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Captures of manta and devil rays by small-scale gillnet fisheries in northern Peru

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ABSTRACT

There is a growing global concern for the conservation of manta and devil rays (Mobulidae). Populations of mobulids are falling worldwide and fisheries are one of the main activities contributing to this decline. Mobulid landings have been reported in Peru for decades. However, detailed information regarding the description of mobulid captures is not available. This study provides an assessment of mobulid captures and fish-market landings by small-scale gillnet fisheries from three landing sites in northern Peru. Onboard and shore-based observations were used to monitor captures and landings respectively between January 2015 and February 2016. All mobulid species known to occur in Peru were recorded from landings, with immature *Mobula japanica* as the most frequent catch. No manta rays (*Manta birostris*) were reported as caught although one specimen was observed as landed. The mean nominal CPUE was 1.6 ± 2.8 mobulids$[\text{km.day}]^{-1}$ while the average capture per set (fishing operation) was 2.0 ± 8.09 mobulids$[\text{set}]^{-1}$. Smooth hammerhead shark (*S. zygaena*) and yellowfin tuna (*T. albacares*) were target species highly associated with mobulid captures. The majority of mobulid captures occurred in nearshore waters and over the continental shelf off Zorritos and San Jose. Mobulid capture showed a temporal trend, increasing between September 2015 and February 2016, with a peak in October 2015 (10.17 ± 0.23 mobulids$[\text{km.day}]^{-1}$), reflected by landings that showed an additional peak in May. A generalized linear zero-inflated negative binomial two-part model (GLM ZINB) indicated that longitude and latitude explained both the zero-inflated binomial model, as well as the count negative binomial model, which also included season as a explanatory variable for differences in mobulid captures. The mean CPUE (mobulids $[\text{km.day}]^{-1}$) and mean Variance values obtained from the fitted final model were 1.73 and 25.51, respectively. Results also suggest that high mobulid captures could reflect an opportunistic behaviour of fishermen who catch mobulids when target species are not as abundant. Considering the global conservation status of mobulids, (*Manta* and *Mobula*), and acknowledging that *M. birostris* was the only species not recorded captured in the study but is the only species legally protected in Peru, further studies are necessary to support the possible inclusion of *Mobula* species in national management plans.

1. Introduction

Mobulids are large planktivorous elasmobranchs from the family Mobulidae, represented by manta (*Manta* spp) and devil rays (*Mobula* spp). These rays are mostly identified by their large body sizes, with disc widths (DW) up to 7 m for *Manta* spp and up to 5 m for *Mobula* spp (Notarbartolo di Sciara, 1988; McClain et al., 2015), and the presence of two cephalic lobes on the head. The genus *Manta* includes two species, while the genus *Mobula* groups nine species. Both genera are widely distributed in tropical and subtropical latitudes (40°N–40°S) where seawater temperatures are between 20 and 26 °C (Clark, 2010; Canese et al., 2011; Croll et al., 2012). However, mobulid individuals do not show large ranges of displacement (Camhi et al., 2007).

Although little is known about the ecology of this family (Couturier et al., 2012), some studies have revealed the high vulnerability of mobulids to anthropogenic threats such as fisheries, habitat loss and

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degradation, and climate change (Dulvy et al., 2008; Rohner et al., 2013; Duly et al., 2014b). Their k-selected life histories may make mobulids highly vulnerable to even small population depletions (Couturier et al., 2012; Dulvy et al., 2014a; Croll et al., 2015). The International Union for the Conservation of Nature (IUCN) Red List categorizes four mobulid species as near threatened, four as vulnerable, one as endangered, and two as data deficient. Some specific management measures to protect mobulids have been applied worldwide. International agreements such as the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) and the Convention on the Conservation of Migratory Species of Wild Animals (CMS) promote better regulations for trade and the establishment of management plans for mobulids. However, there are still limitations in conservation measures among the species, which experts are trying to resolve (Lawson et al., 2017).

Fisheries interactions appear to be the main threat for sub-populations of mobulid species. Estimates of manta and devil rays catches in Africa and Asia have increased from 931 mt in 2000 to > 4000 mt in 2014 (FAO, 2016), with a global catch estimate of ca. 94 000 ind/year (Heinrichs et al., 2011). This information, together with the fact that in some locations mobulid stocks are declining (Ward-Paige et al., 2013; Lewis et al., in press), raises concerns about the status of manta and devil ray populations and their capacities to respond to anthropogenic threats such as fisheries.

Small-scale and recreational fisheries targeting mobulids have been reported for centuries (Croll et al., 2015). Meat, skin, and, more recently, gills, have been used as food, bait (for artisanal fisheries) and leather, as well as in Asian traditional medicine (gills). While only nine countries report having fisheries that target mobulids (Indonesia, Philippines, India, Sri Lanka, Mexico, Taiwan, Mozambique, Gaza Palestinian States and Egypt), it is important to consider other areas where incidental catches of mobulids are used as an “opportunistic catch” due to the increasing values arising from international trade of gills (Couturier et al., 2012; Hall and Roman, 2013; Lewis et al., in press). In addition to directed and opportunistic catches, incidental catches (or “bycatch”) of mobulids have also been reported by small- or large scale fisheries from 30 countries (Croll et al., 2015). The fishing gears with the highest reported quantities of mobulid bycatch were gillnets and purse seines (Alava et al., 2002; Croll et al., 2015,). Of these, tuna purse seine fishing had the highest catch with reports of over 4700 ind/year for the Eastern Pacific Ocean between 1993 and 2009 (Hall and Roman, 2013).

