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Untangling the impacts of nets in the southeastern Pacific: Rapid assessment of marine turtle bycatch to set conservation priorities in small-scale fisheries

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ABSTRACT

Bycatch of marine megafauna by small-scale fisheries is of growing global concern. The southeastern Pacific sustains extensive fisheries that are important sources of food and employment for millions of people. Mismanagement, however, jeopardizes the sustainability of ecosystems and vulnerable species. We used survey questionnaires to assess the impact of small-scale gillnet fisheries on sea turtles across 3 nations (Ecuador, Peru and Chile), designed to fill data gaps and identify priority areas for future conservation work. A total of 765 surveys from 43 small-scale fishing ports were obtained (Ecuador: n = 379 fishers, 7 ports; Peru: n = 342 fishers, 30 ports; Chile: n = 44 fishers, 6 ports). The survey coverage in study harbors was 28% for Ecuador, 37.0% for Peru, and 62.7% for Chile. When these survey data are scaled up across the fleets within surveyed ports, the resulting estimate of total annual bycatch across the study harbors is 46 478 turtles; where Ecuador is 40 480, Peru 5 828 and Chile 170 turtles. Estimated mortality rates vary markedly between countries (Ecuador: 32.5%; Peru 50.8%; Chile 3.2%), leading to estimated lethal takes of 13 225, 2 927, and 6 turtles for Ecuador, Peru, and Chile, respectively. These estimates are remarkably large given that the ports surveyed constitute only 16.4, 41, and 22% of the national gillnet fleets in Ecuador, Peru, and Chile, respectively. Limited data from observer-based surveys in Peru suggest that information from surveys are reliable and still informative. Information from surveys clearly highlight Ecuador and Peru as priority areas for future work to reduce turtle bycatch, particularly given the status of regional populations such as leatherback and hawksbill turtles.

1. Introduction

Incidental catch in fisheries, or bycatch (Davies et al., 2009), is thought to pose a major threat to marine vertebrates at a global level (Anderson et al., 2011; Baum et al., 2003; Lewison et al., 2004). This has been confirmed in detail for sea turtles, where many populations face large impacts due to bycatch in industrial fisheries (Crowder et al., 1994; Spotila et al., 2000; Wallace et al., 2010b). In small-scale fisheries, directed harvest is now greatly reduced (Humber et al., 2014) but bycatch is thought to be significant although relatively poorly quantified (Lewison and Crowder, 2007; Peckham et al., 2007; Rees et al., 2016). Onboard observer programs have been shown as the most accurate source of information to estimate bycatch levels (Babcock et al., 2003). However, in cases where data are deficient, such as in small-scale fisheries (Chuenpagdee et al., 2006; Salas et al., 2007), or in which the logistical and funding challenges to implement observer programs are prohibitive (Moore et al., 2010), assessments using interview-based surveys can provide crucial information that can help define the scale and range of fishing effort as well as offer insights into the magnitude of bycatch (D'Agrosa et al., 2000; López et al., 2003).

Sea turtle populations extend over broad spatial scales and the turtles found in the southeastern Pacific originate from across the basin (reviewed by Alfaro-Shigueto et al., 2011). Green turtles (*Chelonia mydas*) foraging in Peru originate in the Galapagos Islands and Mexico (Hays-Brown and Brown, 1982; Seminoff et al., 2008; Velez-Zuazo and Kelez, 2010), leatherback turtles (*Dermochelys coriacea*) originate from breeding colonies in Mexico, Costa Rica, as well as the western Pacific (Dutton et al., 2010; Eckert and Sarti, 1997; Saba et al., 2008).

