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Occurrence and bycatch of juvenile and neonate whale sharks (*Rhincodon typus*) in Peruvian waters

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Abstract
In the Eastern Pacific Ocean, whale sharks (*Rhincodon typus*) have mostly been studied off the Galapagos Islands, Ecuador and Baja California, Mexico. Recently, satellite telemetry data revealed connectivity between whale sharks off the Galapagos Islands and Peru. Historic, as well as some recent observations, reported rare occurrences of whale sharks in waters off northern Peru. However, no current detailed information on the occurrence of whale sharks in Peruvian waters has been published. In this study we compiled 27 records of whale sharks along the Peruvian coast as a first step to better understand their use of Peruvian waters. Northern Peru was identified as the main area of occurrence for whale sharks and reports were more frequent during the austral summer (January to March) and spring (October to December). Moreover, the presence of neonatal whale sharks reported in this study, in addition to that of previously satellite-tracked presumably pregnant females, suggests the use of northern Peruvian waters as a pupping ground. Interactions occurred only with net fisheries and were evident in most (89%) of the records, but further studies should evaluate the extent of fisheries-shark interactions. As whale shark population numbers decline, effective conservation measures will require the understanding of whale shark occurrences, and waters of northern Peru may play an important role in the species' biology and ecology. Systematic research is recommended to improve our understanding of habitat use of individuals present in Peruvian waters.

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Introduction

The whale shark, *Rhincodon typus* (Smith, 1828) is a highly migratory species with a circumglobal distribution in tropical and subtropical waters (Compagno 2001), including the Mediterranean (Jaffa and Taher 2007). Considered the largest living fish, the whale shark is a filter feeder whose migration patterns are driven mainly by climatic and oceanographic processes (Wilson et al. 2001, Sleeman et al. 2010, Afonso et al. 2014, Ryan et al. 2017).

Evidence of a dramatic decline in whale shark population numbers (Bradshaw et al. 2008, Pierce and Norman 2016), mostly due to direct captures and bycatch in net fisheries (Alava et al. 2002, Akhilesh et al. 2012, Li et al. 2012), has placed the species at risk of extinction. Thus, whale sharks are currently listed as Endangered by the IUCN (Pierce and Norman 2016), which emphasizes the need for immediate conservation measures, especially in the Indo-Pacific where ~75% of the population occurs (Pierce and Norman 2016).

In the Eastern Pacific, whale sharks occur seasonally around the Galapagos Islands, Ecuador (Acuña-Marrero et al. 2014) and the Gulf of California, Mexico (Ramirez-Macias et al. 2012, Ketchum et al. 2013), where rarely seen apparently gravid female individuals are encountered (Eckert and Stewart 2001, Hearn et al. 2016). Whale sharks have also been reported off the coast of Costa Rica (Sibaja-Cordero 2008, Pacheco-Polanco et al. 2015). Off northern Peru, observations conducted from 1974 to 1985 revealed that whale shark sightings were sporadic, and most individuals were observed during the austral summer (January-March, Ramirez 1995). However, there is no current published information on whale shark numbers along the Peruvian coast.

Recently, satellite telemetry data have shown that some large females, presumably gravid, tagged at the Galapagos Islands move to areas off the shelf break of northern Peru (Hearn et al.

2016). The evidence of connectivity between an important female whale shark aggregation area in the eastern Pacific and Peru highlights the need to further understand their use of Peruvian waters. As an initial approach, this study aims to (1) summarize current records of whale shark occurrence in Peru, and also (2) investigate interactions between whale sharks and fisheries in the area.

MATERIALS AND METHODS

Information on the occurrence of whale sharks was obtained from two different sources (1) onboard and shore-based monitoring, and (2) local news reports and social media videos. Opportunistic whale shark data were obtained from onboard observations and shore-based monitoring conducted from January 2014 to October 2017 by the NGO ProDelphinus as part of its marine fauna bycatch project. On-board observers collected information on trips of artisanal gillnet vessels in the ports of San Jose (06.75°S, 79.96°W) and gillnet and longline vessels in Salaverry (08.23°S, 78.98°W) in northern Peru, and gillnet vessels in Ancon (11.77°S, 77.17°W) in central Peru (Figure 1*A*). Shore-based observers also gathered information on fishing activities at San Jose and Salaverry, which was collected through daily interview with fishers after landing. Whale shark bycatch data were also collected from the shore-based observer program of the Peruvian Marine Institute (IMARPE), which records landing information from small-scale fisheries at key fishing ports along the Peruvian coast. Given the limited amount of research conducted on whale sharks in Peru, additional observations and bycatch information were compiled from local news reports, and social media videos from reliable sources. Sighting reports were also compiled from ecotourism activities and were only included in our analysis if reports were verifiable (e.g., person was contacted and provided detailed information).