In Peru, the catch and landing of mobulids has also been reported. Gonzalez-Pestana et al. (2016b), ranks it as the 15th country in global batoid landings, representing 11% of total landings worldwide between 2005 and 2011. The study indicates that mobulid landings were 28% of total batoid landings in the country, with the largest proportion of landings coming from the northern coast, and gillnets the main fishing gear used for mobulid captures. Researchers have reported mobulid catches in Peru both in small-scale and industrial fisheries (Ayala et al., 2009; Alfaro-Shigueto et al., 2010; Hall and Roman, 2013). The purse seine tuna fishery off the Peru between 1994 and 2009 reported an average of more than 600 mobulids/year captured as bycatch (Hall and Roman, 2013). Additionally, observations of mobulid bycatch have been reported in the small-scale gillnet fishery operating along the north coast of Peru (Castañeda, 1994; Ayala et al., 2009).

The lack of accurate data at the species level on mobulid landings does, however, prevent a clearer understanding of the catch rates of individual species. Data gaps such as these can lead to inaccuracies in the development or implementation of conservation and management measures. Since 2014, the five species of mobulids present in Peru waters (*M. munkiana, M. tarapacana, M. japanica, M. thurstoni* and *M. birostris*), have been included in the National Action Plan for Elasmobranch Conservation (PAN-Tiburón) (Supreme Decree N° 002-2014 PRODUCE). However, only *Manta birostris* is subject to specific regulations, which establish the ban on its capture, landing, processing, and/or trade. In cases of bycatch, specimens are to be returned to the water without injuries (Ministerial Resolution N° 441-2015 PRODUCE).

The main objective of the present study was to describe the mobulid small-scale gillnet fisheries in three ports in northern Peru (Zorritos, Mancora and San Jose). More specifically, we were interested in (1) estimating the rate of mobulid captures by small-scale gillnet fisheries in the study zone, (2) estimating the landing of mobulids and its fluctuation along the year, and (3) evaluating if mobulid captures are influenced by temporal and/or spatial variables.

2. Methods

2.1. Study area

The study was conducted from January 2015 to February 2016 at three landing sites in northern Peru: Zorritos (3°40′S, 80°40′W); Mancora (4°06′S, 81°02′W) and San Jose (6°45′S, 79°58′W). These sites comprise one of the areas with the majority of elasmobranch and mobulid landings in the country (Ayala, 2014; Gonzalez-Pestana et al., 2016a,b).

The marine ecosystem of Peru comprises the Northern Humboldt Current System (NHCS), known for its unique oceanographic conditions, characterized by strong upwelling and the confluence of many currents, which generate high fishing productivity (Chavez et al., 2008). In northern Peru, the NHCS borders with the Pacific Equatorial System (PES), composed of warm waters and high biodiversity. The study area corresponds to the convergence zone (4° − 7° S) between these two systems (Strub et al., 1998; Flores et al., 2013).

2.2. Onboard observations

Five trained onboard observers collected information aboard small-scale artisanal fishing vessels (maximum of 32.6m^3 GRT, up to 15 m length and operating manually, Supreme Decree N° 012-001-PE) from the above-mentioned ports. Observers monitored the fishing activity of eight surface driftnet vessels during 85 trips (331 individual fishing sets). Skippers (N = 8) whose vessels were monitored participated voluntarily in the project. The pelagic gillnet fishery in the study zone is considered a multi-species activity mainly targeting sharks such as smooth hammerheads (*Sphyrna zygaena*) and thresher sharks (*Alopias* spp.), and pelagic bony fishes such as yellowfin tuna (*Tunus albacares*). The net size is highly variable between vessels. Vessels typically set the net during the afternoon and retrieved the following morning (soak duration ~14.5 h) (Alfaro-Shigueto et al., 2010).

Data related to fishing activities, concerning fishing net dimensions, fishing timing and position (using GPS) per set, and species caught in numbers (target and not target) were recorded. Retained fish were counted as catch since discards in this fishery are typically very low, given its multi-specific nature. Observers did not take part in fishing activities. When conditions allowed, biometric data, sex and weight of mobulids caught were recorded. Identification to the species level was attempted onboard using identification guides provided during this study, as well as on land using pictures of the catch. Data were analysed to the genus level (Mobula spp. or Manta spp) due to difficulties in Mobula species identification (mainly between *Mobula munkiana* and *Mobula thurstoni*) because of challenging sampling conditions at sea.

Observers worked every month (2–3 trips per month per observer) over a total period of 14 months (from January 2015 to February 2016) in order to account for any potential seasonal variability in catch rates. Onboard observer data were managed in a Microsoft Access database.

2.3. Shore-based observations

In order to monitor total mobulid species landings by this gillnet fishery, shore-based observers were also deployed in San Jose from September 2015 to January 2016, and in Zorritos from January 2015 to

February 2016. These shore-based observers collected data on the total number of mobulids for each species landed per vessel per fishing trip. Identification to the species level was attempted using ID guides. Since large mobulids are mainly landed in pieces (pectoral fins without tail nor head) species identification was made based on colour patterns on pectoral fins and verified using mDNA barcoding through a parallel study. When conditions allowed (whole animal or mobulid pieces with the pelvic fins and reproductive organs visible), biometric data and sex of mobulids landed were recorded. Individuals landed in pieces were measured for disc width by doubling the length of the right fin. Data collection was based upon daily monitoring of dockside activity.

Mobulid landings in Mancora could not be monitored during the study period because the port was in the process of being rebuilt. Shore-based data from Mancora collected by the local NGO ProDelphinus in 2013, which included data on mobulid landings (kg of mobulid per vessel per trip), was used as a proxy to analyse mobulid fishing trends in this zone.

2.4. Data analysis

To facilitate our objective of better understanding how mobulid captures relate to other fish catch, and to simplify data analysis, capture data recorded by onboard observers was split into two groups, based on the species caught by fishermen: (1) *Mobulids*, which correspond to all *Manta* and *Mobula* species, and (2) *Target*, corresponding to all other commercial species, excluding Mobulids (mainly sharks and tuna).

