Ecology and Conservation of Sea Turtles in Peru

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I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

Signature:

Abstract

Some of the key elements to assess the status of any wildlife population in a given geographical area are the levels of recruitment, survival and mortality. Whilst most of the information on marine turtles has been obtained from nesting sites, turtles spend most of their lives at sea.

The conservation status of marine turtles in the southeast Pacific is poorly documented. This is particularly true for countries like Peru, where nesting events are very rare, although five species of turtles from populations from all over the Pacific basin, use these waters as foraging grounds. Little information exists on the threats to turtle populations in foraging areas or the magnitude of these impacts.

Small-scale fisheries are a globally important economic activity serving as a source of food and employment for *ca*. 1 billion people; however we show that they also have serious impacts on marine turtle populations from all over the Pacific basin in the form of incidentally captured marine turtles.

The five chapters that constitute this thesis are intended to increase our understanding of small-scale fisheries impacts on this taxon during their aquatic life stages. This work focuses on describing these fisheries, their impacts on marine turtles and proposes methodologies to monitor and assess the level of bycatch from small-scale fisheries. We also discuss alternative ways to prevent fisheries interactions and promote the involvement of artisanal fishermen in the southeast Pacific in implementing conservation solutions.

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ProDelphinus staff has been wonderful to us during these last few years, Francisco 'Chaval' Bernedo, Paola Melly, David Montes, Mariela Pajuelo, Celia Caceres, Natalia Ortiz, Nadia Balducci, Andrea Luna and Eliana Alfaro, and the several international volunteers who came to Peru to help us (Robin, Liz and Phil). My deepest acknowledgement to the wonderful fishermen who had no reservations sharing their experiences and boats during my PhD work, Genaro Diaz, 'Alemania', Raul Beltran, Miguel Cuentas, Miguel Lopez, Mateo Mamani, Jimmy, Jose Justo and Miguel 'Papelito' Fiestas.

Thanks to my mentors Peter Dutton and Jeffrey Seminoff for being so kind and supportive to our work in Peru and to friends in conservation and long term consellieurs Rebecca Rose, Janice Molloy, Koen Van Waerebeek, Nigel Brothers and Jessica Hardesty. This work was conducted thanks to the support of several agencies such as National Fish and Wildlife Foundation, Columbus Zoo, International Fund for Animal Welfare, Idea Wild, International Seafood Sustainability Foundation and National Oceanic and Atmospheric Administration. Support from Darwin Initiative for sustainable artisanal fisheries in Peru is allowing us to expand the scope of our work over the next few years. My doctoral studies were made possible thanks to the ESR scholarship received from University of Exeter.

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Abbreviations and Acronyms

SSF: Small-scale fisheries

SST: Sea Surface Temperature

EEZ: Exclusive Economic Zone

FAO: Food and Agricultural Organization

UN: United Nations

IUCN: International Union for Conservation of Nature

CMS: Convention for Migratory Species

NOAA: National Oceanographic and Atmosferic Administration

SWFSC: Southwest Fisheries Science Center

SEFSC: Southeast Fisheries Science Center

NMFS: National Marine Fisheries Service

CMC: Center for Marine Conservation

ABC: American Bird Conservancy

IATTO: International Association of Antartica Tour Operators

ORSAS: Overseas Research Students Awards Scheme

Conversions

1 km: 0.539 nm

1 nm: 1.852 km

ID pictures and graphics from Supplemental material (survey form) of Chapter 4: common names in English, Spanish and latin names, as well as fishing gears names in English, appear in pages 122-125.

Author's declaration of contributions to co-authored chapters/research papers

Chapter I: Where small can have a large impact: Structure and characterization of small-scale fisheries in Peru

Joanna ALFARO-SHIGUETO, Jeffrey C. MANGEL, Mariela PAJUELO, Peter H. DUTTON, Jeffrey A. SEMINOFF and Brendan J. GODLEY

In this chapter I described the modus operandi of four important small-scale fisheries, the characteristics of the fishing gears used. It provides an idea of the magnitude of these fisheries and their extension along the country and the implications to bycatch. I wrote this chapter under the supervision of Dr. B. Godley. J.C. Mangel assisted with mapping of data. M. Pajuelo assisted with project implementation at fishing ports. Dr. P. Dutton and Dr. J. Seminoff assisted with logistical resources for this work and coordination and data protocols for onboard observers. This chapter was published in Fisheries Research in 2010.

Chapter II: Demography of loggerhead turtles, *Caretta caretta* in the southeastern Pacific Ocean: fisheries-based observations and implications for management

Joanna ALFARO-SHIGUETO, Jeffrey C. MANGEL, Jeffrey A.SEMINOFF and Peter H.DUTTON

In this chapter I described the age composition of the loggerhead turtles obtained from bycatch interactions with small-scale fisheries in eleven ports in Peru. I wrote this chapter under the supervision of Dr. B. Godley. J. C. Mangel assisted with spatial data analysis. J.A. Seminoff and P.H. Dutton assisted with logistics for the project and research concepts. This chapter was published in Endangered Species Research in 2008.

Chapter III: Small-scale fisheries of Peru: a major sink for marine turtles in the Pacific

Joanna ALFARO-SHIGUETO, Jeffrey C. MANGEL, Francisco BERNEDO, Peter H. DUTTON, Jeffrey A.SEMINOFF and Brendan J. GODLEY

In this chapter I quantify bycatch of four species of turtles at four small-scale fisheries operating at three fishing ports, showing the implications to other turtle populations in the Pacific basin. I wrote this chapter under the supervision of Dr. B. Godley. F. Bernedo assisted with project implementation and, data collection. J.C. Mangel assisted with spatial analysis. P.H. Dutton and J.A. Seminoff provided input in the analysis of data. This chapter was published in Journal of Applied Ecology in 2011.

Chapter IV: Untangling the impacts of nets in the Pacific: use of rapid assessments of turtle bycatch to set conservation priorities in small-scale fisheries

Joanna ALFARO-SHIGUETO, Jeffrey C. MANGEL, Andres BAQUERO, Jodie DARQUEA, Miguel DONOSO, Natalia ORTIZ and Brendan J. GODLEY

In this chapter I present the results of a rapid assessment study conducted in Ecuador, Peru and Chile, to assess the impact of gillnets on sea turtles. I did the analysis and wrote this chapter under the supervision of Dr. B. Godley. A. Baquero, J.Darquea, N.Ortiz and M.Donoso assisted with project implementation, logistics and data collection. J.C. Mangel provided assistance with spatial analysis and data management. This chapter is in preparation for publication.

Chapter V: Trading information for conservation: a novel use of radio broadcasting to reduce sea turtle bycatch

Joanna ALFARO-SHIGUETO, Jeffrey C. MANGEL, Peter H.DUTTON, Jeffrey A. SEMINOFF and Brendan J. GODLEY

This chapter presents a way to prevent or abate bycatch of sea turtles at small-scale fisheries. I wrote this chapter under the supervision of Dr. B. Godley. J. C. Mangel assisted with project implementation and data collection. P.H. Dutton and J.A. Seminoff assisted in the logistics and in the design of protocols used during the project. This chapter is In press with Oryx.

Introduction

This thesis presents five chapters focusing on the impact on marine turtles caused by small-scale fisheries in Peru, ways to assess the magnitude of these impacts and measures that can be taken to reduce them. Although the main subject of these chapters is to document impacts on turtles, they have also served to contribute to our understanding of small-scale fisheries, an important economic activity for thousands of people on the Peruvian coast. While this work was progressing the linkage of these two subjects had become progressively more obvious: small-scale fisheries need to continue to operate, however there is also a need to establish certain recommendations for their continuance in a sustainable way, minimizing their impacts on threatened marine fauna.

The first chapter describes the operational characteristics of the most common fishing gears used in small-scale fisheries in Peru, including the physical configuration of the fishing gear itself. This chapter also includes information on the spatial distribution of their fishing areas and the evolution in number of fishermen, number of vessels and fishing gears used over a decade, by comparing official data with surveys data we collected in a third of the total number of small-scale fishing ports in Peru (Alfaro-Shigueto et al. 2010a). This chapter therefore provides information necessary in contextualizing the bycatch of marine turtles and other threatened fauna such as birds, mammals and elasmobranchs caused by these fisheries, and how the growing small-scale longline fishery and the high magnitude of gillnets used in Peru might cause considerable impacts to marine turtle populations along the coast.

Chapter two addresses the impact of small-scale fisheries on the south Pacific stock of the loggerhead turtle *Caretta caretta*. Loggerhead turtles have only recently been reported in Peruvian waters (Alfaro-Shigueto et al., 2004). Loggerhead turtles visiting Peruvian waters do not nest in Peru, but originate in Australian and New Caledonian nesting rookeries (Alfaro-Shigueto et al., 2004; Boyle et al., 2009). Data came from an onboard observer program operated for several years in an artisanal fishing port. This chapter presents information on how certain stages of turtles, especially juveniles and sub-adults are being impacted by small-scale longline fisheries. This is particularly important given the fisheries 357% growth rate in the last decade (showed previously in Alfaro-Shigueto et al. (2010a)). Information presented in Mangel et al. (2010) on loggerhead turtles satellite tracking, nicely complements this chapter, providing more detailed insights into habitat preference and regional distribution, and showing how juvenile loggerhead turtles might be long-term residents off Peru and Chile. Thus, recommendations include the establishment of regional plans to mitigate the impacts of small-scale longline fisheries.

The third chapter presents an assessment of the total bycatch estimates in three fishing ports, combining two data sources: onboard observers to document bycatch events at sea (number of turtles per species and size of individuals incidentally caught); and shore-based observers to account for fishing effort of each fishery and port (given in number of trips). We also assess the final fate of turtles, per species (leatherback turtle *Dermochelys coriacea*, green turtle *Chelonia mydas*, loggerhead turtle and the olive ridley turtle *Lepidochelys olivacea*), helping to estimate the mortality rates of turtles in these ports. This chapter highlights the detrimental consequences of small-scale fisheries operating in Peru over certain marine turtle stocks in the Pacific, given that the majority of turtles inhabiting Peruvian waters originate in nesting rookeries from eastern Australia, Papua New Guinea, Solomon Islands, as well as the west coast of Mexico, Costa Rica, Colombia and Ecuador.