<<Fig. 1 near here>>

Six shark individuals were measured (total length, TL), seven others were only photographed or video recorded, and three were only weighed. For photographed and video recorded individuals, total length was estimated by comparing the length of the shark with that of other objects of known size in the photo or video. To estimate TL of sharks with weight data only, we used a weight-length power regression from Hsu et al. (2012), $M_T = aL_T^b$, where M_T is body mass (kg), and coefficients a = 12.10 and b = 2.862. Sharks were categorized, based on size, as juveniles (<8m TL, Norman and Stevens 2007) or neonates (<1.5m TL, Rowat and Brooks 2012).

RESULTS

A total of 27 records were compiled (Table 1). Records were located mainly in northern Peru (Figure 1*B*) and occurred from January to April and between July and December, with 56% of reports occurring during the austral summer (January to March, 33.3%) and spring (October to December, 22.2%) (Figure 2). April 2015 was the month with the most (22%) records (Table 1). During winter, individuals were only reported in the northernmost areas (north of 4°S), while in the southernmost area (~12°S) sharks were reported only during warmer months (Table 1). The in-water locations of only fourteen sharks were available and, except for four of these individuals, most sharks were encountered over or on the edge of the continental shelf, in coastal waters (Figure 1*B*).

<<Fig. 2 near here>> <<Table 1 near here>>

No adults were recorded. Total length of individuals with body size reported or estimated ranged from 0.6 to 6.0m TL (mean ± SD: 4.0 ± 1.9.m). Most individuals with TL reported were juveniles, except for three neonatal individuals incidentally captured in nets. The first

neonatal individual was captured by a small-scale gillnet fisher based at the Port of San Jose on April 2015 and was ~0.8m TL (Table 1, Figure 3*A*). The second and third neonatal individuals were incidentally captured in gillnet vessels based at the port of Salaverry on February and March 2017, and measured 0.61m TL (Table 1, Figure 3*B*) and ~0.6m TL, respectively (Table 1, Figure 3*C*).

<<Fig. 3 near here>>

A total of 1,990 small-scale gillnet fishing trips targeting mostly rays and sharks and 111 small-scale longline trips targeting sharks and dolphinfish were monitored from January 2014 to October 2017 by ProDelphinus. Bycatch of thirteen individual whale sharks were reported during the monitoring period. The bycatch of one additional individual was reported outside of this monitoring period. These fourteen sharks were caught in gillnets, and no individuals were reported caught on longlines. The fishing grounds use by these small-scale fisheries were mainly coastal (Figure. 1*A*). On the other hand, no information on fishing effort was available for the IMARPE monitoring program, which reported the bycatch of eight whale sharks from 2006 to 2016, two of those by small-scale purse seines and the rest by small-scale gillnets (Table 1). Five other whale shark observations were also reported from local news reports (n =2), social media videos from reliable sources (n =2), and ecotourism activity (n =1) (Table 1). Overall, in approximately 89% (24 out 27) of the records, whale sharks interacted with small-scale net (gillnet and purse seine) fisheries (Table 1).

Information on the fate of captured individuals was available for some sharks and revealed that whale sharks were either released alive or retained for consumption (Table 1). Direct take was reported for one individual, when fishers were offered monetary compensation for the fins (http://rpp.pe/peru/tumbes/pescadores-matan-a-un-tiburon-ballena-para-quitarle-sus-aletas-noticia-939404).

Out of nine sightings from ecotourism activities only one was verifiable and included in our analysis. The other eight non-verifiable observations were also compiled (Table S1) to show that whale sharks are reported as also being encountered by tourism companies but were not included in our analysis.

DISCUSSION

In the Eastern Pacific, little is known about whale sharks in areas other than the Galapagos Islands, Ecuador or the Gulf of California, Mexico (Hearn et al. 2016, Ramírez-Macías et al. 2012). The first report of a *R. typus* in Peruvian waters occurred in 1955, after the capture of an adult individual by whalers in Pisco (13.7°S), southern Peru (Barreda 1978), and a further study 40 years later revealed the seasonal occurrence of juvenile and adult whale sharks in northern waters (Ramirez 1995). The present study provides recent records of whale sharks in Peruvian waters, confirming their sporadic presence off northern and central Peru.