To provide an empirical description of the data collected by observers, nominal captures per unit effort (CPUE) for *mobulids* and *target* fish were calculated per set, based on net length (km) and set duration (day). To analyse temporal trends in nominal CPUE, values per set were grouped by month. Rates obtained were expressed in mobulids $[\mathrm{km.day}]^{-1}$ and fish$[\mathrm{km.day}]^{-1}$. In order to broaden comparability to other studies, average Capture of Mobulids per Set (CPS) was also calculated and expressed in mobulids$[\mathrm{set}]^{-1}$ and fish$[\mathrm{set}]^{-1}$. Descriptive statistics are presented as mean ± standard deviation (SD). Statistical tests were performed using R 3.1.3 (R Core team, 2016).

In order to standardize mobulids CPUE, using different covariates to better understand their influence over catch rates, a Generalize Linear Model (GLM) was applied (Minami et al., 2007; Amandè et al., 2008). The data for mobulid captures was recorded as counts (i.e. number of individuals caught per fishing set). A first assessment of the frequency distribution showed a long right tail and a large amount of zeroes (80.25% of all sets, see supplementary material for a more detailed model description). Thus, given the nature of the data, Generalised Linear Models (GLMs) were applied, testing both the Poisson and Negative Binomial (NB) families. Due to the large number of zeroes in the data, and further overdispersion issues, a zero-inflated negative binomial (ZINB) distribution with a log link function was applied. The ZINB GLM is a two-part model that combines the probabilities of measuring positive integers and 'true' zeroes, with observations containing 'false' zeroes, which need to be accounted for (for example, mobulid disentanglements), allowing for the assignation of different predictive variables to each part. The model was built and optimized as follows: Mobulid captures was the response variable, whereas season (summer: January-March, fall: April-June, winter: July-September, and spring: October-December), longitude, latitude and target species catches were selected as predictor variables. Effort was considered as an offset variable. A top-down approach was followed in order to obtain a first full significant model. For this approach, all covariates, as well as their interactions, were first included and taken out in a step-wise fashion according to each model's significance. This first full model was further tested to see if more terms could be dropped while improving the fit. The process was done by removing all terms in turns and comparing each resulting model against the full model (because the former were all nested in the latter), using a likelihood ratio test, as well as the Akaike Information Criterion (AIC). The ZINB model was fitted in R 3.1.3 (R Core Team, 2016), using the *zeroinfl* function of the *pscl* package (Zeileis et al., 2008).

Mobulid landings from shore-based data were analysed per month. For Zorritos and San Jose, the mean of total mobulid individuals per month were calculated. In the case of Mancora, the mean of total mobulid weight (kg) per month were calculated. Rates obtained were expressed as mobulids$[\mathrm{month}]^{-1}$ for Zorritos and San Jose, and as kg $[\mathrm{month}]^{-1}$ for Mancora.

A Length–Weight relationship for specimens of *M. japanica* measured and weighed was obtained by applying the following equation: $TW = aDW^b$, where TW is the total weight of the *Mobula* in grams, and DW is the disc width in cm. The resultant equation was used to estimate the mean weight for captured individuals. The process was not applied for other species due to the small number of samples.

3. Results

3.1. Summary of mobulid catches

A total of 657 mobulids were recorded as captured by onboard observers during the study period across all study sites, representing 10.1% of the total catch (number of specimens). Thirty-three percent of all the monitored trips and 19% of all sets had mobulid captures. In all cases, captured mobulids were from the genus *Mobula*. There was only one observation of a *M. birostris* entanglement, which was disentangled and released alive. The mean nominal CPUE for *Mobula* spp. was 1.6 ± 2.8 mobulids$[\mathrm{km.day}]^{-1}$ (Range: 0–10.2), while the average CPS was 2.0 ± 8.09 mobulids$[\mathrm{set}]^{-1}$ (Range: 0–85). Eighty percent of the mobulids captured were recovered alive. All the mobulids caught (captured and retained) were landed and sold.

The nominal CPUE for target species (sharks and tuna) was 13.25 ± 11.29 fish$[\mathrm{km.day}]^{-1}$ (Range: 0.69–35.57), while the average CPS of target species was 17.6 ± 37.7 fish$[\mathrm{set}]^{-1}$ (Range: 0–310). Eighty-two sets had no catch. Twenty-two target species were identified as associated with mobulid catches. The species most highly associated with mobulid captures were the smooth hammerhead shark (*Sphyrna zygaena*) which represented 16% of the total catch in sets with mobulid captures and was present in 37% of all sets; and yellowfin tuna (*Thunnus albacares*) which represented 13% of the total catch in sets with mobulid captures and was present in 14% of all sets. In 19 sets, mobulids were the only species caught (30% of sets with mobulid catches), representing 55% of the total catch quantity of mobulids.

3.2. Spatial and temporal patterns and predictive variables

Mobulid captures primarily occurred in near-shore waters (65% of sets with mobulid captures occurred within the first 50 km from the coast, being the closest at 3.6 km off San Jose; see Fig. 1) and over the continental shelf, with the highest nominal CPUE of mobulids in the fishing grounds off Zorritos and San Jose (27% and 13% of all sets with captures of mobulids, respectively. Fig. 1). Mobulid catches also showed a temporal trend, rising between September 2015 and February 2016, with a peak during October 2015 (10.17 ± 0.23 mobulids $[\mathrm{km.day}]^{-1}$). Catches of target species showed a different pattern, with high values from January to March 2015, and December 2015 to February 2016 (Fig. 2). In most cases, mobulid captures occurred when target catches were low (Fig. 3).