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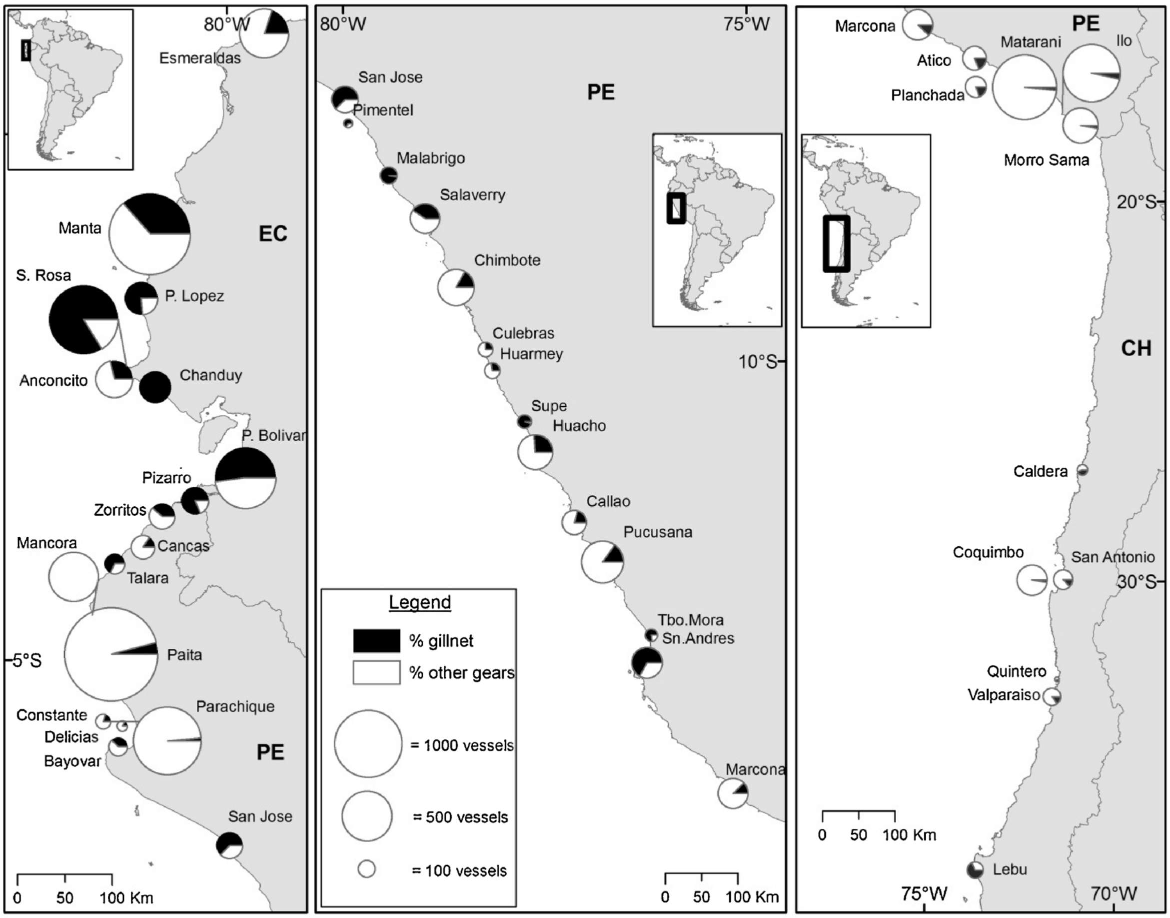

Fig. 1. Distribution of gillnet use at small-scale ports sampled from Ecuador to Chile. From left to right (north to south: EC = Ecuador, PE = Peru, CH = Chile). Circle area indicates the fleet sizes at each port in number of boats, shaded areas show the composition of gillnets in relation with all small-scale fishing fleet at each port (from Supplemental Table 1).

Loggerhead turtles (*Caretta caretta)* foraging in Peru and Chile, originate in Australia and New Caledonia (Alfaro-Shigueto et al., 2004; Boyle et al., 2009), whilst olive ridley turtles (*Lepidochelys olivacea*) inhabiting Peruvian waters come from stocks breeding in Costa Rica, Colombia and Mexico (Velez-Zuazo and Kelez, 2010; Zeballos and Arias-Schreiber, 2001). The hawksbill turtle (*Eretmochelys imbricata*) is relatively rare in Peru, but is likely to be linked to the closest rookery in Ecuador (Gaos et al., 2017). Eastern Pacific leatherbacks and hawksbills are two of the eleven most threatened sea turtle subpopulations in the world (Wallace et al., 2011).

These turtle populations are present year-round in the southeastern Pacific, primarily foraging, thus they interact with multiple fishing fleets, including longlines, trawls, purse seines and gillnets. Seasonal peaks in bycatch interactions have been described for loggerheads and longlines for mahi and sharks during austral summer (Alfaro-Shigueto et al., 2011); for hawksbills in the coastal net fisheries during spring and summer (Alfaro-Shigueto et al., 2010a,b); while for leatherback turtles, peaks of landings in the 1980′s occurred in the summer (Hays-Brown and Brown, 1982), similar to what Alfaro-Shigueto et al. (2007) reported based on strandings and landings reports. There are no similar analyses for seasonality of bycatch for either greens or olive ridleys. However, information from Peru suggests that olive ridleys occur more often from the northern to the central Peru coast, with higher numbers in summer months (Alfaro-Shigueto et al., 2011), while greens are the most common species bycaught year-round in longlines and gillnets along the coast (Alfaro-Shigueto et al., 2011).

These complex inter-relations highlight how bycatch occurring in foraging areas in the southeastern Pacific can have wide ranging detrimental impacts. Empirical information suggests that within small-scale fisheries, gillnets play a major role in the bycatch of sea turtles (Wallace et al., 2010b). Gillnet fisheries include the use of surface nets, usually driftnets, bottom set nets, trammel nets and encircling nets (Nédélec and Prado, 1990). Levels of fishing effort of small-scale fisheries, particularly in gillnets, in the eastern tropical Pacific are among the highest worldwide (Stewart et al., 2010).