The fourth chapter is a follow-up to the third chapter and shows how gillnets have high levels of marine turtle mortality as a consequence of fisheries interactions (dead at capture or retained for use for food, to be commercialized or used for medicinal purposes). This chapter provides detailed information on gillnet fisheries for the large geographical region stretching from Ecuador to Chile. In this chapter I used questionnaire surveys to interview fishing captains as a means to rapidly assess the scale of impacts caused by gillnets on marine turtles. Given the fleet sizes and the occurrence of turtle interactions in the fisheries of Ecuador, this country is identified as of highest concern for gillnets in the southeast Pacific. The information presented also highlighted the lack of information on small-scale fisheries in other countries such as Ecuador and Chile and, given the magnitude of these fisheries and the number of people depending on these resources, this work stresses the need for additional detailed studies of small-scale fisheries and their impacts on threatened marine species in the region.

The fifth chapter presents an alternative way to reduce or prevent bycatch in Peruvian small-scale fisheries. We initiated an outreach program using high frequency radio to communicate in real-time with fishermen at sea to request information on areas where bycatch events were occurring and at the same time provided these vessels oceanographic information useful for their fishery. The radio programme was effective in reaching fishing vessels over a vast geographic region from Ecuador to northern Chile. Enhancement of this communication tool can serve as an effective means to prevent marine turtle bycatch, as well as promote marine conservation with this essential stakeholder group.

Current regulations on marine turtles in Peru, prohibits the capture, use or retention of marine turtles since 1995 (Morales & Vargas 1996). Peru is also a ratified member of the Interamerican Convention for Marine Turtles, part of the Convention for Migratory Species CMS, an international agreement that includes countries of America to promote marine turtle conservation. Similarly Ecuador and Chile are also part of this non-legally binding measure established in 2001.

Small-scale fisheries in countries like Ecuador, Peru and Chile, have limited regulations (Salas et al., 2001). International regulations established by the UN in the 1990’s, banning the use of High seas driftnets, are not applicable since this fishing gear is not used in Peru, Ecuador or Chile EEZ. This highlights the need to specific fishing gear regulations for small-scale fisheries at a regional and globally level.

Chapter I: Where small can have a large impact: Structure and characterization of small-scale fisheries in Peru

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Abstract

Small-scale fisheries in Peru constitute an important source of food and employment for coastal communities where fish is the single most important natural resource. Utilizing official statistics and extensive survey data from 30 fishing ports and by onboard observers operating from 11 ports, we review how these fisheries grew from 1995 to 2005, and provide insights into the relative importance of different fishing gears and their modes of operation. Small-scale fisheries operate along the entire Peruvian coast and have continued expanding in number of vessels and fishers in all geopolitical regions except one. Nationwide, the number of fishers grew by 34% from 28 098 to 37 727 and the number of vessels increased by 54% from 6268 to 9667. At 30 harbors, the number of vessels increased for purse seiners (17.8%) and longliners (357.4%), while gillnets decreased (–14.5%). These dramatic changes could jeopardize the sustainability of these fisheries and the livelihoods of those who depend upon them, especially considering the limited capacity for management. Despite increase in effort, catch and catch per vessel have decreased, especially in some of the sub-regions that previously constituted the majority of effort and landings, raising concerns regarding their sustainability. Of the fishing gears monitored, gillnets were shown to have the most frequent interactions with threatened taxa such as marine mammals, seabirds and sea turtles. The total length of gillnets set in Peru was estimated at >100 000 km of net per year, about 14 times the length used by the Taiwanese high seas driftnet fleet in the Pacific before it was banned. Longlines, although shown to be a more efficient fishing method (economically and in terms of selectivity), still had bycatch of turtles and seabirds, and marine mammals are targeted to be used as bait. We conservatively estimate that longline vessels operating in Peru set an average of 80 million hooks per year; equivalent to one-third of the annual effort of the global industrial swordfish longline fishery. We conclude that, despite their definition as small-scale, the magnitude of these fleets and their fishing effort are vast and are of concern with regard to their long term sustainability and their impacts and interactions with large marine vertebrates. We highlight the need for increased research and management measures to ensure the long term viability of these fisheries.

Introduction

Studies of large-scale and industrialized fisheries are more numerous than those addressing small-scale fisheries (SSF; Panayotou, 1982; Berkes et al., 2001; Chuenpagdee et al., 2006; Zeller et al., 2007). In many developing countries, however, SSF are often the mainstay of the fisheries sector (Béne, 2006). This arises not only from their role in food security, with fisheries acting as a source of animal protein for more than 1 billion people (Béné, 2006), but also as a generator of employment and as a potential route to poverty alleviation (FAO, 2005). Approximately 35 million people worldwide are involved in fishing and fish processing and 80% of those are associated with SSF (Béné, 2006). When family units are considered, this number rises to 200 million people (McGoodwin, 2001). Landings by SSF are thought to constitute between 25 and 33% of the worldwide catch (Chuenpagdee et al., 2006) but the contribution often remains unclear since it is reported to FAO combined with industrialized fisheries (Chuenpagdee et al., 2006; Salas et al., 2007). In some countries, the SSF fleet size and the number of people that depend upon it are unknown (Béné, 2006; Salas et al., 2007). This paucity of information, together with the complex socio-economic conditions of communities involved in this sector can result in their marginalization, leading to disregard by government agencies. This situation often leads to a cycle of poor management and threatens the sustainability of individual fisheries (McGoodwin, 2001; Chuenpagdee et al., 2006; Salas et al., 2007).

The environmental impacts of SSF have, until recently, been largely overlooked and, when addressed, often resulted in differing findings (Béné, 2006; Chuenpagdee et al., 2006; Jacquet and Pauly, 2008). Some argue that SSF contribute to the current general decline of fisheries resources worldwide (e.g. dynamite fishing, reef bleaching; Béné, 2006; Mora, 2008) while others claim that SSF are more sustainable than industrial fisheries when considering their relatively lower levels of fuel consumption, discards and subsidies received (Tyedmers et al., 2005; Chuenpagdee et al., 2006; Jacquet and Pauly, 2008).

One impact that has thus far been under-investigated in SSF is bycatch. This unintentional take (Hall et al., 2000) often includes marine vertebrates such as cetaceans, seabirds, sea turtles and sharks (Soykan et al., 2008). Industrial fisheries such as high seas driftnets (Northridge, 1991) or the North Pacific swordfish longlines (Wetherall et al., 1993) have been shown to cause detrimental impacts to marine species in the form of bycatch. In the case of high seas driftnets this led to their closure in the 1990's (UN Resolution 99-415). SSF have, however, also been shown to affect threatened marine fauna through bycatch (Godley et al., 1998; Van Waerebeek et al., 1997; Awkerman et al., 2006; Lee Lum, 2006; Alfaro-Shigueto et al., 2007, 2008), and in some cases, the level of impact is thought to be significant (Eckert and Sarti, 1997; James et al., 2005; Rojas-Bracho et al., 2006; Awkerman et al., 2006; Lewison and Crowder, 2007; Peckham et al., 2007, 2008; Mangel et al., 2010). This problem is often accentuated by the fact that SSF mainly operate in developing countries (Berkes et al., 2001), where there are few protective measures in place and/or limited enforcement of any existing measures (Berkes et al., 2001; Dutton and Squires, 2008). Furthermore, bycatch rates are often hard to assess due to the nature of the SSF itself, i.e. diffuse effort, remote landing sites and marginalization (Chuenpagdee et al., 2006; Salas et al., 2007).

Recently, mitigation measures for bycatch have been utilized to help minimize the impacts of fisheries on threatened marine fauna (Anonymous, 1992; Melvin et al., 1999; Cox et al., 2007; Gilman et al., 2007, 2008a; Ward et al., 2008). These measures are based upon the modification or adaptation of fishing gears to reduce bycatch whilst not compromising the catch of the target species (Cox et al., 2007; Ward et al., 2008). In order for such schemes to be effective, reliable information is needed regarding fishery characteristics and the spatio-temporal patterns of any bycatch.

Fisheries agencies in Peru have reported ca. 740 industrial vessels fishing for pelagic resources such as anchovies *Engraulis ringens* and sardines *Sardinops sagax* in the Peruvian exclusive economic zone (Alvarez, 2003). This catch is mainly for the production of fishmeal for export. The fisheries sector is Peru's second most important after mining, and by 2001 it reported revenues greater than USD 1.1 billion (FAO, 2008). Although the number of vessels involved in SSF is at least an order of magnitude greater (Alvarez, 2003; Salas et al., 2007), most of the fisheries research in Peru has, to date, focused on the large-scale industrial fisheries (Chavez et al., 2003; Bertrand et al., 2004; Gutierrez et al., 2007). Fisheries landings from Peruvian SSF constitute less than 4% of the national total (Estrella et al., 1999, 2000) but the sector provides the majority of fish for domestic human consumption (26.1% of animal protein) (Béné, 2006) and employs four times more people than the industrial fisheries (Alvarez, 2003). SSF in Peru have also been shown to be highly variable over time in their selection of main target species, a situation likely influenced in part by changes in environmental conditions such as El Niño/La Niña (Estrella Arellano and Swartzman, 2010).

A universal definition for SSF is not available, largely because of their complexity (Chuenpagdee et al., 2006). There are, however, a number of common metrics used to define SSF, such as the vessel size and Gross Registered Tonnage (GRT) (Chuenpagdee et al., 2006; Salas et al., 2007) and according to Peruvian fisheries regulations SSF are defined as containing boats with a maximum of 32.6 m^3 GRT, up to 15m in length and operating predominantly using manual work (El Peruano, 2001a). While regulations exist that set aside all seas within 5 nautical miles of the coast as exclusively for the use of SSF (El Peruano, 2001a), these fisheries also regularly operate beyond this area. SSF in Peru are an open access fishery where the GRT, vessel length, manual labor stipulation, mesh sizes for nets and a prohibition of beach seines (El Peruano, 2009) are the sole management measures by which they are regulated. There are limited regulations directed specifically toward the marine resources targeted by SSF. These include minimum catch lengths specified for some elasmobranch species as well as protective regulations for cetaceans, sea turtles and seabirds (El Peruano 1996, 2001b, 2001c and 2004).

Local efforts to support the development of SSF in Peru have largely failed in the past (Sabella, 1980), however this sector continues to be an investment priority (Christy, 1997; FAO, 2008). Access to basic information on SSF would allow for more efficient and effective investment of resources toward the development of sustainable activities in Peru. This study describes in detail the basic structure of the SSF operating in Peruvian waters, provides summary statistics on the fleet and landings, discusses how it has changed in recent decades, and describes detailed fishing gear characteristics, configurations and basic operational costs.

Methodology

We reviewed available government reports (Escudero, 1997; Estrella, 2007) on SSF operating in Peru (number of fishers, number of vessels and number of trips) and publicly available data on gross landings by geopolitical region, and compared them with results obtained from two additional original data sources: (i) harbor-based surveys of fishers and local representatives of the national marine authority (DICAPI) conducted in SSF ports and (ii) data gathered by onboard observers on SSF vessels using longline or gillnets.