The first full significant ZINB model was:

MobCatch ~ Season:Latitude + Season + Latitude + Longitude + offset (log(Effort)) | Season + Latitude + Longitude + offset(log(Effort)).

During model selection, eight new models were obtained (Table 1, from A–H) from dropping terms out of the full model (model 0). The p-values from the likelihood ratio tests showed that all new models were

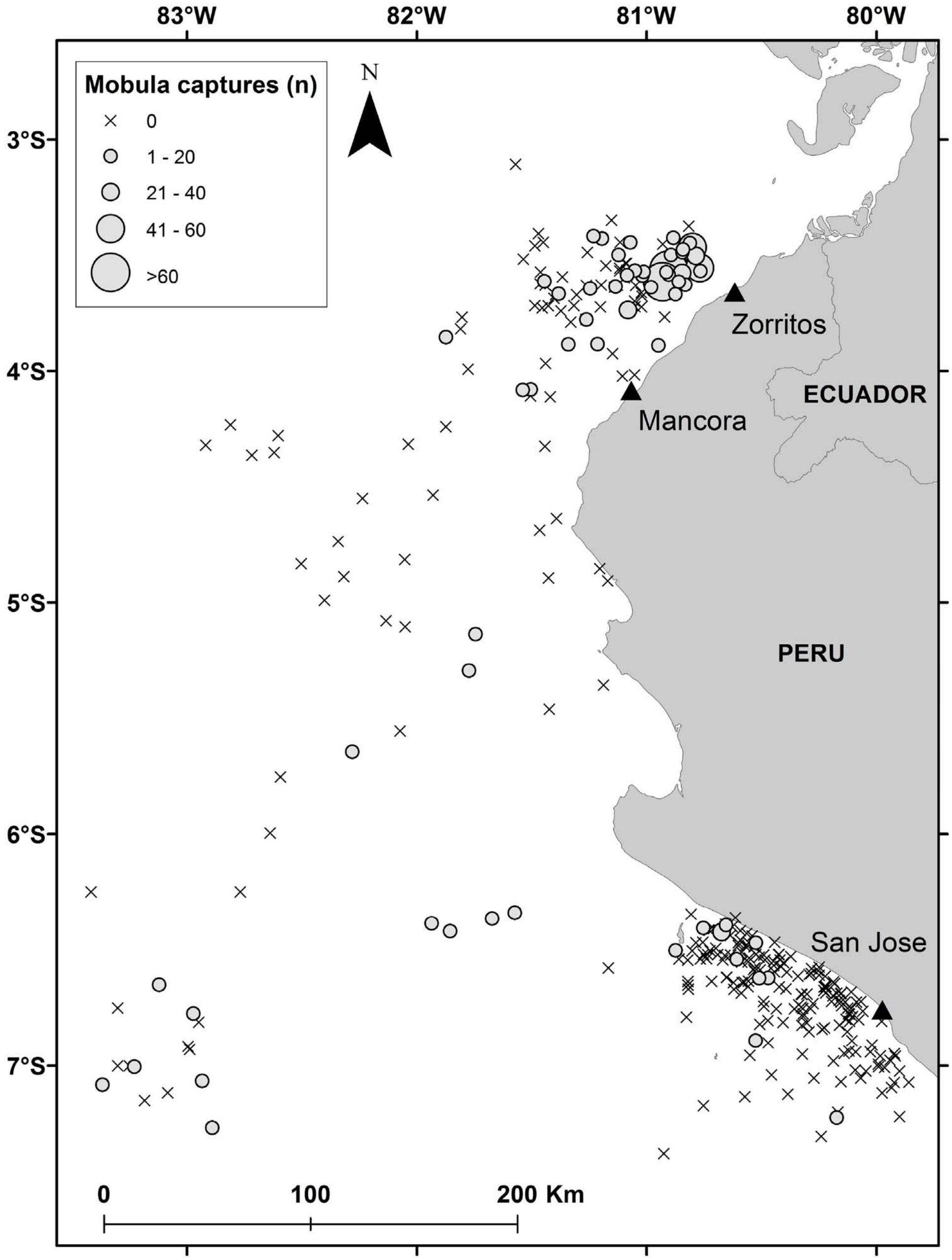

Fig. 1. Map showing mobulid captures (in numbers) registered in every trip by observers on-board small-scale driftnet fishery vessels in northern Peru. Sets where no mobulids were caught are represented by a cross. Bubble sizes are related to the number of mobulids captured.

significantly different after dropping their respective selected terms, meaning that model 0 could be improved if simplified. New models were tested for validation and only model F showed significance when applying a linear model to the observed vs. fitted values of each, though the fit was not perfect ($R^2 = 22.97\%$). The final model F differed from the full model 0 in that it did not include the interaction between season and latitude for the count model (μ_i), and the cov`ariate season for the binomial model (π_i). The final model was:

MobCatch ~ Season + Latitude + Longitude + offset(log(Effort)) | Latitude + Longitude + offset(log(Effort)).

Using the estimated probabilities μ_i and π_i, from the count and the binomial models, respectively, the parameters (i.e. mean and variance) were calculated for the GLM ZINB: (i) mean CPUE = 1.73 mobulids/km*d; (ii) mean Variance = 25.51 (summary table in complementary material).

3.3. Shore-based observations

Daily shore-based monitoring of mobulid landings indicated 1985 mobulids landed by 20 fishing vessels in Zorritos from January 2015 to February 2016 (142 mobulids[month]$^{-1}$, Range: 6–679). The months with the highest landings were May and October (37% and 26% of mobulid landed in 2015). In San Jose, 895 mobulids were landed by 16 fishing vessels between September 2015 and January 2016 (179 mobulids[month]$^{-1}$, Range: 90–256). September and December had the highest reported landings (28% and 25% of mobulids during 2015) (Fig. 4).

