca*), five smooth hammerhead sharks (*Sphyrna zygaena*), two tiger sharks (*Galeocerdo cuvier*), one Galàpagos shark (*Carcharhinus galapagensis*), one short-fin mako shark (*Isurus oxyrinchus*), and one unidentified shark (missing head, tail, fins and part of body) (Table 2). Subsequent external photo-validation for species identification was utilized via consultation with taxonomists where needed (i.e., degraded carcasses, morphological ambiguity, etc.). Also onboard the vessel was 10 yellow-fin tuna and 4 marlins.

Body mutilation was only observed in two of the species, *A. superciliosus* and *S. zygaena*, as the top lobe of the caudal fin was removed for all thresher sharks and the cephalofoils removed for all smooth hammerhead sharks. Heads were also removed from 184 *A. superciliosus*. The remaining sharks were intact.

The total shark biomass found onboard was estimated to be 22.03 metric tons (Table 2). There was almost twice as much female (14.1) than male biomass (7.9) (Table 2). The sex ratio for *A. superciliosus* (44:100) departed significantly from the expected 1:1 sex ratio, with females outnumbering males ($\chi^2=21.78$, $\rho<0.001$). Females outnumbered males for *P. glauca* (85:100), however, there was no significant departure from the 1:1 sex ratio ($\chi^2=1.22$, $\rho=0.27$). Males significantly outnumbered females for *C. falciformis* (162:100, $\chi^2=14.67$, $\rho<0.001$). No males were found for any of the other species.

Table 1
Illegal shark fishing seizures in the Galápagos Marine Reserve from 2001 to 2004. Data were collected by the Galápagos National Park and the WildAid Organization.

Date	Vessel (Nationality)	Seizure location within GMR	Fishing gear	Catch information
3/2001	B/P Dilsun (Ecuador)	Isabela Island	Longline	Shark bodies (350), shark fins (600)
3/2001	B/P Maria Canela II (Costa Rica)	Wolf Island	Longline	Shark bodies (60), shark fins (1036)
7/2001	B/P Indio (Costa Rica)	Darwin Island	Longline	Shark bodies (1300), shark fins (619)
7/2001	B/P Calima (Columbia)	Wolf Island	Longline	Shark body (1 thresher)
7/2001	B/P Cruz Ariceli (Ecuador)	Isabela Island	Longline	Shark bodies (10)
1/2002	F/M Pajaro Azul II (Ecuador)	Santiago Island	Net	Shark fins (52 Galápagos)
7/2002	B/P Sergio Gustavo (Ecuador)	Isabela Island	Longline	Shark bodies (28 blue, 1 Galápagos)
11/2002	B/P Adionay IX (Ecuador)	Fernandina Island	Longline	Shark bodies (12 blue)
1/2003	B/P Don Daniel (Costa Rica)	Pinta Island	Longline	Shark bodies (3 thresher)
1/2003	F/M Cristel, Hermano Gergorio, Soledad (unknown)	Pinzon Island	Net	Shark bodies (27 Galápagos, 1 silky, 1 blacktip), shark fins (124)
2/2003	Abandoned longline	Wolf Island	Longline	Shark bodies (8 blue, 1 Galápagos)
3/2003	Abandoned net	Wolf Island	Net	Shark bodies (30)
3/2003	B/P Marcelo Caiza (unknown)	Isabela Island	Net	Shark fins (4147; reconstructed to comprise 942 sharks of silky, blacktip, Galápagos, blue, hammerhead)
3/2003	B/P Adionary V (Ecuador)	Unknown	Longline	Shark bodies (3 silky)
3/2003	Campsite	Santa Cruz Island	Net	Shark fins (46)
9/2003	F/M Canaima XI (unknown)	Isabela Island	Unknown	Shark fins (815; reconstructed to comprise 202 sharks of blacktip, Galápagos, hammerhead, silky, other)
10/2003	M/N Virgen de Monserrate (unknown)	San Cristobal Island	Unknown	Shark fins (211)
4/2004	Multiple pangas (unknown)	Floreana Island	Longline	Shark bodies (22 Galápagos)
7/2004	B/P Primero Matricula (unknown)	Wolf Island	Longline	Shark fins (9; 6 thresher, 3 blue)

Within species, female and male mean total lengths were similar (Fig. 1). All of the female and most [79%] of the male thresher sharks were under the published minimum length (332 and 280 cm, respectively) at maturity (Fig. 1) [17]. This difference in juvenile and adult male thresher sharks was significant ($\chi^2=47.13$, $\rho<0.0001$). In addition, most [61%] of the silky sharks caught were juveniles [19]. However, there was no significant difference between juveniles and adults for either female or male silky sharks ($\chi^2=0.93$, $\rho=0.32$ and $\chi^2=0.15$, $\rho=0.69$, respectively). All of the males and 3 of the female blue sharks were of reproductive size [18]. There were significantly more juveniles (206) than adults (159) ($\chi^2=6.05$, $\rho=0.013$) for the three most abundant shark species onboard the *Fer Mary I.*

4. Discussion

While several models were recently developed to estimate global shark biomass in the shark fin trade [8], there is a general lack of information about what sharks are actually onboard the individual fishing vessels. In this case study, the majority of sharks found onboard the *Fer Mary* I were juveniles and females. The sexual segregation of females and juveniles in the catch could be indicative of reproductive activity within the GMR, as both silky sharks and blue sharks display ontogenetic sexual segregation throughout their range [18,19]. Another possibility is that the high ratio of juveniles and females in the catch could represent bias in the fishing gear used. Regardless, large removals of juveniles and females are a cause for concern, and more information is needed regarding pelagic shark demographics in the waters around the GMR.