SSF from official statistics

Specific information on SSF, including number of fishers, vessels and gear used in each port were obtained from official reports of the Instituto del Mar del Peru (IMARPE) for 1995–1996 and 2004–2005 (Escudero, 1997; Estrella, 2007). Most of these data were given aggregated by geopolitical region (North to South: Tumbes, Piura, Lambayeque, La Libertad, Ancash, Lima, Ica, Arequipa, Moquegua and Tacna). In addition, we compared fleet and gear composition at 30 ports in 1995–1996 (Escudero 1997), and similar data collected by the authors in 2004.

Detailed data on landings from SSF were not available; however landings of products for human consumption (mostly from SSF) were obtained from the Ministry of Production (www.produce.gob.pe) as an index. The overall landings included data by geopolitical region for major taxa with a category for "other" additional unspecified landings. These data were reviewed to look for changes over time. Data were not available from the Tacna region. Using additional Ministry of Production publicly available data sets we also assessed SSF catch composition of some of the main target species of the fisheries studied (longlines and gillnets). These data grouped landings into broad categories (e.g. sharks, rays and smooth hounds).

Harbor surveys

Peru's SSF operates from 106 landing sites (Escudero, 1997). We conducted a survey between January and April 2004 in 38 of these sites distributed along the 3000 km coastline of Peru (Fig. 1). This allowed for the relatively rapid and inexpensive gathering of information on the composition of fishing methods by port. Ports were selected based upon government reports on the SSF fleet (Escudero, 1997) and were typically locations with high landings or large numbers of vessels. The distribution of sampled ports from the northern to southern borders provided for broad spatial coverage of the fleet. Trained biologists with experience working with SSF administered the surveys. At the beginning of each survey, participants were informed that specific data collected would remain anonymous and would only be used for research purposes.

At each port visited we gathered information on fishing methods used from one of two sources: (i) from the local officer of the national marine authority or (ii) from the 'beach sergeant'–a local authority present at each fishing village, usually an experienced fisherman respected locally and who serves as leader and enforcer whenever necessary. We obtained data on the number of vessels operating and the proportion of vessels using each fishing gear.

Onboard observations of fishing trips

Between 17 November 2000 and 29 May 2007, trained biologists, fisheries engineers and technicians were placed aboard fishing vessels to monitor fishing trips as part of an observer program to monitor bycatch of non-target vertebrate species. Those vessels and crews that participated in the program did so voluntarily. Observers were deployed on vessels using four gear types (i) driftnets, (ii) bottom set nets, (iii) longlines for dolphinfish and iv) longlines for sharks; operating from 11 ports along the Peruvian coast : Mancora, Paita, Constante, Salaverry, Chimbote, Supe, Ancon, Pucusana, Callao, San Juan and Ilo. The selection of gear sampled was based on the fact that gillnets had been identified as the most common fishing gear used in Peru's SSF (Escudero, 1997; Estrella, 2007) and longlines have a known impact on seabirds and sea turtles in other regions (Brothers, 1990; Lewison et al., 2004).

Observers recorded the following information for each fishing trip: target species, number of sets, set locations (longitude/latitude), time of gear deployment, duration of each operation such as set deployment, soaking and hauling or retrieval times. Information on the gear used included relevant dimensions of gear, such as line and branchline length and the height of nets. Results are presented as mean ± SD. Data were also recorded on catch and associated bycatch (sea turtles, seabirds, small cetaceans and other species) although a detailed presentation of these results by species and fishery is beyond the scope of this paper (but see Table 1 and references therein).

Finally we estimated the profitability of monitored fishing trips by collating information from observers, vessel captains, vessel owners, crew and fishing gear vendors on (i) investment in the trip operation that included cost of fuel, food, and bait and ice when appropriate and (ii) the value from the catch sales. Values were estimated in US dollars at the 2007 exchange rate.

Results

Changes in magnitude and distribution over time

The SSF sector in Peru is distributed along the whole coast (Fig. 1) and is large and growing. Nationwide, from 1995 to 2005 the number of fishers grew by 34% from 28 098 to 37 727 and the number of vessels increased by 54% from 6268 to 9667 (Estrella, 2007; Table 2). This increase occurred in all regions except for Lambayeque (Table 2). The most rapid increases were in the Arequipa and Moquegua regions where SSF increased by >175% during the study period.

Our independent surveys in 2004 were carried out targeting the main fisheries (Estrella, 2007) with an emphasis on the pelagic fisheries–gillnets, purse seiners and longlines at 38 (35.9%) of the 106 artisanal ports described by Escudero (1997). Based upon the data of Escudero (1997) from November 1995 to April 1996, these harbors hosted 56.4% of the Peruvian SSF when considering numbers of vessels. However, for analysis of changes to the fleet over time, we used paired data from 30 of these ports (there was detailed information for 8 sites sampled during our surveys of 2004 that were missing in Escudero, 1997). Overall, the number of vessels at these sampled ports increased by 21.5% from 2665 to 3179 between 1995–1996 and our sampling in 2004 (Appendix 1). However, when considering individual gear types, gillnets decreased by 14.5% while there were increases of 17.8% for purse seiners and 357.4% for longliners (Appendix 1). Fig. 2 shows the relative distribution of three key fisheries in 1994–1995 (Escudero, 1997) and 2004 (this study) at the sampled ports. Gillnets (Fig. 2a) continue to be the gear used by most vessels, but despite the broad increase in fishers throughout the country, we note an apparent reduction in gillnet distribution in the central-northern coast. On the other hand, we observed that longline fisheries have increased, especially in the northern and southern ports of Paita and Ilo (Appendix 1, Fig. 2b). Purse seiners (Fig. 2c) generally maintain a similar distribution pattern with an apparent fleet reduction in central-northern ports.

SSF Landings

Landings of SSF for the period of 1995–2005 showed trends that differ across geopolitical regions (Fig. 3a-f). Although reported landings including 'other' category showed no significant trend (Fig. 3a:

regression $F_{(1,9)}$=0.02, r^2=0.002, p=0.9), when we consider the total landings assigned to geographic areas we observed a significant decrease (Fig. 3a: $F_{(1,9)}$=8.3, r^2=0.48, p=0.02). Widespread downturns in landings were observed during the ENSOs of 1997–1998 and 2002–2003 (Fig. 3a), but there were also significant negative trends in 2 regions (Piura: $F_{(1,9)}$=7.35, r^2=0.024, p=0.024; and Ancash: $F_{(1,9)}$=18.05, r^2=0.67, p=0.002), while there were significant increases in 4 regions (La Libertad: $F_{(1,9)}$=2.59, r^2=0.22, p=0.002; Lima: $F_{(1,9)}$=8.45, r^2=0.48, p=0.02; Arequipa: $F_{(1,9)}$=36.86, r^2=0.8, p=0.0002; and Moquegua: $F_{(1,9)}$=14.99, r^2=0.62, p=0.003). Tumbes and Lambayeque showed no significant changes ($F_{(1,9)}$=0.3, r^2=0.3, p=0.6 and $F_{(1,9)}$=3.04, r^2=0.25, p=0.12, respectively). Over the study period the two main centres of landings were Piura and Ancash which accounted for between 56% and 89% of total annual landings (Appendix 2a). Here, decreases in overall landings were partly due to decreases in fishing effort in these regions but also in the radical decline in catch per vessel, especially in Ancash (Table 2).

Landings of the major target species by longlines and gillnets (1995–2005) showed that dolphinfish (*Coryphaena hippurus*) landings increased significantly from 1999 ($F_{(1,9)}$=29.82, r^2=0.77, p<0.001; Fig. 4a); while landings of the other species grouped as elasmobranchs showed no significant trend ($F_{(1,9)}$=1.24, r^2=0.12, p=0.29) (Appendix 2b, Fig. 4a). This relationship disguises a significant increase in sharks ($F_{(1,9)}$ =11.54, r^2=0.56, p=0.01), whilst smooth hounds and rays showed no significant trend (smooth hounds: $F_{(1,9)}$=0.0006, r^2=0.0001, p=0.98; rays: $F_{(1,9)}$ =0.03, r^2=0.003, p=0.87; Appendix 2b, Fig. 4b).

Profile of fisheries

To describe the operation of some of these key fisheries in detail, a total of 328 trips were monitored by onboard observers during the study period (Table 1). Observers were aboard from 1 to 27 days (9.7 ± 0.3, n=328 trips). A total of 2 176 sets were monitored (7.3 ± 3.0 sets per trip). Longline trips comprised 73.8% of all monitored trips with the remaining 26.2% being gillnetting trips. The characteristics of these fishing gears are summarized in Table 3.

Longlines

We sampled longlines fishing for dolphinfish (December to March) and for sharks (April to November) operating out of 8 ports from Paita in the north, to Ilo in the south (Table 1). Sampled vessels were generally not equipped with highly technological fishing gear such as automatic line winches, lineshooters, sonar, radio buoy finders or light stick lures. Cooling systems were basic, consisting of shaved ice stored in the vessel hold.

General Description. All longline trips monitored set their gear at the sea surface and 99% of sets occurred in oceanic waters >200m in depth (4 181.6 m depth ± 34.4, n=1730). The main target species for these fisheries included dolphinfish and sharks mainly blue (*Prionace glauca*) and shortfin mako (*Isurus oxyrinchus*), but also included porbeagle (*Lamna nasus)* and other Carcharinidae shark species. The mainline 'linea madre' was held at the surface by groups of buoys placed at the beginning and end of the line. Materials used for the mainline were synthetic multifilament propylene. Small buoys were placed at the top of each branch line to assure the superficial deployment of the gear. Branchlines were tied directly to the mainline. Cable leaders were used during shark season due to their improved ability to retain sharks and reduce gear loss (Gilman et al., 2008b). Swivels were used at the top end of the leader.

Hook sizes varied by port, with vessels in the northern locations using smaller sizes, whilst at southern ports (Callao, Pucusana, and Ilo), hooks used were J hooks, Mustad classic type, with a 10 degree offset. Hooks employed were of low quality, usually replaced after one fishing season, with the price per 100 hooks varying from $25 to $30.

Bait used included giant Humboldt squid *Dosidicus gigas*, mackerel *Scomber japonicus*, flying fish *Exocoetus* spp. and small cetaceans, including common dolphins *Delphinus* spp. and dusky dolphins *Lagenorhynchus obscurus* (Mangel et al., 2010). Gear was typically set in the morning. Mean soak times for the shark fishery were usually longer than those targeting dolphinfish due to the risk involved in the operation, weather conditions and greater length of mainline. Most (85%) sets were 'counter-retrieved' (Ward et al., 2004). One-third of vessels (31%) monitored their gear by patrolling the line. The navigation systems used by the longline fleet were various handheld and mounted Global Position Systems (GPS). For safety at sea, an Emergency Position Indicating Radio Beacon (EPIRB) is required for small-scale vessels, but due to the high costs involved, groups of 4 to 5 vessels typically share the cost and use of a single device. For ship to shore communication, larger vessels typically used HF radios while smaller vessels (which operated closer to shore) used VHF radio systems.