Mobula japanica was the most landed species in both ports, representing 97.0% and 99.8% of all mobulid landings in Zorritos and San Jose, respectively. All five mobulid species were recorded for Zorritos (one specimen each of *M. birostris* and *M. tarapacana*). In San José three mobulid species were recorded (*M. japanica, M. munkiana* and *M. thurstoni*) (Table 2).

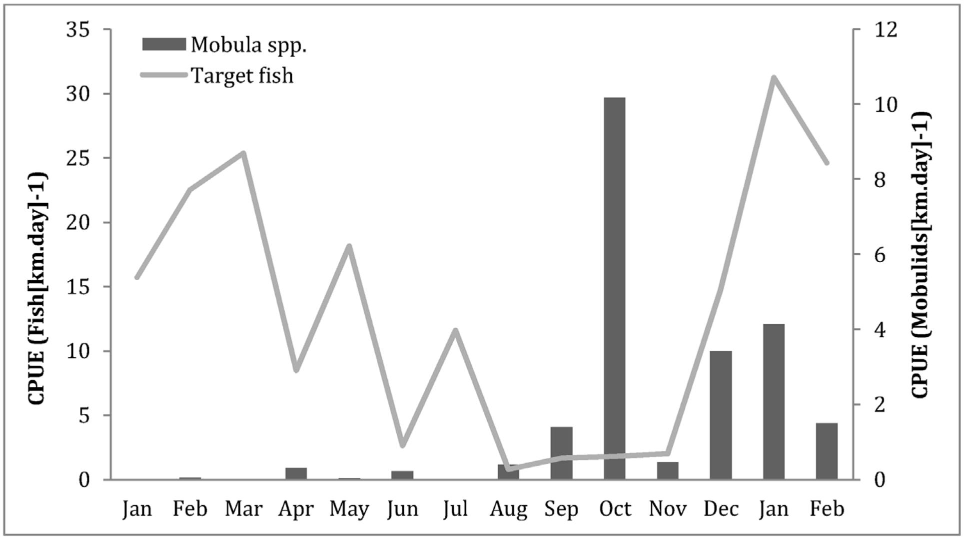

Fig. 2. Catch per unit effort (CPUE) of target fish and mobulids during the study period, January 2015 to February 2016. Values represent the mean nominal CPUE calculated per set for the corresponding month. Data was provided by observers on-board small-scale driftnet fishery vessels in northern Peru.

Trade of mobulid meat was observed in both ports. Prices per kilogram fluctuated between 2.5 and 4 Nuevos Soles (0.75–1.20 US dollars) in both ports, depending upon the colour of the meat (white meat had higher prices than grey) and the other species available for purchase. Mobulid meat from Zorritos was sold mainly in Chiclayo (nearest city to San Jose port) while mobulid meat from San Jose was sold in local markets. We also became aware of an apparent cross-boundary market of mobulid meat between Peru and Ecuador, but we did not investigate this in detail as it was beyond the scope of the project.

Mobulid landings in Mancora during 2012 and 2013 averaged 28.1 ± 13.9 kg[month]$^{-1}$ (Range: 8.8–56.3). The highest numbers of landings were recorded from March to May. Eighteen target species were associated with mobulid landings, with yellowfin tuna as the most common species (45.8% of total landings with mobulids), followed by the smooth hammerhead shark and the thresher shark (10.9 and 10.4% of total landings with mobulids, respectively). Mobulid landings represented 31.6% of total landings. There were no landings reports in which mobulids comprised the unique captured species.

3.4. Biological characteristics of caught mobulids

A total of 651 mobulids were measured and sexed (*M. japanica* = 517, *M. munkiana* = 56, *M. thurstoni* = 56, *M. tarapacana* = 13, *Mobula* spp. = 9). The mean DW for *M. japanica* was 173.0 ± 32.1 cm, for *M. munkiana* was 114.0 ± 73.4 cm for *M. thurstoni* was 142.2 ± 29 cm, and for *M. tarapacana* was 235 ± 29.1 (Fig. 5).

Seventy-six *M. japanica* ($n_{\text{Female}} = 37$, $n_{\text{Male}} = 35$) were measured and weighed, obtaining a Length − Weight relationship represented by the following equation: $TW = 0.025DW^{2.7337}$ (Rsq = 0.753). By applying this equation on all measured *M. japanica*, we estimated a mean total weight of 35 ± 14.6 kg (Range: 0.78–89.8 kg).

4. Discussion

4.1. Mobulid captures

The high mobulid catch rates we report here could be reflecting a higher relative abundance of mobulids along the northern Peru coast