In this study, similar to a previous observational study (Ramirez 1995), most individuals were reported off Peru during warmer months, which correspond with the peak of chlorophyll concentration and productivity in the area (Pennington et al. 2006). Similarly, whale sharks are mostly abundant in the Galapagos between July and December (Acuña-Marrero et al. 2014), closely coinciding with the period with highest chlorophyll-*a* concentrations found in the area, between August and December (Palacios 2004). Recently, a study revealed the association of whale sharks with the equatorial upwelling present around the Galapagos from July to November and with upwelling habitats off Peru during warmer months (December to March), indicating that whale sharks use areas with enhanced productivity (Ryan et al. 2017).

Interestingly, our results showed that whale shark reports also occurred during the 2015-2016 weak El Niño Southern Oscillation (ENSO, NOAA 2015) event. ENSO impacts the

Peruvian marine community distribution and composition, especially of plankton (Tam et al. 2008) on which whale shark feeds. It is possible that the weak ENSO conditions still allowed the presence of sharks off Peru. However, during the strong 1982-1983 ENSO, no whale sharks were observed in northern Peruvian waters (Ramirez 1995). Future research should investigate how dramatic environmental changes such as ENSO affect the movement patterns and habitat use of whale sharks.

We also found that whale shark records were frequent in months where sea surface water temperatures are lower (winter and spring), but only in the northernmost area, where various ecotourism agencies appear to be reporting whale shark sightings (Table S1). Long-term monitoring of this northernmost area, where sharks seem to be present for most of the year, will allow us to better understand the distribution and connectivity patterns of whale sharks in the southeast Pacific.

Information suggests that Peruvian waters are used by adult females (Hearn et al. 2016) and juvenile whale sharks of both sexes (This study). As with many other shark species, whale sharks segregate by sex and size (Rowat and Brooks 2012). Most whale shark aggregations are composed primarily of immature males found in coastal areas (see review in Rowat and Brooks 2012). In the Gulf of California, juvenile males are predominant in the north, while further south most individuals are adult females (Ramirez-Macías et al. 2012). In general, gravid females are rarely seen and are mostly found using oceanic waters (Hearn et al. 2016, Macena and Hazin 2016, Ramirez-Macías et al. 2017). No adults were reported in this study, where whale shark monitoring occurred almost exclusively in coastal waters, but the apparently gravid females tracked from the Galapagos Islands to northern Peru appear to use oceanic waters just off the continental shelf (Hearn et al. 2016). It is likely that, as other studies have found, juvenile

individuals are mostly using coastal waters in Peru, while adult whale sharks are less likely to be found in these coastal areas.

Neonatal individuals are also rarely encountered (Rowat and Brooks 2012). The three individuals incidentally captured in northern Peru are the first reported for the southeastern Pacific. These neonates were encountered in February and early April, which coincides with the time of year with the highest number of whale shark occurrences (Ramirez 1995, this study). Additionally, large females with distended abdomens tracked from the Galapagos Islands have been observed off Peru by December (Hearn et al. 2016). Because neonatal individuals appear to have limited swimming abilities compared with juvenile and adult whale sharks (Martin 2007), areas where neonatal individuals are found are thought to be pupping grounds (Rowat et al. 2007). Thus, the presence of neonatal individuals, in addition to that of large gravid females, strongly suggests that the region off northern Peru is a pupping ground.

The neonatal individuals captured in Peru were reported off the continental shelf or close to it, which would support the idea raised by various authors that offshore areas may provide suitable habitats for pupping (Norman et al. 2017). Continued dedicated long-term monitoring of Peruvian waters will allow us to elucidate the role they play in whale shark occurrence and distribution.

Fisheries interactions and management implications

Peru recently passed legislation to protect whale sharks against direct capture and commercialization (Resolución Ministerial N°331-2017). This is a precautionary measure taken by the Peru government given that a direct capture of whale sharks does not exist in the country (Resolución Ministerial N°331-2017), except for the anecdotal report of direct take of an individual for its fins reported in this study.