Within the vast region of the Southeast Pacific, the waters of Ecuador, Peru, and Chile, form the Major Fishing Area 87 (FAO Major Fishing Areas). By 1999, 84.7% of Ecuadorian ports used gillnets, while the total number of small-scale fishing vessels was 15 494 operated by 56 068 fishers (Solis-Coello and Mendivez, 1999). In Peru, gillnets are the main fishing gear used in small-scale fisheries, which comprised 9 667 vessels operated by 37 727 fishers (Estrella and Swartzman, 2010), and effort has been estimated at ca. 100 000 km of nets deployed each year (Alfaro-Shigueto et al., 2010a,b). In Chile, although the number of small-scale vessels is 12 526 and these are operated by 85 268 fishers (Registro SERNAPESCA de Pesca Artesanal 2011, available at www.sernapesca.cl), gillnet use is currently limited and includes a swordfish *Xiphias gladius* fishery (DecretoNo.657 2002). Landing sites for these three countries total ca. 500 ports in Ecuador (Solis-Coello and Mendivez, 1999), 106 ports in Peru (Alfaro-Shigueto et al., 2010a,b) and 230 ports in Chile (Bernal et al., 1999). Sea turtle bycatch in the region has been reported for the small-scale fleet since the 1970′s and 1980′s for Peru and Chile (Hays-Brown and Brown, 1982; Frazier and Brito Montero, 1990), with more recent information published for Ecuador (Andraka et al., 2013); Peru (Alfaro-Shigueto et al., 2011; Pingo et al., 2017); and Chile (Donoso and Dutton, 2010).

Here we implemented a rapid data gathering approach using a survey instrument modified from those applied in other locations (e.g., Moore et al., 2010). We set out to gain insights into the magnitude and geographic scale of sea turtle bycatch in small-scale gillnet fisheries across the southeastern Pacific Ocean. Our specific objectives were to classify the magnitude of turtle bycatch and mortality events, to identify priority geographic areas where these events occur; and to identify the turtle species affected in each of 43 ports distributed among three countries along the Pacific coast of South America.

2. Materials and methods

2.1. Survey design and planning

Our surveys were conducted in Ecuador, Peru, and Chile (Fig. 1; Supplemental Table 1) and were completed between August and November 2010 in Ecuador and Chile and between November 2010 and March 2011 in Peru (8 months overall duration). Survey forms were tested in the three countries prior to full-scale implementation to eliminate ambiguous terms and to ensure that wording would mean the same in each country. Surveys were undertaken by nationals from each country. Most questions used were closed questions, with options that were read to the interviewees. For all ports we counted the number of fishermen who were approached, including those who did not agree to participate in the survey. To avoid surveying multiple members of the same vessel leading to pseudo-replication of data, surveys were only conducted with vessel captains. In Ecuador and Chile, gillnets were separated into surface nets, midwater nets, trammel nets and bottom set nets while in Peru, surveys addressed gillnets as a single category. This differentiation in net categories between surveys was related to the implementation of two separate survey research projects, where for Peru the broader 'gillnets' category was used, while for Ecuador and Chile, the categories were more specific.

2.2. Survey forms

Surveys contained 63 questions for fishermen, and four directed to the researchers conducting the surveys, and also included species and fishing gear identification guides (see Supplemental Document 1 for survey form and species identification plates). Surveys were initiated by specifying the purpose of the interview (i.e, research purposes) and the confidential nature of responses. Questions were designed to provide a general description of the fishermen (e.g. age, experience, if a boat owner) and the vessels (e.g. motor power, length). Bycatch questions were formatted to indicate the number of bycatch events in the most recent annual time frame (e.g. number of turtles caught per year), turtle species composition (i.e. loggerhead turtles, leatherback turtle, green turtle, olive ridley, and hawksbill turtles), and the final fate of bycatch as described in Alfaro-Shigueto et al. (2011; i.e. released alive, dead at capture (drowned), or retained to be commercialized, used as food, bait or for medicinal purposes). Other bycatch taxa such as marine mammals (sea lions and cetaceans) and seabirds were also included in the survey. Questions also pertained to the interviewee's knowledge of legislation regarding marine turtles. The final few questions were completed by the interviewer and were an assessment of the interviewer's confidence in the quality of information provided by the interviewee.

2.3. Bycatch estimates

We obtained general information about each port from the local fishing authorities. This included the total number of boats using gillnets by sampled port. Supplemental Table 1 summarizes this information per port. For each site and for the three countries, we calculated bycatch by gillnets, based on the median interquartile (IQ) range survey responses for bycatch per year by port. These data were scaled according to the fleet size for these specific sites to obtain the estimate of annual turtle bycatch only for the visited ports (Supplemental Document 2).

Using data gathered from questionnaires on the fate of turtles, we were then able to estimate the total take including those dead (herein 'mortality' is defined as the number of turtles killed as consequence of fisheries) at capture (drowned), and those live retained to be sold, eaten or otherwise used (Alfaro-Shigueto et al., 2011). The final fate categories were: released live, dead, sold (retained to be commercialized), eaten (retained to eat), and medicine (retained for medicine) (Supplemental Table 2).