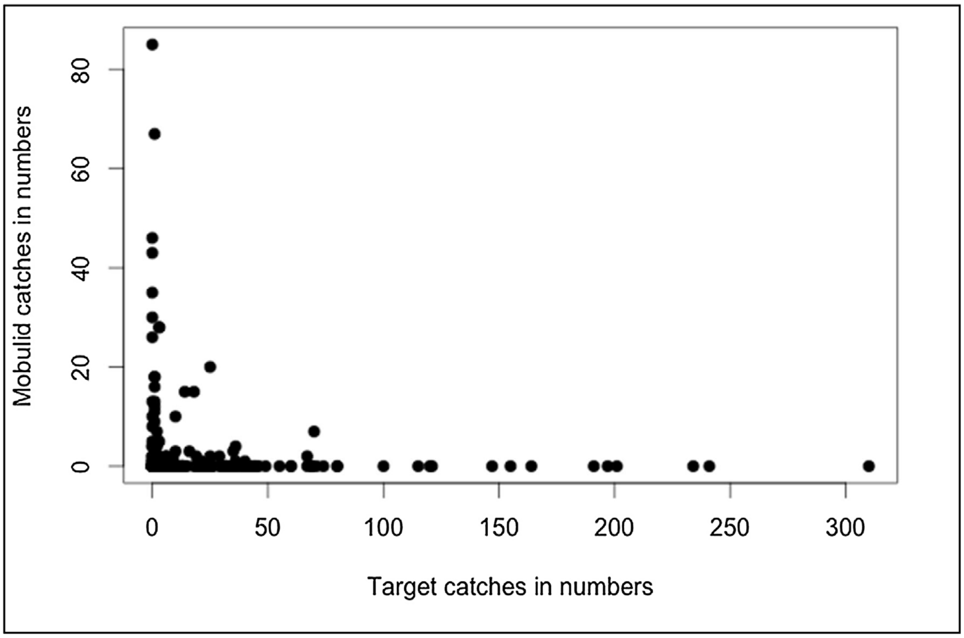

Fig. 3. Correlation between captures of target species and mobulid species during observations on-board small-scale driftnet fishery vessels in northern Peru between January 2015 and February 2016. Each circle represents one fishing set.

Table 1
Results of the model selection. Models A-H are nested in the full significant Model 0, after dropping different terms for each. Chi-squared (X^2) and p-values (p) are shown for the likelihood ratio test for comparisons between the nested models against Model 0. df = degrees of freedom. AIC = Akaike Information Criterion.

Model	Dropped term	ZINB model component changed	df	AIC	Likelihood ratio test	
0	None		16	615.894		
A	Longitude	Count NB model (μ_i)	15	638.159	$X^2 = 24.265$	(df = 1, $p < 0.001$)
B	Season:Latitude		13	619.634	$X^2 = 9.740$	(df = 3, $p = 0.021$)
C	Season	Zero-inflated Binomial model (π_i)	13	621.704	$X^2 = 11.810$	(df = 3, $p = 0.008$)
D	Latitude		15	638.672	$X^2 = 24.778$	(df = 1, $p < 0.001$)
E	Longitude		15	651.767	$X^2 = 37.873$	(df = 1, $p < 0.001$)
F	Season:Latitude from μ_i Season from π_i	Both μ_i and π_i	10	622.238	$X^2 = 18.344$	(df = 6, $p = 0.005$)
G	Season:Latitude + Latitude from μ_i Season from π_i		9	622.236	$X^2 = 20.342$	(df = 7, $p = 0.005$)
H	Season:Latitude + Season + Latitude from μ_i Season from π_i		6	624.883	$X^2 = 28.989$	(df = 10, $p = 0.001$)

and/or a higher consumption of mobulid species by the local coastal population (i.e. higher mobulid captures). Even though the nominal CPUE and CPS of mobulids obtained by this study were smaller than those for the target species, they were higher than the bycatch reported by other studies worldwide, including pelagic purse seines which had the highest reported bycatch values (0.45 mobulids.[set]$^{-1}$ in Hall and Roman (2013), 1.67 mobulids.[set]$^{-1}$ in Molony, (2005)). It is important to recognize, however, the potential impacts of the 2015–2016 El Niño Southern Oscillation event (ENSO) (Quispe and Vásquez, 2016; L'Heureux et al., 2017) in comparison with non-ENSO years. It is known that during ENSO events that Pacific Tropical Surface Waters (PTSW) migrate eastward reaching the southern Peruvian coast while displacing colder waters. This could be expanding habitat suitability for some mobulid species, since they are likely to occur in tropical and warm-temperature waters (Croll et al., 2012; Lawson et al., 2017). Further studies in normal climatological conditions would help clarify the influence of ENSO on this fishery.

The general trend we observed of higher mobulid and target captures between October and January could be reflecting a natural pattern in their abundance during warm and productive periods. The presence of hammerhead sharks and tunas as target species highly associated with mobulid captures, agrees with Hall and Roman (2013) in a global analysis of mobulid catches by tuna purse seines. These overlap

Table 2
Information on mean mobulid captures and landings recorded by observers for each port during the study. Capture per unit effort (CPUE, in mobulids[km.day]$^{-1}$) and Capture per set (CPS, in mobulids[set]$^{-1}$). Units for landings are in number of observed specimens in the case of Zorritos and San Jose, and in kg for Mancora.

	Onboard observers				Shore-based observers	
Port	Fishing sets	Captures	CPUE	CPS	Species	Landings
Zorritos	74	567	5.5	7.66	*Manta birostris*	1
					Mobula japanica	1927
					Mobula munkiana	12
					Mobula tarapacana	1
					Mobula thurstoni	44
San Jose	171	64	0.5	0.37	*Manta birostris*	0
					Mobula japanica	893
					Mobula munkiana	1
					Mobula tarapacana	0
					Mobula thurstoni	1
Mancora	75	26	0.6	0.34	*Mobulidae*	72 754 (kg)