In this study, we provide the first records of whale shark bycatch in Peruvian waters using a systematic monitoring of small-scale fisheries. Bycatch in Peruvian net fisheries, although rare, may pose a threat to the already small whale shark population in the eastern Pacific, as revealed by the few reports of consumption of bycaught whale sharks. In particular, juvenile whale sharks could be more at risk of bycatch because of their likely use of coastal waters, where most small-scale gillnet fishing activity occurs (Alfaro-Shigueto et al. 2011, this study) and also given the ubiquity of these small-scale gillnet vessels in the northern Peru area (Alfaro-Shigueto et al. 2010). However, most bycaught individuals were released by fishers, suggesting that fishers may be keen to adopt safe release techniques and measures to prevent bycatch. Net damage during the release of bycaught individuals can affect fishing activities, which could also be an incentive to adopt bycatch mitigation and release techniques. The enforcement of current Peruvian legislation, which also requires the reporting of bycaught whale sharks and the safe handling and immediate release of individuals (Resolución Ministerial N°331-2017), as well as the implementation of education and outreach programs, may help reduce fishery-related mortality events.

Whale shark numbers reported in Peru may be higher if we consider that tourism companies based in northern Peru (e.g., North Shore Peru Expeditions and Pacifico Adventures) have reported several other sightings through social media platforms. Recently, it has been revealed that ecotourism companies and ecotourists, as part of the citizen science project "Wildbook for Whale Sharks", have provided vital information on the life history and demography of whale sharks worldwide (Norman et al. 2017). Whale shark tourism is not regulated in Peru, thus conservation measures should also address the management of these activities, which can also negatively impact whale sharks (Quiros 2007, Ramirez-Macías et al. 2012).

CONCLUSIONS

Likely due to their rare occurrence in Peruvian waters, whale sharks were not brought into focus until recently when global declines in population numbers threatened the viability of the species. In this study, we provided the first detailed records of whale shark occurrence along the Peruvian coast in over 30 years, including their interactions with small-scale fisheries. According to past and new information gathered in this study, occurrence of individuals appears to be seasonal. As found in only a few other areas in the world, female adults and juveniles (of both sexes) use waters off Peru. Whale sharks may use Peruvian waters as a pupping ground. However, there still is a lack of knowledge about the life history, movements and habitat use of whale sharks in Peruvian waters, in particular of juvenile individuals. We do not know, for instance, whether whale sharks using Peruvian waters are transient or form part of a resident population. Effective conservation measures of endangered species for which little is still known will require a better understanding of its ecology. Thus, efforts should be focused on conducting systematic research to increase our ecological knowledge on whale sharks in Peru to inform conservation measures. The previously revealed connectivity between Galapagos and Peru emphasizes also the need to address conservation measures of endangered whale sharks through the implementation of regional strategies.

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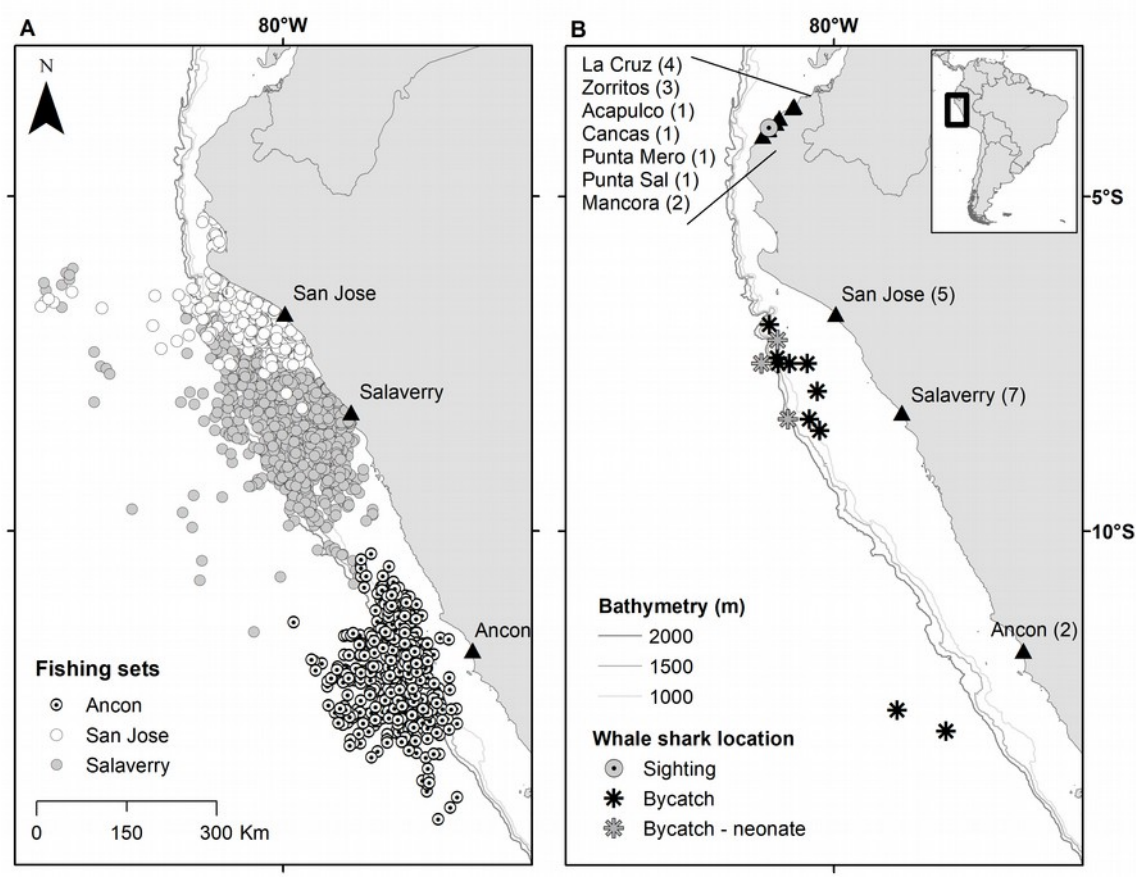