Approximately 3% (n=239) of trips suffered from mechanical failures that resulted in trip cancellations or early returns. Another 15% (n=232) of longline trips lost gear due to weather conditions, especially at the beginning of each winter season.

Profitability. Based on the 2007 market prices of materials, the cost to fully equip a longline vessel with 1,500 hooks (mainline, branchline, floats, weights, swivels and hooks) was ca. $2500–3000, with the difference in gear costs due to the varying quality of materials employed. Also, trip costs were greater for longline vessels targeting sharks than for vessels fishing for dolphinfish. The vast majority of longline trips were profitable (100% and 92% of the sharks and dolphinfish trips, respectively) (Table 3). During the shark season, meat was sold to both domestic and international markets. Shark fins were treated as a bonus and these earning were usually kept by the vessel owner, or, if trip profits were low, were left for the crew members.

Bycatch. Species that were captured as bycatch included loggerhead turtles *Caretta caretta*, green turtles *Chelonia mydas*, olive ridley turtles *Lepidochelys olivacea*, leatherback turtles *Dermochelys coriacea*, black-browed albatrosses *Thalassarche melanophris*, white chinned petrels *Procellaria aequinoctialis*, short-beaked common dolphins *Delphinus delphis*, rays *Dasyatis* spp., sun fish *Mola mola, Masturus lanceolatus*, opah *Lampris* sp., swordfish *Xiphias gladias,* and yellowfin tuna *Thunnus albacares*. From these, only the last two species were kept for sale.

Gillnets

The net fisheries monitored used surface drift gillnets and bottom set nets. Bottom set nets were sampled only from the port of Constante while driftnets were monitored in the ports of Mancora, Salaverry and Supe (Table 1). Gillnet vessels operated in coastal neritic waters (<200m depth). Overall, the total net length per set of the bottom set nets and driftnets ranged from 0.8 to 3.3 km (1.9 ± 0.7, n=89 trips). GPS navigation systems were used by some driftnet vessels but not by bottom set net vessels. Since net vessels worked close to shore, few were equipped with HF or VHF radios and most lacked EPIRBs.

Bottom set nets

Target species of 33 trips observed for this fishery included guitarfish *Rhinobatos planiceps,* flounder *Paralichthys adspersus*, lobster *Panulirus gracilis*, smooth hounds *Mustelus* spp., *Triakis* sp., and rays *Myliobatis* spp.

All sets were in shallow water (9–27m). Profits were distributed based upon the number of net panels each crew member brought. As with longline vessels, a 'share' was allotted to both the vessel owner and to the vessel (to offset repair costs).

The mean ± SD length of the net was 2.2 ± 0.7 km (1.3–3.3), and number of sets was 1.2 ± 0.4 (1–2) per trip. Average number of panels per trip was 38.5 ± 11.4 (25–60). The purchase price per net pane was $100–$120. Average trip costs for this fishery were the lowest of the sampled fisheries at $22.9. The gross gain was also the lowest with only 54.6% of trips being profitable (positive net gain) and with a highly variable mean net gain of $103.8 (Table 3).

Bycatch included green turtles, olive ridleys turtles, hawksbill turtles *Eretmochelys imbricata*, Burmeister's porpoises *Phocoena spinipinnis*, Humboldt penguins *Spheniscus humboldti*, catfish Ariidae, sea horses *Hippocampus* sp. and molluscs Muricidae, Melongenidae and Turbinidae. Most bycatch other than catfish was retained for consumption onboard or for sale.

Driftnets

This fishery targeted multiple species and during 53 trips observed, these included primarily blue and short fin mako sharks, but also hammerhead sharks *Sphyrna zygaena,* and thresher sharks *Alopias vulpinus,* as well as rays *Myliobatis* spp., *Mobula* spp., angel sharks *Squatina californica,* smoothhounds, bonito *Sarda chilensis* and dolphinfish.

Once gear was set, the vessel was tied to the end of the gear and drifted together with the gear. The average length of the net was 1.7 ± 0.6 km (0.8–2.6), with 6.5 sets/trip (1–11). The number of panels used per trip was 20.2 ± 4.3 (10–36). The cost for materials for the entire gear was approximately $2 000. Trip costs averaged $592.6, with 52% of trips being profitable and with a mean profit of $1 056.8 per trip (Table 3).

This fishing gear had bycatch of several taxa including: green, olive ridley, loggerhead and leatherback sea turtles, sunfish, swordfish, yellowfin tuna, mantarays *Manta* sp., black-browed albatrosses, guanay cormorants *Phalacrocorax bougainvillii*, Humboldt penguins, sooty shearwaters *Puffinus griseus*, white-chinned petrels, pink-footed shearwaters *Puffinus creatopus*, bottlenose dolphins *Tursiops truncatus*, dusky dolphins, Burmeister's porpoise and common dolphins. Species discarded included albatrosses, petrels, shearwaters, some sea turtles and sunfishes. However, cormorants, penguins and marine mammals were often kept for consumption or later sale. Also, when bait was used it consisted of small cetacean meat, typically from common or dusky dolphins (Mangel et al., 2010).

Overall SSF fishing effort

We estimated the overall fishing effort by Peruvian SSF using the number of gillnet trips from 1999 (63 083; the most recent data available; Estrella et al., 1999, 2000) and using the average net length of 1.9km determined from onboard observations (Section 3.3.2). We estimated that the SSF gillnet fishery constitutes > 100 000 km of nets broadcast per annum. Because our estimate does not account for multiple sets per trip, we believe this figure should be considered conservative, even though this sector appears to have slightly decreased in magnitude in recent years (Appendix 1).

A similar calculation can be made to contextualize Peruvian longline effort in terms of hooks deployed. By 2002, 11 316 longline trips were conducted (IMARPE, 2005 unpublished data). Using conservative estimates of number of hooks per set (955) and number of sets per trip (7.4) from this study (Table 3), we estimated a total of some 80 million hooks set per annum. As with our gillnet estimate, this should be considered a conservative estimate, as it does not account for recent growth in the sector.

Discussion

This study provides the first assessment of the Peruvian SSF and how this fishery has changed in terms of number of fishers, fleet size, landings and operations in the past decade. This information provides a valuable baseline for better understanding how these fisheries operate. The sector is of immense national importance with Alvarez (2003) estimating that >500 000 people are directly or indirectly dependent upon SSF locally, four-fold greater than the number of people dependent upon industrial fisheries. The same trend is observed in the role of SSF as a food supplier, with most production going for local consumption rather than for export as in the case for the large-scale fisheries for anchovies (Béné, 2006). Additionally, reliance of coastal human populations on marine resources is intensified due to the desert geography and climate of the Peruvian coastline (Reitz, 2001).

The 34% increase in the number of fishers observed from 1995–1996 to 2005 exceeded the total annual population growth rate for Peru of 24.7% from 1993 to 2007 (www.inei.gob.pe). During this same period, immigration to coastal areas from the Andes and forest areas constituted 19.9% of the total population (www.inei.gob.pe). SSF offers a relatively accessible form of employability for these migrants, as it operates with few legislative requirements and poorly enforced regulations. An important additional concern is that these fisheries are subject to the unpredictable nature of oceanographic variables such as the El Niño Southern Oscillation ENSO. Taken together these variables stress the need for further attention from managers and decision makers to make SSF more resistant to these perturbations and thus more sustainable in the long term.

Spatial–temporal variability

A change from pelagic to benthic target resources has probably helped maintain the overall landings of the Peruvian SSF (Estrella Arellano and Swartzman, 2010). However, there was variability in SSF landings during this 11-year study period (1995–2005). Some of this variability is correlated with the 1997–1998 ENSO, and to less degree the 2002–2003 ENSO, which impacted landings (especially in the regions of Piura and Ancash), and led to abrupt declines in landed tonnage. In most cases landings per region followed similar trends from 1995 to 2005 as those seen in the numbers of fishers and vessels (Estrella, 2007), although this was not the case in Piura and Ancash (Table 2, Appendix 2a), thus impacting on the livelihoods of the people involved in SSF activities.

Peru SSF fishing effort in global context

Richards (1994) noted how many small nets of SSF can be thought of as equivalent to fewer, larger industrial driftnets. This analogy applies to the Peru SSF gillnet fleet where fishing effort, based on our estimates on the km of net deployed per year, is fourteen times larger than that of Taiwanese squid driftnets used before their ban in the high seas (Northridge, 1991). Additionally, there are fourteen times more Peruvian gillnets than in the Italian swordfish driftnet fishery that operated in the Mediterranean until 1990 (Northridge, 1991). The number of small-scale gillnet vessels operating in Peru is not necessarily atypical; in fact, it is similar to other countries in the region (Alvarez, 2003). Moreover, bycatch caused by SSF to threatened fauna has been documented for other gillnet fisheries with similar characteristics as those operating in Peru (Frazier and Brito, 1990; Barlow and Cameron, 2003; Rojas-Bracho et al., 2006; Peckham et al., 2008).

A similar pattern is seen with longline vessels. The number of hooks used by small-scale longliners in Peru equates to one third of the fishing effort reported by the global swordfish longline fishery (Lewison et al., 2004) and double that of the Hawaiian-based longline fleet in 2008 (http://www.pifsc.noaa.gov). Small-scale longline vessels operating in Peru use similar numbers of hooks per set as some industrial fisheries, such as the swordfish longliners in Chile (Vega and Licandeo, 2009), or Italian pelagic swordfish longliners (Megalonofou et al., 2005).

Fishing gear efficiency

Estrella (2007) identified gillnets as one of the five main fishing gear types used in the Peruvian SSF, followed by hand line, diving, purse seines and longlines. We also observed a continuing predominance of net fisheries, which can be considered ‘gateway’ fisheries, understandable from the economic perspective given their low operational costs. This is of concern given their non-selectivity and interaction in the form of bycatch with several marine vertebrate taxa. However, the continuous rapid growth of longlines since their reintroduction in the 1990s (Reyes, 1993), requires particular attention with regard to the fleet's rapid expansion (a 357% increase in 11 years) and its fishing effort, particularly along the southern coast. Even though longlines are considered a more selective gear, they also have associated bycatch, including sea turtles (Alfaro-Shigueto et al., 2007; Chapter 2) and seabirds (J. Mangel *pers obs.*). Moreover, bycatch regulations should be considered in any future management plan for the dolphinfish longline fishery which has experienced substantial growth and represents one of the major fisheries in Peru's SSF (Estrella Arellano and Swartzman, 2010).