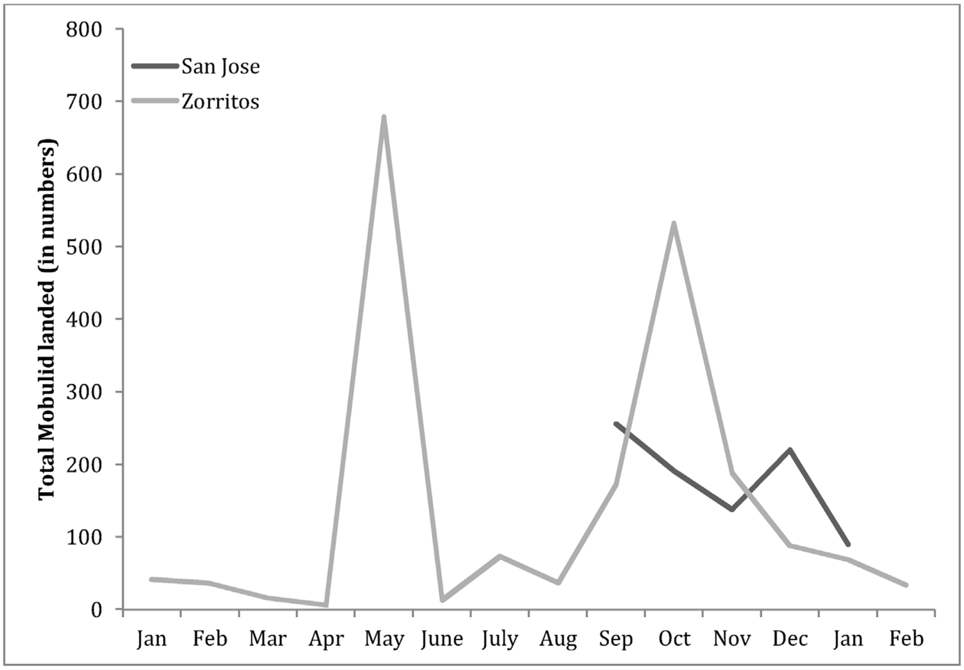

Fig. 4. Shore-based reports of total mobulid landings by small-scale driftnet fisheries in northern Peru: Zorritos and San Jose, during the study period (January 2015-February 2016).

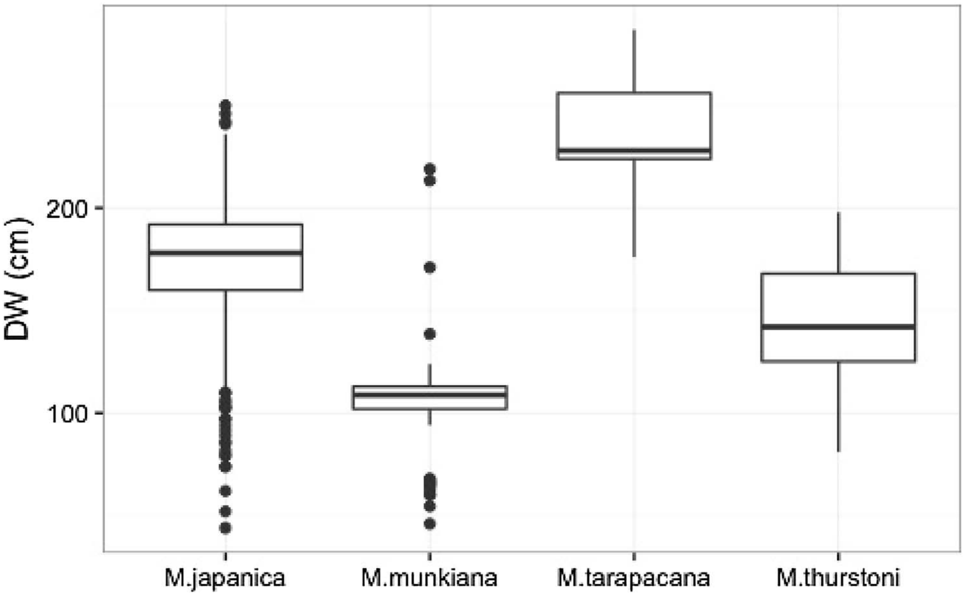

Fig. 5. Box plot of Disc width (DW) of all *Mobula* species measured. *M. japanica* (n = 517), *M. munkiana* (n = 56), *M. thurstoni* (n = 56), *M. tarapacana* (n = 13). Data was provided by on-board and shore-based observers working with small-scale driftnet fisheries in northern Peru.

between mobulids and pelagic target species could be due to their aggregations over high productivity marine zones (Couturier et al., 2012; Croll et al., 2015). Despite the fact that 'target fish captures' was dropped as a predictive variable from the GLM, some disparate temporal fluctuations between mobulid and target captures suggest an opportunistic behaviour by fishermen, meaning they aimed to capture mobulids when target species captures were low. This negative correlation between captures of mobulids and target species apparent in the October 2015 values, where mobulid captures were at their highest and target species catches were near their lowest (Fig. 3).

Opportunistic behaviour of fishermen related to mobulid captures was described by Dulvy et al. (2014b) where they mentioned that fishermen retained mobulids as a secondary catch when target species were unavailable. Similarly, this opportunistic behaviour is comparable to our finding that some fishermen indicated changing fishing grounds towards catching mobulids when sharks or tuna were scarce.

4.2. Mobulid species composition

Despite the fact that we did not identify mobulids to the species level during onboard observations, shore-based observations confirmed that all five mobulid species known from Peru were landed and that *M. japanica* comprised the vast majority of landings. This was previously described by Ayala (2014) and Gonzalez-Pestana (2015) at these same study areas. However, at least one other study based on analysing historical reports of batoid landings suggests that *M. thurstoni* is one of the primary mobulid species landed in Peru (Gonzalez et al., 2016). This contradiction could be explained either by annual variations in *Mobula* abundance, or by species misidentification during shore-based evaluations, due to the morphological similarities between mobulid species (Couturier et al., 2012; Poortvliet and Hoarau, 2013). Mobulid species identification is even more challenging during shore-based evaluations, where animals arrive butchered (i.e. in pieces or missing diagnostic features).