Figure 1. Locations of (A) small-scale gillnet sets monitored off the ports of San Jose, Salaverry and Ancon from 2014 to 2017, and (B) whale sharks, *Rhincodon typus*, bycatch and sightings reported off Peru from 2006 to 2017. Fishing grounds used by fishers at each port are represented by location of fishing sets. Ports where whale shark reports were gathered are also shown. The numbers in parentheses indicate the number of whale sharks reported by the onboard and/or land-based monitoring program at each port.

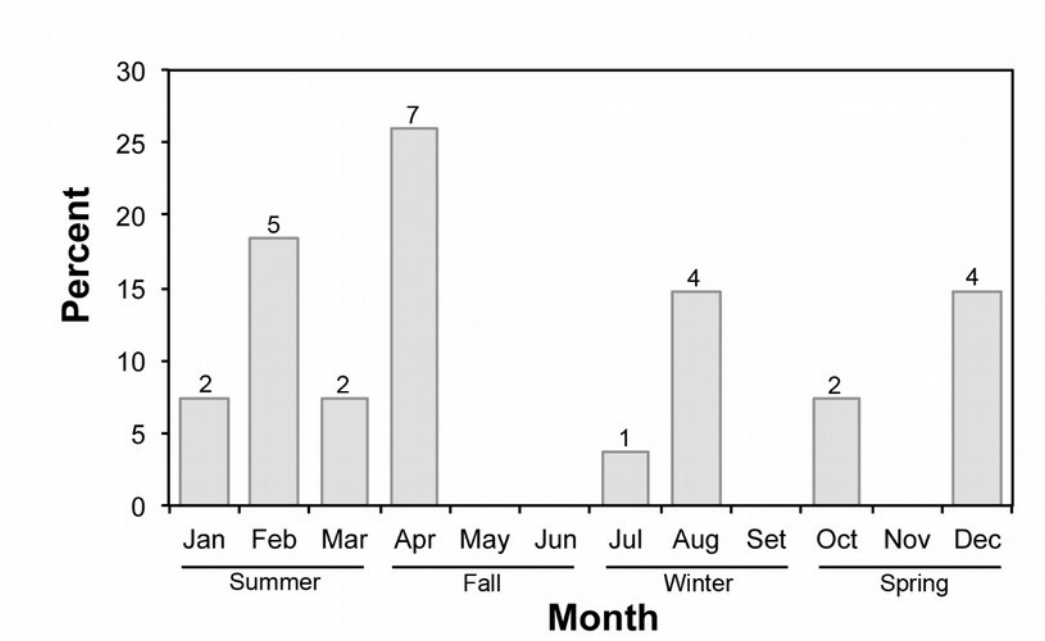

Figure 2. Percent occurrence by month (and season) of whale sharks, *Rhincodon typus*, in waters off Peru from April 2006 to August 2017. Numbers above histograms are number of individuals reported.