The higher tonnage, as well as navigation and communication technology used by the longline vessels allows them to conduct longer trips further out to sea, thereby increasing their efficiency. Thus, fishing areas used by SSF in Peru are no longer limited to the 5nm proposed by managers; indeed the vast majority of longline vessels use areas beyond 10 nm (this study; Estrella Arellano and Swartzman, 2010).

The growth in fishers and fleet was not uniformly associated with the increase in landings, and for some regions the CPUE declined. This suggests that fishing efficiency also declined in some regions. However, as we have shown here, gillnets and longlines remain profitable, even if only marginally (as in the case of gillnets), with much of the revenue for longline vessels coming from the additional value of shark fins (Gilman et al., 2008b).

Bycatch and fisheries sustainability

All fishing gears observed had bycatch of non-target marine vertebrates. Given the profound magnitude of gillnetting and longlining efforts in Peru, there is a clear need for additional work to more fully describe and quantify the impacts of these activities. We observed a tendency for greater selectivity by longlines for target species (lower bycatch) in comparison with gillnets. These results should be considered preliminary, however, because specific fleets can have significant takes of particular species or taxa. For example, dolphinfish longliners in Peru have an impact on sea turtles, especially loggerhead and leatherback turtles (Alfaro-Shigueto et al., 2007; Chapter 2) and we have also previously reported how longlines at Salaverry port that target sharks, use small cetaceans for bait (Mangel et al., 2010).

In the past several decades there have been increasing calls by conservationists, fisheries managers, as well as Regional Fisheries Management Organizations (RFMOs), to develop and use bycatch mitigation measures (Cox et al., 2007; Gilman et al., 2007, 2008a; Southwood et al., 2008) thus contributing to the long term sustainability of their associated fisheries. In SSF, however, the use of mitigation measures can be exceedingly challenging due to economic costs involved and the relatively limited enforcement mechanisms available. Easily implementable measures such as line patrolling (observed here practiced by some artisanal longliners) could help reduce bycatch rates at a relatively low cost.

Future approaches to promote the use of these measures in SSF also need to incorporate approaches that target the behaviors and attitudes of fishers (Campbell and Cornwell, 2008).

Future directions

There is clearly a need to broaden the spatial coverage of this work as well a need to look at inter-annual variability given the pronounced unpredictability of the oceanic system of the eastern Pacific and its associated effects (i.e., location of fishing areas, target catch, bycatch, etc.). Adaptive management plans have been proposed for the anchovy purse seine fishery to prevent negative impacts as a result of ENSO events (Bertrand et al., 2008). Given their comparable sensitivity to environmental conditions, similar management practices should be considered for the SSF in order to support their long term viability as an important source of food and employment. Other management measures could include permit extensions or regulation of fishing capacity and fishing gears (Salas et al., 2007).

There is clear potential for rapid ecological and economic changes within SSF of such magnitude, threatening the livelihoods of many. This highlights the need for carefully designed investments in this fisheries sector (Salas et al., 2007). In 2008, $7 million was invested by government agencies to support SSF in Peru (www.fondepes.gob.pe), however, this amount is small when one considers the level of support for industrial fisheries worldwide (Jacquet and Pauly, 2008). Investment should not only be for technological modernization but can also address capacity building, and encouragement of other processes to improve the status of these fisheries (Allison and Ellis, 2001; Salas et al., 2007; Jacquet and Pauly, 2008).

From our study, longlines were shown to be the most profitable fishery and the most selective gear with regard to bycatch of threatened fauna. However, we recommend caution before promoting longlines until consideration is given to making this fishing method sustainable in the long term. Future studies to fully quantify and understand SSF, monitoring spatio-temporal changes of these fisheries, and making use of multidisciplinary approaches in researching and implementing future management policies, are recommended to help inform stakeholders and ensure the sustainability of SSF in Peru.

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Table 1. Fishing ports sampled with on board observers (2002–2007) (Fig. 1). Check marks indicate observed bycatch (a. Alfaro-Shigueto et al. 2007; b. Alfaro-Shigueto et al. 2008; c. Mangel et al. 2010; d. Awkerman et al. 2006).

Ports	Number trips	Number sets	Number sets/trip	Gear	Bycatch by Taxa		
					Mammals	Turtles	Seabirds
Mancora	2	2	1.0	Driftnet		✓[a]	
Paita	4	34	8.5	Longline		✓[b]	✓
Constante	33	39	1.2	Bottom net	✓	✓[a]	✓
Salaverry	23	148	6.4	Longline	✓[c]	✓[b]	✓[d]
	53	359	6.5	Driftnet	✓[c]	✓[b]	✓[d]
Supe	1	8	8.0	Driftnet	✓[c]	✓[a]	
Chimbote	3	23	7.7	Longline		✓[b]	
Ancon	4	30	7.5	Longline		✓[b]	
Callao	19	139	7.3	Longline		✓[b]	
Pucusana	15	88	5.9	Longline		✓[b]	
San Juan	1	12	12.0	Longline			
Ilo	170	1294	7.6	Longline	✓	✓[b]	✓
Total	328	2176					

Table 2. SSF variation (in %) per region (Fig. 1) from 1995 to 2005 (from Estrella, 2007). Landings information from PRODUCE on direct human consumption landings between 1995 and 2005.

Region	Fishers			Vessels			Landings tn			CPUE tn/vessel		
	1995-1996	2004-2005	%	1995-1996	2004-2005	%	1995	2005	%	1995	2005	%
Tumbes	2125	2861	+35	468	667	+43	2787	3929	+41	6	6	–1
Piura	9103	13050	+43	2200	2898	+32	308 969	226 743	–27	140	78	–44
Lambayeque	2938	1422	–52	285	222	–22	40519	15 652	–61	142	71	–50
La Libertad	1080	1221	+13	172	333	+94	9085	25 735	+183	53	77	+46
Ancash	3033	3523	+16	713	1294	+81	195 207	38 944	–80	274	30	–89
Lima	3952	5613	+42	1286	2178	+69	28 496	48 159	+69	22	22	0
Ica	2372	3525	+49	636	784	+23	11 742	30 741	+162	18	39	+112
Arequipa	2318	4172	+80	260	816	+214	5850	37 422	+540	23	46	+104
Moquegua	687	1640	+139	126	347	+175	3571	42 635	+1094	28	123	+334
Tacna	490	700	+43	122	128	+5	NA	NA	NA	NA	NA	NA
TOTAL	28 098	37 727	+34	6268	9667	+54	606 226	469 960	–22	707	492	–30

Table 3. Description of driftnets and longline fisheries

	Gillnet Driftnet	 Bottom set	Longline For dolphinfish	 For sharks
Vessel length (m)	8.0±0.9 (5.5-9.3, n=16)		10.2±2.1 (6.4-16.5, n=49)	
GRT	8.9±7.7 (2.2-6.5, n=15)		13.0±8 (2.1-32.5, n=44)	
Net/mainline length (km)	1.74±0.6 (0.8-2.6, n=53)	2.2±0.7(1.3-3.3, n=33)	5.2±2.1 (1.9-11, n=117)	7.4±2.9 (1.8-18.8, n=101)
Target species	Sharks, rays, dolphinfish, bonito	Sharks, rays, flounder, lobster	Mahi mahi	Blue and shortfin mako
Vertebrate bycatch:				
Turtles	✓	✓	✓	Low
Seabirds	✓	✓	✓	Low
Mammals	✓	✓	0	Low
Trips observed	56	33	117	125
Sets observed	369	39	922	846
Trip duration (days)	7.3±3.2 (1-13, n=53)	1.4±0.8 (1-5, n=31)	8.4±2.5 (2-17, n=117)	14.5±5.3 (2-27, n=115)
Set deployment	Neritic	Neritic	Oceanic	Oceanic
# Sets/trip	6.5 ±3.1(1-11, n=53)	1.2±0.4 (1-2, n=33)	7.4±3 (2-16, n=117)	7.8±2.9 (2-14, n=98)
Branchline length (m)	-	-	9.1±3.1 (5.5-18,n=117)	14±4.7 (4.6-38, n=101)
Distance between hooks	-	-	19.6±4.4 (10.9-29.2, n=117)	27±7.7 (9.1-45.7, n=101)
Branchline material	-	-	0.25 cm nylon Monofilament	0.3 cm polypropylene Multifilament with tar
Leader material	-	-	Nylon monofilament (1.8mm)	Steel cable plastic coated (2.2mm)
Weighted swivels	-	-	39.7 - 42.2g of steel or nickel	
Total hooks observed	-	-	878,947	749,724
Hooks/set	-	-	955±444 (350-2,000)	
Net/mainline material	Multifilament 0.15- 0.5 cm Ø		0.6 cm Ø multifilament polyethylene	
Net color	Green, black, purple		-	-
# Panels/set	20.2±4.3 (10-36, n=53)	38.5±11.4 (25-60, n=33)	-	-
Panel length (m)	86.8±26.3 (54.8-146.2, n=53)	57±5.8 (53-73.1, n=33)	-	-
Panel height (m)	11.2±3.1 (3.7-14.6, n=53)	3.7± 0.03 (3.6-3.7, n=33)	-	-
# Weights/panel	6 units x 42gr/each	6 units x 2kg/each	-	-
Net area/set (km^2)	0.02±0.008 (0.003-0.036, n=359)	0.008±0.002 (0.004-0.01, n=39)	-	-
Total net observed (km^2)	7.86, n=359 sets	0.32, n=39 sets	-	-
Mesh size (cm)	10.2- 25.4 (17.5±3.9, n=53)	15.2-22.9 (21.5±2.3, n=33)	-	-
Hook type	-	-	J2, J3, J4, J5	J0, J1
Bait type	Small cetaceans	None	Giant squid, mackerel flying fish	Giant squid, mackerel, flying fish, cetaceans
Set time	14:53±3.1 h (00:05-23:50, n=357)	13:13±0.1 h (04:38-18:20, n=31)	08:06±3.1 h (0:06-17:30, n=794)	08:35±2.3 h (1:06-19:1,n=820)
Set duration (h)	-	-	2.2±1.0 (0.5-5.3, n=533)	2.7±1.1 (0.4-9, n=701)
Soak time (h)	14.6±3.9 (1.8-23.6, n=341)	16.5±3.0 (11.4-22.6, n=24)	12.5±4.3 (4.1-23.7, n=526)	17.3±4.0 (4.9-38.7, n=691)
Haul time	07:36±4.1 h (00:43-23:55, n=354)	06:15±0.9 h (3:56 to 7:32, n=25)	2:42±3.7 h (0:20 min-23:55, n=905)	3:58±6.0 h (0:30 min-22:24, n=810)
Haul duration (h)	-	-	5.3±2.6 (0.5-5.3, n=530)	6.1±3.1 (0.3-26, n=690)
# Crew	4.1±0.8 (3-6, n=50)	3.5±0.7(2-5, n=19)	5±1.9 (3-11, n=230)	
Gear investment ($US)	2,000-2,400 (based on materials cost for pane and an average number of panels of 20)		2,500-3,000 (based on material costs to equip a vessel with 1500 hooks)	
Gross gain/trip ($US)	1056.8±1224.2 (17.2-5544, n=46)	82±257.4 (0-1017.4, n=17)	3437.3±3236 (839-11250, n=25)	6294.4±6278 (607-24091, n=17)
Net gain/trip ($US)	52% profit 489±183 (-682 to 5044, n=46)	54.6% profit 103.8±311 (-22.9 to 1035.7, n=11)	96.4% profit1,286±2,176 (-2716 to 6536, n=28)	100% profit 2,163±3,472.6 (35.7 to 11393, n=21)
Trip cost ($US)	592.6±20.6 (120-700, n=46)	22.9±8.9 (12.5-35.7, n=12)	1958±1572 (571-5991, n=28)	3811± 2780 (500-12698, n=21)
% Crew blood related	16	100	6	3
% Trips operating at loss	48	45.3	3.6	0
Safety equipment at sea	Limited	No	Yes	Yes