The fact that no *Manta birostris* were caught and that only one was landed, was explained by Ayala et al. (2009) and Castañeda (1994), who described manta captures by gillnets as negative, meaning incidental events in which fishermen lose time, and often fishing gear, while they attempt to disentangle the animal. This has been described also by Alfaro-Shigueto et al. (2012) who mentioned presence of hazardous manta rays for small vessels as dangerous events. We corroborated these finding during the study period. In many cases, local fishermen informed each other about where large mantas (*Manta birostris*) had been observed in order to avoid subsequent entanglements. On one occasion, we observed fishermen work for three days as they attempted to free a *M. birostris* that had become entangled in eight panes of their fishing net (they lost three panes in the end). Therefore, the lack of retention or landings of mantas in our study reflects fisher attempts at species avoidance.

During the study, we observed a poor understanding by fishermen of mobulid species and their identification. Even when results showed that the main genus of mobulids captured and traded were *Mobula*, local people (fishermen, sellers and consumers) use the common name "Manta" for every specimen. Given that species identification is a challenge, it is recommended that likely misidentification be considered in research designs (i.e. interview surveys), as well as enforcement and management measures. Moreover, considering that the single regulation in Peru about fishing and trade of mobulids is focused on *M. birostris,* it is important to acknowledge the fact that local common names are not the best option when conducting product inspections.

4.3. Biological aspects of mobulids caught

Based upon the disc width at maturation for each measured species: *M. munkiana* 180 cm, *M. japanica* 176 cm, *M. thurstoni* 178 cm, *M. tarapacana* 240 cm (Notarbartolo-di-Sciara, 1988; Villavicencio-Garayzar, 2016), our study results indicate that the majority of the catch of the main mobulid capture species were juveniles. This has also been suggested by Gonzalez-Pestana (2015). Despite the fairly limited spatial and temporal scale of the study, this information could be reflecting an important population of juvenile mobulids in northern Peru.

4.4. Spatial and temporal trends in mobulid captures and landings

Gonzalez et al. (2016) note an annual pattern concerning mobulid landings between 2001 and 2010, with January, February and November as the months with higher landings (in tonnes). The model results in our study indicated a relationship between mobulid CPUE and season, with higher CPUEs reported during the spring months (October, November and December). Landings data also showed peaks in mobulid captures for Zorritos between September and December, but also between April and May. This pattern could be due to a combination of (1) low abundances of target fish (inducing fishermen to aim for mobulids) and (2) seasonal variation resulting in greater presence of mobulids in the study zone. The latter situation is likely related to the mid-range sea surface temperature (SST) fluctuating between 21 and 23 °C (IMARPE, 2016), which coincides with worldwide reports of habitat characteristics (Clark, 2010; Canese et al., 2011; Croll et al., 2012). Furthermore, the presence of an observed peak in mobulid landings during May (a peak not observed in the onboard observer data) could be a signal of an increase in fishing effort in terms of driftnet vessels in the zone. In other words, CPUE values may be low during these months, but more boats could be catching mobulids. Further studies are needed to better understand these dynamics, including larger scale tracking of fishing effort and catch.

The model results also indicate an influence of latitude and longitude on the probability of capturing mobulids (for both the binomial and the count NB models). This became apparent when plotting the data. We see sets with higher mobulid captures concentrated in front of Zorritos (from 3.4° to 4° S) and north of San Jose (from 6.5° to 6.7° S), with a gap in mobulid catch between 4° and 6.4° S. However, low interaction rates with mobulids in these areas could be related to the fewer sets reported in this region. While this study did not consider fisher behaviour, it could be that fishers know that catches in general are lower in this area, which, interestingly, coincides with a narrowing of the continental shelf. Further studies could help determine the role of particular fishing grounds and fisher's decisions in the overall catches in the area. Shore-based reports also indicated that there were more mobulid landings in Zorritos. However, this tendency was not evident in all months, such as in September, December and January, when mobulid landings were higher in San Jose than in Zorritos. Ayala and Romero (2016), described San Jose as an important artisanal port where mobulid meat is commercialized. Therefore, higher landings could be reflecting more fishing vessels from other zones choosing to land their catch in San Jose, giving the higher demand for mobulid meat.

We also see a clear concentration of mobulid captures near the coast over the continental shelf. High concentrations of pelagic fishes could be an indicator of high productivity (Pauly and Christensen, 1995). The spatial distribution of interactions with mobulids could be a signal of higher productivity in zones near the continental shelf (Bakun and Weeks, 2008).

4.5. *Conservation issues*

Our study identified far greater pressure on *Mobula* spp. than on *Manta*. *Mobula* capture rates by small-scale gillnet fisheries in northern Peru are considerable, yet periodic, particularly when target fishes are not abundant and during warm seasons. These capture rates are high if one considers them a bycatch species but low for a target catch. As a result, we suggest that mobulid captures be considered as opportunistic events in these fisheries. All mobulid species known to occur in Peru were captured and commercialized, with juvenile specimens of *Mobula japanica* comprising the vast majority of landings. *Manta birostris* is a species that fishers actively seek to avoid catching due to its large size and capacity to damage fishing gear.

Considering the varying global conservation status of all the mobulid species, further studies of their ecology and fishery interactions are necessary. Accurate identification to the species level during capture or landing evaluations is a priority. A combination of measures to ensure correct identification to the species level could be applied, including morphological (e.g. identification guides) and molecular tools (e.g. genetic barcoding). Legal provisions to require entire carcasses of all or a proportion of landed mobulids could also help to better identify mobulids morphologically. In addition, molecular kits of genetic barcodes could be used to verify morphological identifications. Although Peru has recently included mobulids in its fishery regulations, this measure only considers *Manta birostris*. Thus, even at the local level, for improving knowledge about captures and trade, or for effective oversight of mobulid fisheries, correct identification is crucial. It is also important to assess the local and international markets for mobulid meat, and the socio-economic characteristics of this trade. Finally, a better understanding of the population dynamics of mobulid species at regional levels, including their genetic diversity and migration patterns, could provide information critical to the implementation of effective management or conservation plans.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.fishres.2017.06.012.

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