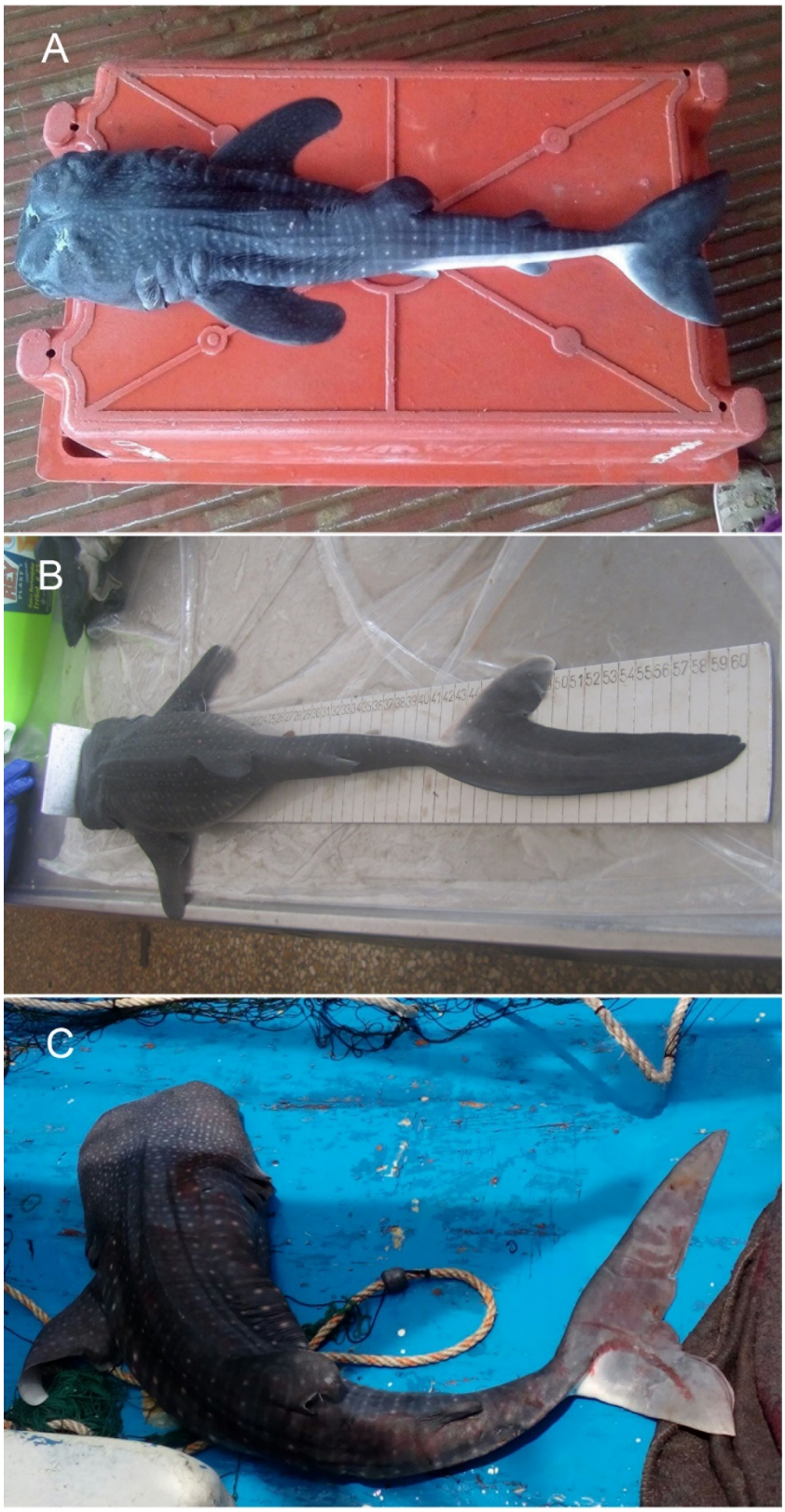

Figure 3. Neonatal whale sharks, *Rhincodon typus,* incidentally captured by small-scale gillnet vessels based at the ports of (A) San Jose and (B, C) Salaverry in northern Peru.

Supplementary information

Table S1. Unverified whale shark sightings from ecotourism activities compiled from their social media networks. Location of ports where ecotourism companies operate or the port associated with the report are indicated.