2.4. Statistical analysis

We also conducted three separate analysis; (i) the effect of latitude on the number of boats within a fishing fleet (n = 43 ports), (ii) the effect of latitude on the proportion of gillnets within fishing fleets (n = 43 ports), and (iii) the effects of latitude and gear type on the bycatch of turtles per fishing port (n = 765 questionnaire responses from 43 ports). These analyses were tested using negative binomial Generalised Linear Models (GLMs) in the MASS package (Venables and Ripley, 2002) in R v4.4.0 (R Core Team, 2017). Negative binomial models were applied to account for overdispersion of data. An offset term of the loge of fishing effort (boats per port) was included in the analysis of bycatch to account for variation in fishing effort. The use of the offset allows the intercept parameters estimated by the GLM to be interpreted as bycatch per port. The response variables were (i) total number of boats in fishing fleet at each port; (ii) proportion of gillnets within fishing fleet at each port; and (iii) bycatch of turtles. Models were ranked by Akaike's Information Criteria (AIC) using subset selection of the maximal model using the MuMIn package (Barton, 2018). All combinations of terms within the maximal model were examined. Top ranked models were defined as models $\Delta\text{AIC} \leq 6$ units of the best supported model, after excluding further models where a simpler model attained stronger weighting ("nesting rule"; Richards et al., 2011; Table 2). Where more than one model fit these criteria, model averaging was applied (Burnham and Anderson, 2002).

3. Results

A total of 765 surveys from 43 fishing ports were obtained across the three countries (Ecuador: n = 379 fishers, 7 ports, 1.4% of total ports and 16.4% of total gillnet vessels for the country; Peru: n = 342 fishers, 30 ports, 28.3% of total ports and 41% of total gillnets for the country; Chile: n = 44 fishers, 6 ports, 2.6% of total ports, 22% of total gillnets for the country; Fig. 1). Survey coverage per port was on average 28% for Ecuador, 37.0% for Peru and 62.7% for Chile (Supplemental Table 1). In general, fishermen who declined to participate (n = 125) accounted for 15.8% of all captains approached (31 (7.6%) in Ecuador, 94 (27.5%) in Peru, and 0 in Chile). Supplemental Tables 3 and 4 detail the target species for each site and per fishery in association with demographic and associated technical and economic details of the survey respondents. Most fishermen operated year-round, except in Chile where net fisheries were seasonal. The main employment of respondents was fishing for most ports although other employment (i.e., construction, small business) was reported. The reliability of the fishermen interviewed, as perceived by interviewers was high for most ports across the three countries (99.6, 98.2, and 93.3% for Ecuador, Peru and Chile, respectively; Supplemental Table 5).

From the statistical analysis, we determined that: (i) The variation observed in the total number of boats in fishing fleets at each port was best described by latitude. Number of boats showed a negative relationship with increasing southerly latitudes, with fleets of larger sizes occurring towards the equator (Table 2; Fig. 3A); (ii) The null model best described the variation in proportion of gillnets within fishing fleets at each port; and (iii) Latitude and gear type were retained in the

Table 1
Bycatch by taxa: seabirds, mammals and turtles. Percentages of surveys with positive responses on bycatch given by number of ports and by number of surveys for each country. For turtles, information on estimated number of animals incidentally captured (Bycatch), released alive (Released) and Mortality, is also provided by country (presented in detail in Supplemental 2).

Taxa	Ecuador		Peru		Chile	
	% Harbors	% Surveys	% Harbors	% Surveys	% Harbors	% Surveys
Seabirds	42.9	4.9	86.7	28.4	66.7	20.5
Mammals	100.0	59.2	96.7	49.1	66.7	63.6
Turtles:	100.0	69.0	93.3	50.6	100.0	100.0

	Number	Number	Number
Bycatch	40480	5828	171
IQ Range	19295–76861	2154–10372	130–196
Mortality	13225	2927	6

top ranked model in the analysis of turtle bycatch, obtaining a cumulative adjusted Aikaike’s model weight of 100% (Table 2). Bycatch levels decreased with southerly latitudes (Fig. 3B), and trammel and bottom set gear resulted in higher levels of turtle bycatch (Fig. 3C).

Bycatch was broadly reported throughout the region for seabirds, marine mammals, and sea turtles (Table 1 and Supplemental Table 5). Seabird bycatch in Ecuador was reported in 42.9% of fishing ports (by 1.3% of respondents). In Peru, seabirds were reported caught at 86.7% of the ports (by 41.8% respondents). In Chile 60% of ports (23.9% of respondents) reported seabird bycatch (Supplemental Table 5). Marine mammal bycatch was reported from all Ecuadorian ports and all but one Peruvian harbor (25.3% and 54.5% of respondents, respectively) (Supplemental Table 5). In Chile, the reported level for mammal bycatch was 60% of ports (48.1% interviews at these sites responding affirmatively; Supplemental Table 5).