Fig. 1. Distribution of small-scale fisheries (SSF) in Peru. Map shows the location of all fishing harbors. Filled circles denote site used in this study. Horizontal lines demarcate geopolitical regions of Peru (cf. Table 2 and Estella (2007). The proportion of harbors in each region subject to investigation in this study is given in parentheses. Arrows denote harbors where fisheries observers operated (N to S: Mancora, Constante, Parachique, Salaverry, Supe, Chimbote, Ancon, Callao, Pucusana, San Juan and Ilo fishing ports).

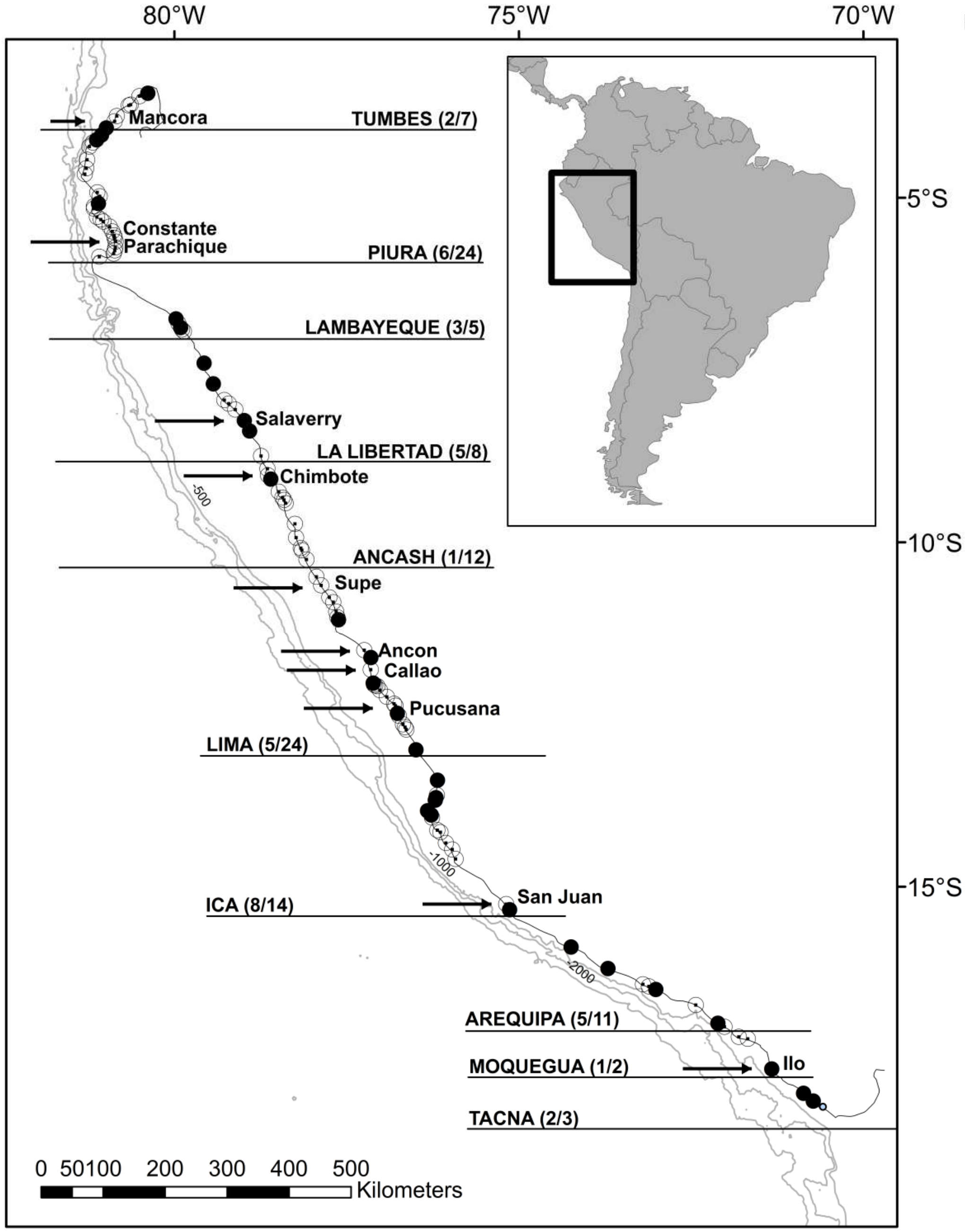


Fig. 2. Coastline maps of Peru showing the change in distribution of net, longline, and purse seine vessels at each sampled port (n=30; cf. Appendix 1) from 1994–1995 (Escudero 1997; left map of each pair) to 2004 (this study; right map of each pair). Number of vessels is indicated by the scaled bubble grams.

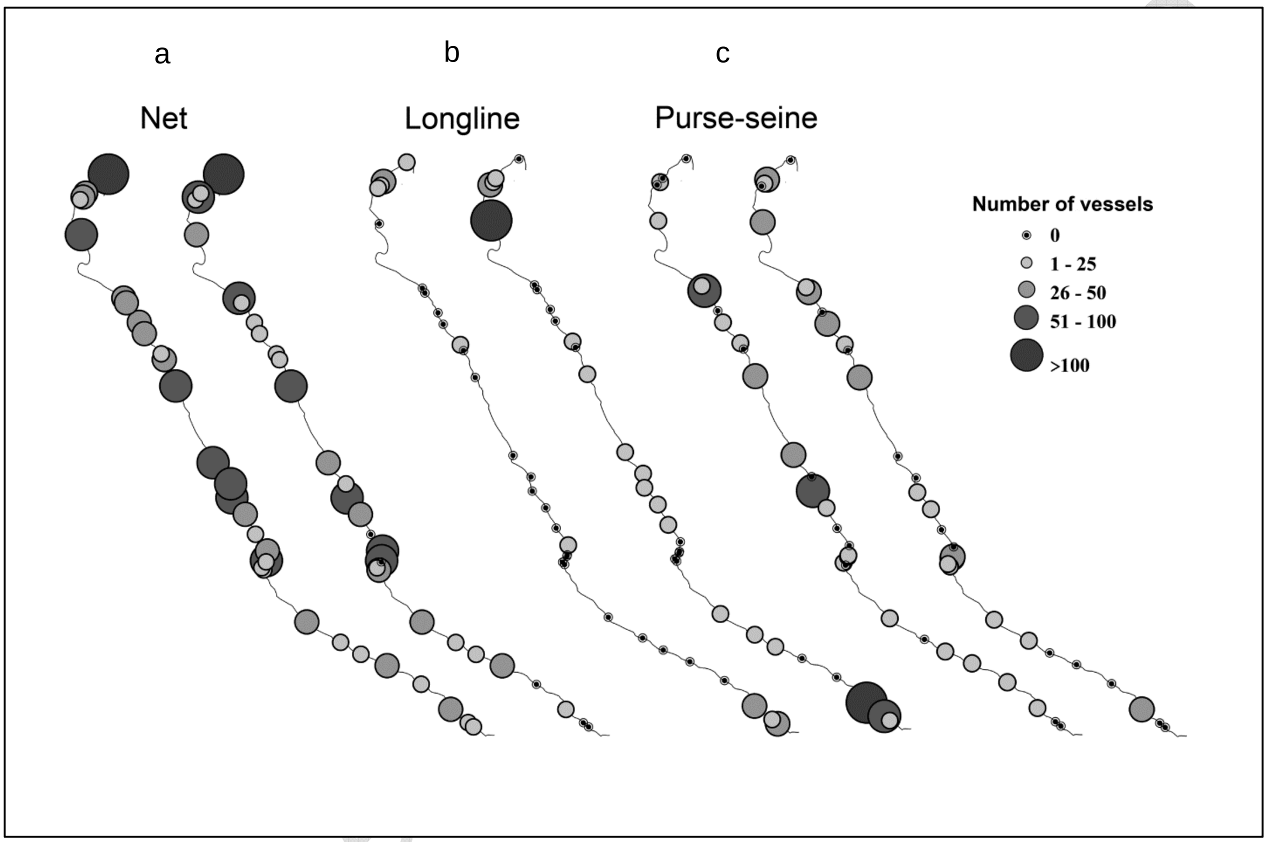


Fig. 3. SSF Landings in thousands of tonnes for human consumption for (a) overall SSF, where 'other' includes landings from unspecified origin and (b-f) by geopolitical region (1995–2005).