Record	Date	Port	Location (°S, °W)	Source
1	25 July 2011			Pacifico Adventures (2011)
2	12 November 2013	Vichayito	04.15°, 81.11°	Pacifico Adventures (2013)
3	07 October 2014	Organos	04.17°, 81.12°	Pacifico Adventures (2014)
4	20 April 2015	Organos	04.17°, 81.12°	Pacifico Adventures (2015a)
5	23 October 2015	Organos	04.17°, 81.12°	Pacifico Adventures (2015b)
6	12 January 2016	Organos	04.17°, 81.12°	Oceanica Expeditions (2016)
7	01 August 2017	Organos	04.17°, 81.12°	Pacifico Adventures (2017)
8	03 October 2017	Puntal Sal	03.87°, 80.83°	North Shore Peru Expeditions/2enruta (2017)

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Table 1. Chronology of records of whale sharks, *Rhincodon typus*, in Peru.

Record	Date	Port	Location (°S, °W)	Report type	TL (m)	Sex	Fate	Source
1	15 April 2006	Zorritos	03.66°, 80.62°*	Bycatch gillnet	3.91[+]		Unknown	This study
2	04 January 2009	Salaverry	08.50°, 80.22°**	Bycatch gillnet			Unknown	This study
3	08 August 2009	Punta Mero	04.00°, 80.86°*	Bycatch gillnet	6.00		Unknown	This study
4	16 July 2010	Zorritos	03.66°, 80.62°*	Bycatch purse seine	6.41	M	Retained for consumption	This study
5	March 2011	Mancora	04.10°, 81.05°*	Bycatch gillnet	4.98[+]		Unknown	This study
6	15 August 2012	Punta Sal	03.58°, 80.58°	Sighting	<8.00		Unknown	North Shore Peru Expeditions (2012)
7	December 2012	Mancora	04.10°, 81.05°*	Bycatch	3.24[+]		Unknown	This study
8	05 October 2013	La Cruz	03.54°, 80.52°*	Bycatch purse seine	4.58	F	Retained for consumption	This study
9	24 December 2013	La Cruz	03.54°, 80.52°*	Bycatch gillnet	4.53	F	Unknown	This study
10	14 February 2015	Salaverry	07.50°, 80.80°**	Bycatch gillnet			Unknown	This study
11	02 April 2015	Salaverry	07.92°, 80.25°**	Bycatch gillnet			Unknown	This study
12	08 April 2015	Salaverry	07.50°, 80.40°**	Bycatch gillnet			Unknown	This study
13	10 April 2015	San José	07.42°, 80.85°**	Bycatch gillnet			Unknown	This study
14	19 April 2015	Salaverry	08.33°, 80.37°**	Bycatch gillnet			Unknown	This study
15	21 April 2015	San Jose	07.50°, 80.67°**	Bycatch gillnet			Unknown	This study
16	29 April 2015	San Jose	07.14°, 80.84°	Bycatch gillnet	0.80[+]	F	Retained for consumption	This study
17	03 December 2015	Cancas	03.99°, 80.99°*	Sighting	<8.00	M	Unknown	El Comercio (2015)
18	19 February 2016	San José	06.75°, 79.96°*	Bycatch gillnet			Released alive	This study
19	19 February 2016	Acapulco	03.82°, 80.82°*	Directed capture			Finned	RPP Noticias (2016)
20	24 August 2016	Zorritos	03.66°, 80.62°*	Bycatch gillnet	4.80	M	Released alive	This study
21	10 October 2016	La Cruz	03.54°, 80.52°*	Bycatch gillnet	4.00[+]		Released alive	Tiburon Ballena Peru (2016)
22	30 December 2016	Ancon	12.95°, 78.33°	Bycatch gillnet			Released alive	This study
23	January 2017	San José	06.78°, 80.02°	Bycatch gillnet			Released alive	This study
24	01 February 2017	Ancon	12.64°, 79.06°	Bycatch gillnet	<8.00		Released alive	This study
25	13 February 2017	Salaverry	07.50°, 81.08°	Bycatch gillnet	0.61	M	Retained for study	This d
26	11 March 2017	Salaverry	08.33°, 80.22°	Bycatch gillnet	0.60[+]		Retained for study	This study
27	01 August 2017	La Cruz	03.54°, 80.52°*	Bycatch gillnet	6.00[+]		Released alive	Tiburon Ballena Peru (2017)

Location of whale shark bycatch or sightings, *location of fishing ports where captured sharks were reported, and ** location of the general fishing areas where individuals were captured. [†]Individuals whose TL was estimated (see *Methods* for more information).