The vast majority (83.2%) of respondents reported having at least some level of sea turtle bycatch, and this was similar among countries (Ecuador: 82.7%; Peru: 82.6%; Chile 84.2%). However, there were clear differences in the relative frequencies at which the sea turtle species were reported as captured (Supplemental Table 5). The most commonly noted species bycaught in Peru and Chile was the green turtle, which was captured across the study region. The olive ridley turtle was the most commonly reported species in Ecuador, although it was also reported in Peru. Loggerhead turtle bycatch was present in all three countries; however, this species showed a more southerly distribution, thus it was more frequently reported by Chilean fishermen. Leatherback turtles were reported in low numbers for all countries, and hawksbill turtle captures were reported in low numbers in Ecuador and Peru only.

Survey data allow us to estimate the total lethal events (total mortality) of marine turtles and their fate by harbor (Supplemental Table 2, Fig. 2). From the estimated total bycatch for Ecuador (40 480, IQ range 19 295–76 861) turtles, and whilst in most sites they were released live (40–100%), turtle retention for use was acknowledged in all but one Ecuadorian harbor. Across 93.3% of the Peruvian ports visited (30 sites), the total bycatch was 5 828 (IQ range 2 154–10 372) turtles. Turtles released varied between sites from 30 to 100%, however, in 22 of these sites turtles were retained and used as food or for medicine. In Chile, from surveys at 6 harbors, we estimated 170 (IQ range 130–196) turtles captured annually, of which the majority were released (50–100%). No turtle consumption was reported in Chile.

Turtle mortality in Ecuador was 13 302 turtles per year in the 7 studied harbors. In Peru, although turtle captures were still widespread, annual estimated mortality (2 927 turtles) was an order of magnitude lower than total estimated mortality in Ecuador. Turtle mortality in Chilean fisheries was the lowest in the region (6 turtles).

When data from three countries are combined the resulting estimate of annual turtle mortality 16 234 turtles, as a consequence of gillnet fishery activity from the study harbors (Supplemental Table 2). There was, however, quite a high level of awareness of the protected status of marine turtles (Ecuador 71.3%, Peru 77.9% Chile 59% of interviewees), although this varied from site to site (Supplemental Table 5).

4. Discussion

There is a growing interest in marine turtle bycatch in gillnets and small-scale fisheries (Lewison and Crowder, 2007; Moore et al., 2010; Wallace et al., 2010b). Our study was designed to fill a major data gap in the southeastern Pacific by using a rapid assessment protocol to estimate regional turtle bycatch in small-scale gillnet fisheries. To further contextualize our data, it is important to note that we estimate that the vessels in the surveyed harbors constituted 16.4%, 41%, and 22% of the small-scale gillnet fishing fleet in Ecuador, Peru, and Chile, respectively (Barria et al., 2006; Estrella, 2007; Martinez et al., 1991). Our results offer insights in the extent of marine mammal and seabird bycatch and indicate that the annual mortality from bycatch of five species of turtles is likely in the low tens of thousands, making turtle bycatch in gillnets in this region among the highest in the world. For example, the turtle bycatch we report here is of similar magnitude to that of the entire Mediterranean, a major bycatch hotspot, where 23 000 turtles were estimated as the incidental catch in small-scale fisheries using set nets (Casale, 2011). A recent study using surveys in Italy reported 52,000 bycatch events, of which 10,000 were fatal (Lucchetti et al., 2017).

Given the fleet size, the annual estimate of turtle mortality, and the turtle subpopulations impacted (Wallace et al., 2010a,b), our work has highlighted several Ecuadorian ports as potentially important sources of sea turtle bycatch (e.g, Puerto Lopez, Manta, Santa Rosa). However, bycatch impact on highly threatened subpopulations of conservation concern such as the eastern Pacific leatherback (‘critically endangered on the IUCN Red List of Threatened Species (Wallace et al., 2013)), were reported in all three nations and thus should not be overlooked,

Table 2
Summary results of negative binomial Generalised Linear Models (GLMs) to test for (i) effect of latitude on the number of boats within a fishing fleet (n = 43 ports), (ii) the effect of latitude on the proportion of gillnets within fishing fleets (n = 43 ports), and (iii) the effects of latitude and gear type on the bycatch of turtles per fishing port (n = 765 responses from 43 ports). Top ranked models and adjusted weights (Adj. Weight) after selection for ΔAIC ≤ 6 and applying nesting rule of () highlighted in bold.

Model (GLM)	Response	Fixed effects	Intercept	d.f	logLik	AIC	ΔAIC	Weight	Adj. Weight
Negative binomial	*Number of boats*	~**Latitude**	**6.32**	**3**	**−287.09**	**580.19**	**0.00**	**0.97**	**1.00**
		~1	5.79	2	−291.67	587.35	7.16	0.03	
Negative binomial	*Proportion of gillnets*	~**1**	**−1.39**	**2**	**−34.16**	**72.31**	**0.00**	**0.68**	**1.00**
		~Latitude	−1.55	3	−33.93	73.86	1.55	0.32	
Negative binomial	*Number of turtles*	~**Gear type + Latitude + offset(log(Effort))**	**1.12**	**8**	**−2881.36**	**5778.71**	**0.00**	**0.87**	**0.87**
		~**Gear type + offset(log(Effort))**	**1.07**	**7**	**−2884.23**	**5782.46**	**3.75**	**0.13**	**0.13**
		~Latitude + offset(log(Effort))	0.33	3	−2894.06	5794.12	15.41	0.00039	
		~1 + offset(log(Effort))	0.13	2	−2899.63	5803.26	24.55	0.000004	