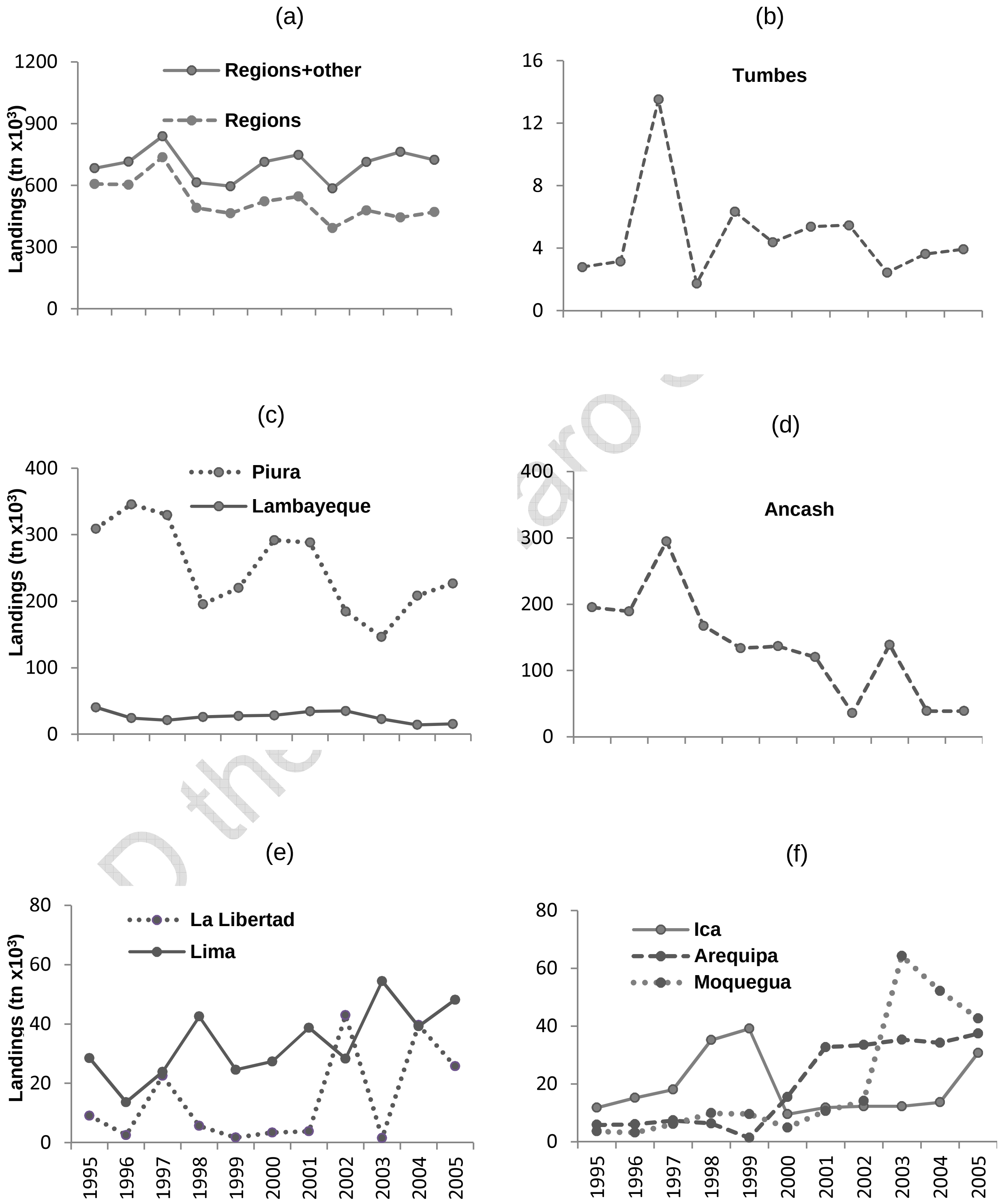
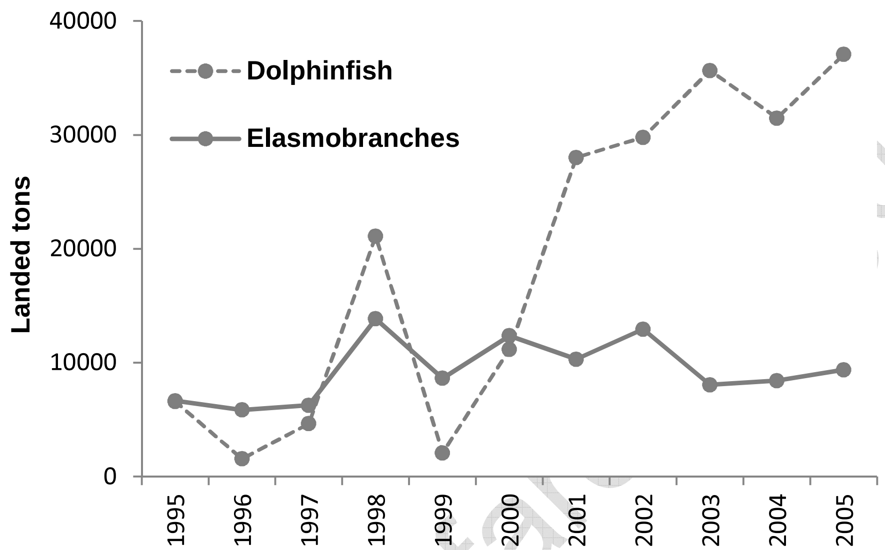
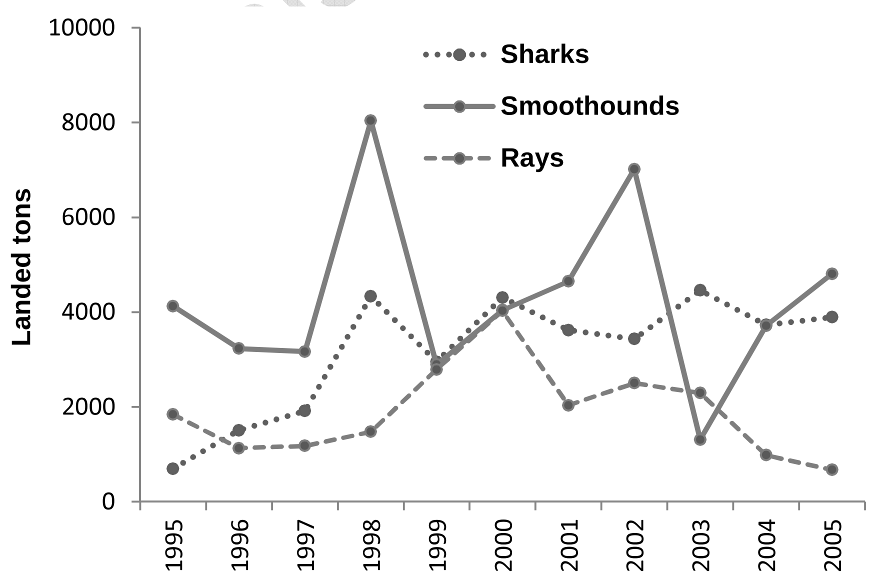


Fig. 4. Landings in tons of target groups for longlines and gillnets (1995–2005) (a) dolphinfish and total elasmobranchs and (b) sharks, smooth hounds and rays.

(a)



(b)



Appendix 1. Fishing gears used per port in November 1995–April 1996 (Escudero 1997) and surveys obtained in this study from January to April 2004.

	1996					2004				
Ports	Vessels	Net	Longline	P/seine	Other	Vessels	Net	Longline	P/seine	Other
Pto Pizarro	148	134	3			231	223			8
Cancas	72	29	37		6	105	11	21	30	43
Mancora	55	27	10	8	10	81	51	23	4	3
Organos	56	4	2		51	109	15	30		64
Paita	190	81		24	84	313	35	200	30	48
Constante	NA					24	20			4
Parachique	NA					80	15		48	17
Puerto Rico	NA					75	15		40	20
San Jose	64	47		14	3	93	79		2	12
Pimentel	NA					96	6	10		80
Santa Rosa	145	36		69	39	65	10		45	10
Pacasmayo	45	45				35	17			18
Chicama/Malabrigo	33	41		7	7	115	12		43	60
Salaverry	52	14	1	5	33	104	24	10	5	65
Morin	35	35				8	5			3
Chao	NA					22	7			15
Chimbote	250	98		34	118	148	98	16	34	
Huacho	145	73		31	42	60	40	20		
Ancon	92	57			8	71	25	18		28
Callao	225	88		53	86	178	60	10	20	88
Pucusana	114	38		21	55	84	39	13	2	30
Cerro Azul	58	24			34	8		8		
Tambo d Mora	44	39	4		2	89	89			
San Andres	153	87		7	58	126	57		32	37
Chaco	46	6		12	29	70			47	23
Lagunilla	52	11		22	13	53	11		16	26
Laguna Grande	68	21			48	192	39		19	134
Rancherio	48	7			55	NA				
Caballa	NA					5	5			
San Juan	62	36		2	23	82	31	23	7	21
Lomas	55	33		8	16	70	30			40
Chala	40	24			16	28	7	7	5	9
La Planchada	NA					56	14	14	6	22
Atico	38	14		2	22	36	6	6		24
Matarani	44	14		4	26	250				250
Ilo	126	30	33	9	54	298	20	138	50	90
Morro Sama	44	12	7		25	65		65		
Vila Vila	66	12	37		17	12		5		7

Appendix 2a. SSF landings in thousands tons per geopolitical region and % of which are landed in Piura and Ancash regions.

Years	Tumbes	Piura	Lambayeque	La Libertad	Ancash	Lima	Ica	Arequipa	Moquegua	TOTAL	% Piura	% Ancash	% Piura & Ancash
1995	2787	308969	40519	9085	195207	28496	11742	5850	3571	606226	0.51	0.32	0.83
1996	3158	345584	24389	2517	189232	13604	15180	5991	3155	602810	0.57	0.31	0.89
1997	13517	329621	21165	22490	294616	23869	18009	7374	6080	736741	0.45	0.40	0.85
1998	1732	195670	26143	5638	167318	42501	35179	6336	9862	490379	0.40	0.34	0.74
1999	6336	219911	27684	1675	133665	24536	39127	1333	9550	463817	0.47	0.29	0.76
2000	4372	291883	28492	3410	136569	27347	9519	15479	4889	521960	0.56	0.26	0.82
2001	5377	288277	34573	3769	120137	38696	11795	32676	10618	545918	0.53	0.22	0.75
2002	5463	184527	35063	43009	35654	28324	12232	33462	14096	391830	0.47	0.09	0.56
2003	2439	146368	23053	1504	138660	54460	12228	35288	64277	478277	0.31	0.29	0.60
2004	3624	208340	14117	39658	38817	39186	13652	34231	52140	443765	0.47	0.09	0.56
2005	3929	226743	15652	25735	38944	48159	30741	37422	42635	469960	0.48	0.08	0.57

Appendix 2b. SSF Landings of target species of longlines and gillnets between 1995–2005.