The shark species composition found on the *Fer Mary I* is consistent with both recent landings data from mainland Ecuador and other recent seizures of illegal shark fishing vessels. For example, blue sharks and thresher spp. currently comprise ~90% of all shark landings in Manta, Ecuador [11]. On the *Fer Mary I*, big-eye threshers and blue sharks were the first and third most abundant shark species and together comprised 87% of the total number of individuals caught. Further, the shark species found among other unpublished seizures within the GMR from 2001–2004 were similar to those

Table 2
Quantification of the illegal shark fishing catch onboard the *Fer Mary I*. Common names of sharks are in parentheses. IUCN status is based on the IUCN list (2011) [15]. Biomass was estimated in metric tons. N/A is used for a measurement that is not applicable (i.e., no males were present for that species).

Species	Total (#)	IUCN Status	Biomass (tons)		Total biomass (tons)
			Female	Male	
Alopias superciliosus (bigeye thresher)	303	Vulnerable	9.93	5.03	14.96
Carcharhinus falciformis (silky shark)	42	Near Threatened	0.81	1.49	2.30
Prionace glauca (blue shark)	24	Near Threatened	2.56	1.39	3.95
Sphyrna zygaena (smooth hammerhead)	5	Vulnerable	0.30	N/A	0.30
Galeocerdo cuvier (tiger shark)	2	Near Threatened	0.39	N/A	0.39
Carcharhinus galapagensis (Galàpagos shark)	2	Near Threatened	0.13	N/A	0.13
Isurus oxyrinchus (shortfin mako shark)	1	Vulnerable	N/A	N/A	
Unidentified shark	1		N/A	N/A	
Total	**379**		**14.12**	**7.91**	**22.03**

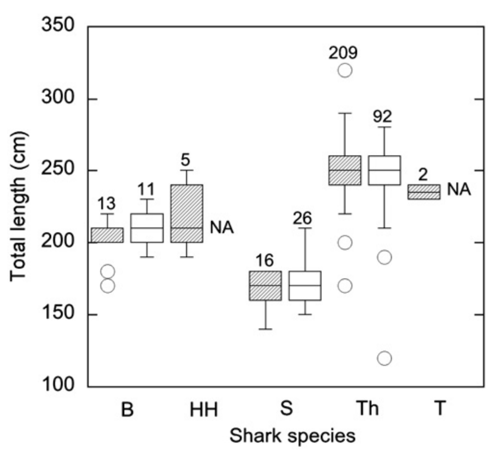

Fig. 1. Box plots of the total length of the five most abundant shark species caught. The box corresponds to the 25th and 75th percentiles and the dark line inside the box represents the median total length. Error bars are the minimum and maximum, excluding outliers (circles corresponding to values beyond 1.5 boxes from the box). B=Blue sharks, HH=Hammerhead sharks, S=Silky sharks, Th=Big-eye thresher sharks, T=Tiger sharks, NA=No males present for that species. Hashed and white bars denote female and male sharks, respectively. Values above bars are sample sizes.

onboard the *Fer Mary I* and included: silky, blacktip, thresher, blue, Galápagos and hammerhead (Table 1). These results underscore the regional pressure concentrated on these species. It should also be noted that morphologically specialized species (i.e., species with disproportionately large fins) were abundant in this study, however whether these species were specifically targeted for increased economic profit is unknown.

The ecological role of pelagic sharks (Galápagos sharks, smooth hammerheads, silky sharks, big-eye threshers) inhabiting Ecuadorian waters, including within the Galápagos archipelago, has never been explicitly studied. Trophodynamic models developed to describe the ecological role of pelagic sharks in different regions suggest they are weak interactors in pelagic food webs. Results demonstrated that either other predators will fill the ecological gap left by pelagic sharks (i.e., billfishes and tuna) [20], or that pelagic sharks only have transient effects on prey species [7]. However, empirical studies and mass-balance models demonstrate that at least some of the shark species (tiger, Galápagos, hammerhead) caught onboard the *Fer Mary I* can influence community dynamics via both indirect and direct interactions [21,22]. Therefore, to better understand the ecological consequences of pelagic shark fishing in sensitive areas like the Galápagos Islands and other remote island atolls, more site-specific models and studies are desperately needed.

5. Conclusions

The *Fer Mary I* case coupled with the descriptions of recent seizures provides new information and insights into illegal shark fishing activities occurring within marine protected areas. Furthermore, this study demonstrates the urgent need for increased management and conservation for regional shark populations, particularly, amongst such ecologically rich "hot-spots" like the GMR. Documented global changes in shark species composition, abundance and distribution [4,5] coupled with the ecological and economic importance of sharks [4,23] indicate that stricter enforcement of compliance with regionally mandated laws should be an immediate priority for officials. Despite recent global shark conservation advances (i.e., shark sanctuaries, fishing bans), shark fishing and finning continues to be a transnational problem, and is particularly alarming when observed in areas that have been afforded policy regulations to theoretically preserve species and biodiversity. Until there is a coupling of marine protected area designation with sufficient enforcement, exploitation (as documented here) is likely to continue.

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