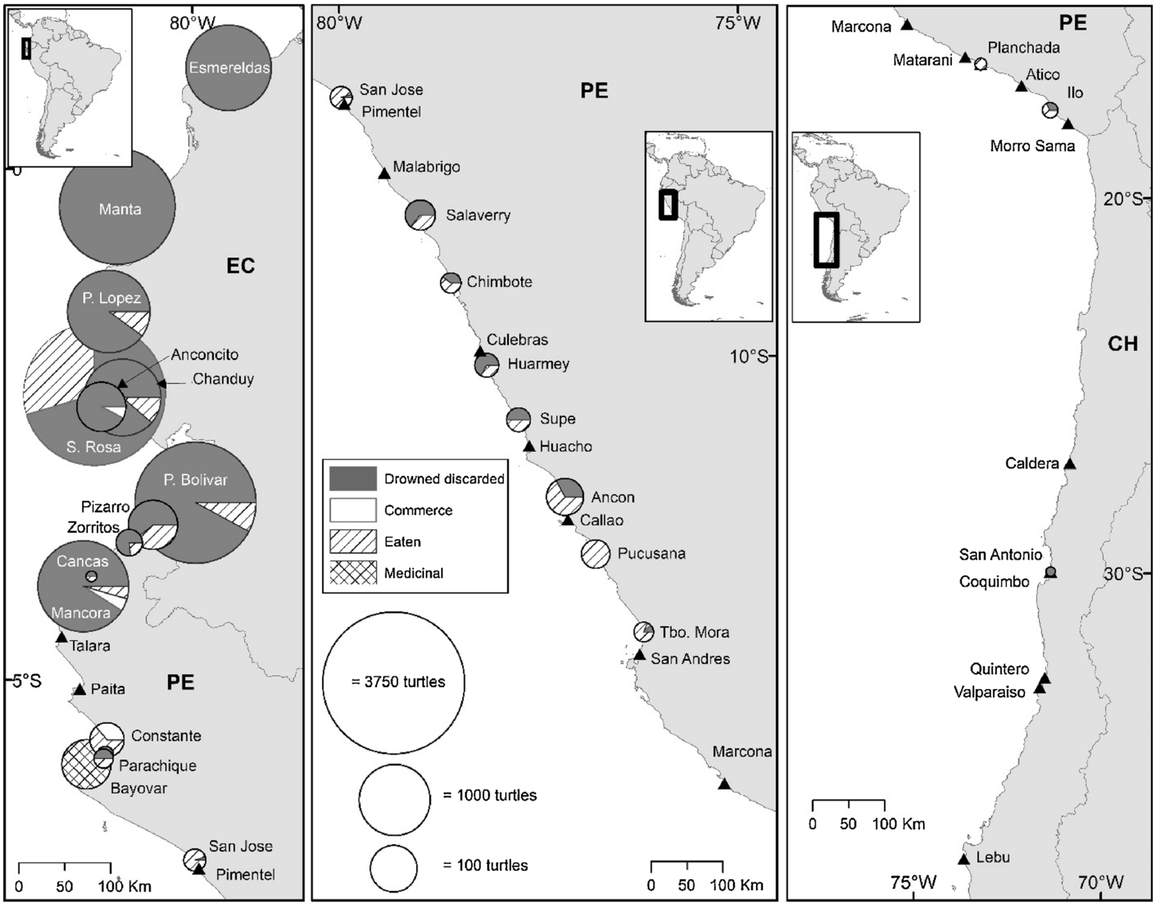

Fig. 2. Distribution of estimated bycatch mortality caused by gillnets sampled from Ecuador to Chile. From left to right (north to south: EC = Ecuador, PE = Peru, CH = Chile), circle size indicates the magnitude of the mortality in number of turtles, shaded area shows turtles caught dead, blanks show turtles commercialized and stripes were used for turtles that were eaten.

particularly as other fisheries and other threats (e.g., egg harvest and coastal development on nesting beaches [Santidrián Tomillo et al., 2009]) also have an impact on these threatened stocks (Frazier and Brito Montero, 1990; Donoso and Dutton, 2010).

Although limitations of Local Ecological Knowledge LEK methods are acknowledged (Huntington, 2000; White et al., 2005), these have been widely used as means to monitor biodiversity and provide insights for its management (Anadon et al., 2008; Jones et al., 2008). In our study we used these methods through a survey questionnaire designed to assess the level of bycatch of marine turtles. Similar studies have also has been used in several other geographic regions (Godley et al., 1998; Carreras et al., 2004; Moore et al., 2010; Panagopoulou et al., 2017). The validation of results obtained from LEK methods with other empirical research has been strongly previously recommended (White et al., 2005).

Results from these survey methods have largely proven consistent with other conventional monitoring methods for bycatch assessments (e.g. onboard observer programs) (Carreras et al., 2004; Álvarez de Quevedo et al., 2012). While previous bycatch studies using onboard observers in gillnets in the southeast Pacific region are currently largely limited to Peru (Alfaro-Shigueto et al., 2011), when comparing these previous results with two ports where survey questionnaires were also applied, comparable estimates of both bycatch and the mortality from fisheries were obtained (Constante port: 368 and 176 turtles in bycatch and killed respectively), from onboard observer data in 2006 (Alfaro-Shigueto et al., 2011); and 113 (IQ range 70–305) and 82 turtles as bycatch and killed respectively, estimated by our current questionnaires. For Salaverry port: 996 and 208 turtles incidentally caught and killed respectively, from observer data in 2007 (Alfaro-Shigueto et al., 2011); and 162 (IQ range 0–567) and 64 turtles as bycatch and killed respectively, using current questionnaires. Discrepancies in CPUE values obtained from onboard observers, log books and interview surveys have been previously reported (Sparrevohn and Storr-Paulsen, 2012; O'Donnell et al., 2012); and while we recognize that similar discrepancies in two ports where other bycatch data were available, we feel that the information obtained from this study provides a reasonable proxy given the logistical constraints of onboard observer programs (O'Donnell et al., 2012), particularly for first-pass assessments of large geographic areas as is detailed here.

Due to their simplicity and relatively low cost, gillnets are one of the most widely used fishing gears in small-scale fisheries (Northridge, 1991). This is particularly true for Ecuador and Peru, where the magnitude of net fisheries is large, and is also partly due to the open access nature of small-scale fisheries (Estrella and Swartzman, 2010; Salas et al., 2007). As a result, the number of gillnet vessels in these two countries surpasses, by two orders of magnitude, the Chilean gillnet fleet. Moreover, Chilean fisheries are firmly regulated by specific, resource-based management measures (Bernal et al., 1999). The use of gillnet fisheries in Chile is restricted to certain resources such as the swordfish fishery (Decreto 657 2002). Despite the challenges to implementing restrictions on the use of gillnets in the region, in Chile such regulations have promoted fisheries management (i.e. establishment of limited size catch, geographic restrictions of the fishery, registration of all vessels operating for the resource, organization of government programs where fishermen report their catch and bycatch) (Barria et al., 2006). A coastal net fishery for hake employing surface

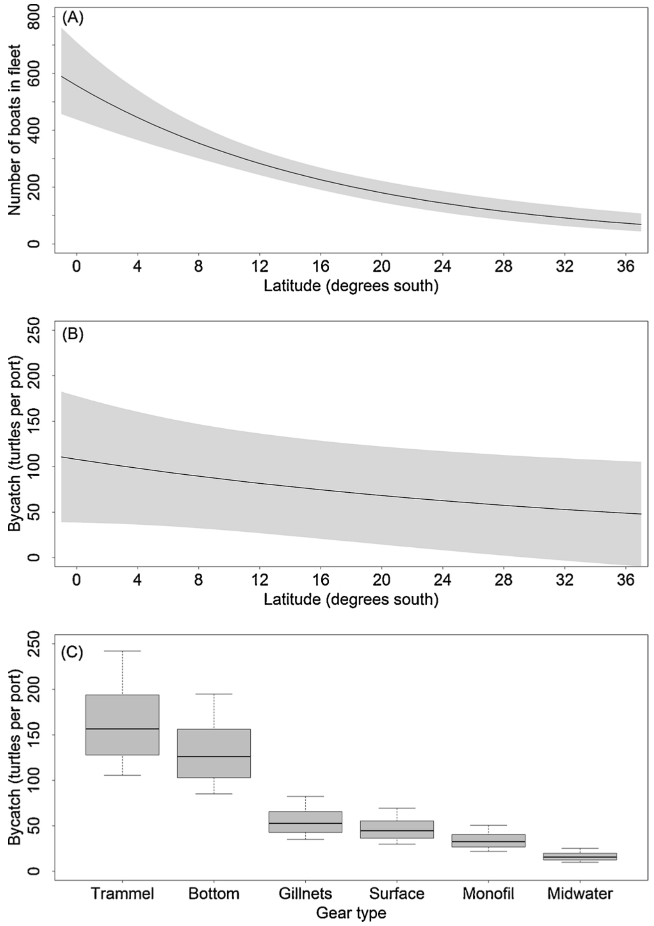

Fig. 3. Relationship between (from top to bottom): (A) latitude and total number of boats in the fleet (n = 43 ports); (B) latitude and bycatch of turtles from questionnaire responses per port (n = 765 responses from 43 ports); and (C) gear type and bycatch of turtles from questionnaire responses per port (n = 765 responses from 43 ports). Solid black lines in (A) and (B) denote predictions from GLM with grey polygon representing standard error (se). Boxes in (C) denote inter-quartile range; horizontal black bar indicates the median (whiskers extend to the 2.5th and 97.5th percentiles).

monofilament is recently developing; however, bycatch information is limited for 393 fishing trips monitored, where two green turtles were captured and released alive (Luna-Jorquera, 2015).

The majority of survey respondents were aware of local legislation for turtle protection but also acknowledged the use of sea turtles as food. In Peru, previous studies have shown how the use of sea turtles as marine bushmeat is the main source of mortality in bottom set nets (Alfaro-Shigueto et al., 2011). This situation, in which protective legislation is acknowledged but ignored, likely relates to the socio-economic characteristics of fishing communities themselves (e.g. impoverished, remotely located, highly dependent on fisheries for food, limited information on legislation, authority absence). Given that most fishermen surveyed reported that fisheries are their main economic activity, these socio-economic constraints should be factored into future conservation projects that seek to understand the causes and potential solutions to sea turtle bycatch and consumption in coastal communities.

However, from the total estimated turtle bycatch, a greater percentage were reported released back to sea, which highlights an opportunity for the use of bycatch mitigation measures in net fisheries (Gilman et al., 2010), such as increasing net visibility (Wang et al., 2010; Wang et al., 2013; Ortiz et al., 2016; Bielli, 2017), reducing net profiles (Price and Van Salisbury, 2007), using buoyless float lines (Gilman et al., 2010; Peckham et al., 2016), tiedown modifications (Eckert et al., 2008); or promoting the use of tools and guidelines to safely release animals (NMFS-SEFSC, 2008). Apart from reducing negative impacts to sea turtles, the use of these mitigation measures can also impart practical benefits to fishermen in the form of cost and time savings resulting from reduced entanglements and net damage. While some of these fishing gear adaptations are being tested and have yet to be implemented on a large scale (Gilman et al., 2010), a local initiative using high frequency radio broadcasting is currently in operation and helps advise fishermen at sea how to avoid fishing in areas with high bycatch and promote the use of safely release bycatch (Alfaro-Shigueto et al., 2012). This approach can be considered a small-scale fisheries alternative to agency-industry programs in developed, highly managed commercial fisheries (e.g. Turtle Watch (Howell et al., 2008)).

Bycatch impacts from small-scale fisheries are widely thought to be important but many past studies have been anecdotal or over limited spatial scales, especially considering the scales over which sea turtle populations occur. Thus, the use of questionnaire-based surveys as shown here can rapidly overcome some of the logistical and funding constraints of researching such fisheries, and they can be a useful tool for assessing turtle bycatch in small-scale fisheries, especially when targeting large geographic areas. Recent worldwide estimates of directly observed turtle bycatch are more than 85 000 turtles for over two decades, although this is thought to almost certainly be an underestimate by two orders of magnitude due to non-reported/observed data and lack of data from small-scale fisheries (Wallace et al., 2010b). Multiple marine turtle populations that occur in the eastern Pacific have been assessed as high-risk and high-threat (Wallace et al., 2011), particularly from fisheries bycatch (Wallace et al., 2010b), thus making this region a conservation priority for turtles. Our results support this high priority designation given the high turtle mortality from fisheries and the presence of highly threatened populations of loggerhead, leatherback and hawksbill turtles in particular.

Small-scale fisheries are the main protein provider for 1 billion people (Béné, 2006) and also support the livelihoods of about 200 million people (McGoodwin, 2001). In the eastern Pacific, these fisheries are key for 1 million small-scale fishermen and their families (CPPS, 2003) and there is, therefore a clear need to identify conservation opportunities that promote their long-term sustainability, both for the communities they serve and the marine fauna with which they interact. While it is acknowledged that a number of years have passed since the gathering of these data, the major lessons learned from the data still stand. There is no suggestion that gillnet fisheries in the region have abated, therefore major improvements in their management (e.g, spatio/temporal areas, control of fishing effort, resource management plans) and reporting system for bycatch are recommended (e.g, official reporting on bycatch, access and transparency to data, use of mitigation methods, promoting governance processes). Indeed, more recent and ongoing studies in Peru show marine turtle bycatch continues at numerous sites and that the use of lights in nets offers strong potential as a mitigation method (Ortiz et al., 2016; Bielli, 2017), along with the use of broader management approaches (i.e. ecosystem-based management) that account for impacts on ecosystems functions and biodiversity. In this study, surveys helped identify ports where, given the reported magnitude of bycatch and the turtle species composition, the gathering of detailed bycatch information would be recommended. This would include fishing effort, species affected, and the final fates of turtles incidentally caught (e.g. Esmeraldas, Santa Rosa and Manta in Ecuador; and Pizarro, Mancora, San Jose, Salaverry, Malabrigo, Ancon and San Andres in Peru; and Lebu in Chile). While the surveys in two ports in this study yielded lower CPUE estimates than those from onboard observers, they were of comparable orders of magnitude. However, the use of multiple methods (i.e., surveys and onboard observer data) is recommended to further validate similar survey studies.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.fishres.2018.04.013.

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