Years	Mahi Mahi	Sharks	Smoothounds	Rays	Elasmobranches
1995	6598	694	4125	1841	6660
1996	1558	1506	3230	1126	5862
1997	4648	1915	3166	1177	6258
1998	21104	4335	8038	1477	13850
1999	2084	2951	2892	2789	8632
2000	11159	4307	4042	4026	12375
2001	28025	3618	4648	2034	10300
2002	29787	3433	7015	2502	12950
2003	35651	4458	1309	2292	8059
2004	31465	3730	3712	983	8425
2005	37078	3894	4806	672	9372

Chapter 2: Demography of loggerhead turtles *Caretta caretta* in the southeastern Pacific Ocean: fisheries-based observations and implications for management

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Abstract

Since 2000 we have used artisanal fishing operations as an opportunistic platform for in-water studies of marine megafauna, including sea turtles. We present data on loggerhead turtles *Caretta caretta* incidentally captured by artisanal longline and gillnet fisheries activities operating from 7 ports along the coast of Peru. Data on location, body size and apparent maturity class of loggerheads were gathered. A total of 323 loggerhead turtle captures were recorded between latitudes 13 and 22°S in waters from 46.5 to 637.1 km off shore. Curved carapace length (CCL) ranged from 35.9 to 86.3 cm (mean ± SD = 57.2 ± 9.18 cm, n = 307), which equated to a predominance of juvenile turtles. The substantial fishing effort of the fisheries sampled (63 083 gillnet and 11 316 longline trips yr^{-1}) underscores the importance of mitigating fisheries impacts on loggerheads in the southeastern Pacific. We recommend that regional research and conservation work quantitatively document and, where possible, reduce impacts to loggerheads in the southeastern Pacific foraging area.

Introduction

The loggerhead turtle *Caretta caretta* is listed globally as endangered on the World Conservation Union (IUCN) Red List (IUCN 2007). In the Pacific, the primary nesting populations are located in Japan and eastern Australia (Uchida & Nishiwaki 1992, Bowen 1995, Limpus & Limpus 2003a), and annual nesting abundance has declined in recent decades in both regions (Limpus & Reimer 1994, Chaloupka & Limpus 2001, Kamezaki et al. 2003). These reductions are largely the result of impacts at nesting beaches (i.e. egg predation by foxes, raccoons, and weasels at nesting sites), but also due to impacts from interactions with marine fisheries gear (Wetherall et al. 1993, Poiner & Harris 1996, Lewison et al. 2004a). Until recently, the issue of fisheries bycatch of sea turtles has been largely focused on the high-seas industrial fisheries (Wetherall et al. 1993, Poiner & Harris 1996, Lewison et al. 2004a, Casale et al. 2007). Bycatch in artisanal fisheries has now been recognized as a major threat (Gallo et al. 2006, Lum 2006, Pupo et al. 2006, Alfaro Shigueto et al. 2007, Bal et al. 2007, Dossa et al. 2007, Lewison & Crowder 2007, Peckham et al. 2007, Dutton & Squires 2008). Nevertheless, small-scale artisanal fisheries are distributed throughout the world in areas that overlap important sea turtle habitats, and are therefore a significant challenge for sea turtle conservation efforts (Koch et al. 2006, Read 2007, Dutton & Squires 2008).

In the Pacific Ocean, the bulk of research on migratory behavior and habitat use has been conducted in the North Pacific (Polovina et al. 2000, 2004, 2006). TransPacific linkages have been demonstrated, connecting loggerhead activity in and around Baja California, Mexico, to breeding areas in Japan (Bowen 1995, Resendiz et al. 1998, Nichols et al. 2000, Seminoff et al. 2004, Koch et al. 2006, Peckham et al. 2007). Less is known about the loggerheads in the South Pacific, although the recent discovery of loggerheads off the coast of South America suggests life-history patterns that are similar to the North Pacific, with linkages between the southern nesting stocks in Australia and distant foraging grounds in the eastern tropical Pacific (Donoso et al. 2000, Kelez et al. 2003, Alfaro Shigueto et al. 2004). Ongoing genetic studies indicate that the loggerhead turtles off Peru and Chile originate from southern hemisphere nesting stocks in eastern Australia (Donoso et al. 2000, Alfaro Shigueto et al. 2004) and perhaps New Caledonia (P. H. Dutton unpubl. data).

In Peru, loggerhead turtles are known locally as ‘amarilla’ (yellow) or ‘cabezona’ (big head) turtles, and are commonly captured in artisanal fisheries off the southern coast (Alfaro Shigueto et al. 2004). Their meat is sometimes used for human consumption either on board, at fishing communities, or commercialized in domestic markets (Alfaro Shigueto et al. 2004). However, few demographic data are available, due largely to the pelagic nature of their distribution and the difficulty of accessing these areas for scientific studies.

There is scant information on the stock's spatial distribution, the size classes of the pelagic stages, and the foraging ecology of loggerheads in the South Pacific. Fisheries can provide a useful and practical platform for gathering information on marine species, such as sea turtles, that spend most of their lives at sea. By placing onboard observers on artisanal fishing vessels from several ports along the Peruvian coast, we describe the occurrence and distribution of loggerhead turtles in coastal Peruvian waters and use this information to define the size classes of loggerhead turtles captured by artisanal vessels off the coast of Peru and, ultimately, to provide information for sea turtle conservation and management decision making.

Materials and Methods

Study area

The southeastern tropical Pacific contains highly productive waters, due largely to the wind-driven upwelling of the cold, nutrient-rich waters of the Peru-Humboldt Current System along the west coast of South America (Fiedler et al. 1991, Bertrand et al. 2004, Hatziolos & de Haan 2006). The normal sea-surface temperature (SST) typically ranges from 15 to 17°C in the austral winter (June to September) and 21 to 26°C in the austral summer (December to March). Higher temperatures (>26°C) are restricted to northern areas near the tropics (Bertrand et al. 2004). Chlorophyll a (chl a) ranges from 39 to 47 mg C mg^{-1} chl a d^{-1} (Fiedler et al. 1991). The productivity of Peruvian waters is also shown by the large number of fishing ports (106 landing sites) (Escudero 1997) distributed along the 3000 km of Peruvian coastline, with approximately 9667 artisanal fishing vessels (Estrella 2007).

Fisheries platforms

Artisanal vessels are defined here (and according to Peruvian fisheries regulations) as boats with a maximum of 32.6 m^3 of storage capacity, 15 m in length, and that are principally based upon manual work rather than mechanically operated fishing gear (El Peruano Ministerio de la Producción 2001). Due to their large capacity, these can be considered as small- to medium-scale vessels. There are an estimated 63 083 gillnet (Estrella et al. 1999, 2000) and 11 316 longline trips annually (IMARPE unpubl. data).

This study was conducted from 11 ports along the coast of Peru (Table 1, Fig. 1). Data were collected from artisanal longline and gillnet vessels between 17 November 2000 and 29 May 2007 through an onboard observer program. Participation of vessels in the program was voluntary. Sampling effort of fishing trips depended on the availability of infrastructural resources (observers, funding), availability of vessels, and weather conditions.

Onboard observers were trained in data and sample collection methods and species identification, including seabirds, sharks, small cetaceans, and sea turtles (Harrison 1983, Jefferson et al. 1993, Onley & Bartle 1999, Pritchard & Mortimer 1999, Compagno et al. 2005). For data collection on target and non-target species, observers recorded information on fishing operations, locations of fishing areas, vessel-specific gear used, and the catch and bycatch obtained during the fishing trip. In addition, observers photographed turtles for subsequent confirmation of species identity (see Alfaro Shigueto et al. 2004). A total of 328 trips (of these 7 were unable to conduct regular fishing operations and thus were excluded) were observed during the study period (Table 1). Fishing trips monitored lasted 1 to 27 d (mean ± SD = 9.68 ± 0.3 d, n = 321 trips). Trips targeting mahi mahi operated in the austral summer season (December to March), while those targeting sharks were conducted during the remainder of the year (autumn through spring). Observers in Paita, Chimbote, Ancon, Callao, Pucusana, Marcona, and Ilo monitored longline trips. For Mancora, Constante, and Supe, only gillnets were sampled. In the port of Salaverry, we monitored both longlines and gillnets (Table 1, Fig. 1).

Gillnet vessels sampled in our study targeted multiple species, including blue sharks *Prionace glauca* and shortfin mako sharks *Isurus oxyrinchus*, and, to a lesser extent, hammerhead sharks *Sphyrna zygaena*, thresher sharks *Alopias vulpinus*, smooth-hound sharks *Mustelus* spp., rays *Triakis* sp., *Myliobatis peruvianus*, and *M. chilensis*, mahi mahi *Coryphaena hippurus*, angelsharks *Squatina californica*, guitarfishes *Rhinobatos planiceps*, lobsters *Panulirus gracilis*, and flounder *Paralichthys adspersus*, among other coastal species (Alfaro Shigueto et al. unpubl. data). Longline vessels targeted mahi mahi and sharks (especially blue and shortfin mako). The areas of operation of these artisanal vessels included oceanic (>200 m) and neritic waters (<200 m).

Morphometric data and turtle handling

Hooked or entangled turtles were brought on board, measured, photographed, and sampled for other studies not described here (i.e. genetics, stable isotopes). Information collected for each turtle included the location (latitude and longitude) of capture, curved carapace length (CCL; measured from the nuchal notch to posterior-most tip), and carapace curved width (CCW; at the widest part of the shell) (Bolten 1999). Measurements were made using a metric tape (±0.1 cm). Turtles in good condition were typically released within 1.5 h of landing. Released turtles were double tagged with Inconel tags (Style 681; National Band and Tag Company) applied to the trailing edge of both front flippers. For injured and comatose turtles, we followed handling and resuscitation techniques described on the NOAA Southeast Fisheries Science Center website for onboard observers (www.sefsc.noaa.gov/seaturtlefisheriesobservers.jsp). Dead turtles were measured then discarded at sea.

The level of injury of bycatch turtles was classified as 'severely hooked' or 'lightly hooked'. We defined severely hooked as a hook that was compromising the tongue, esophagus, or was swallowed, or when the hook was located in the upper jaw, potentially compromising brain functions. Turtles classified as lightly hooked were those hooked externally (neck, flippers), or where the hook was located in the sides of the mouth or in the lower jaw.

We inferred maturity status using size thresholds from the literature on the eastern Australia loggerhead population (Limpus & Limpus 2003b), which is believed to be part of the same genetic stock as loggerheads in the southeastern Pacific (Donoso et al. 2000, Alfaro Shigueto et al. 2004, P. H. Dutton et al. unpubl. data). We acknowledge that there is no knife-edge differentiation for animal size and stage class of maturation, especially since no internal analyses were conducted for the individuals caught during the present study. However, to facilitate comparisons with studies in the western Pacific (Limpus & Limpus 2003b), we classified loggerheads as juveniles, subadults, and adults, based on CCLs of <70 cm, 70 to 85 cm, and >85 cm, respectively (Limpus & Limpus 2003b).

Mean lengths (±1 SD) are given unless otherwise indicated. We used SPSS 15.0 for statistical analyses. Significance was established when $p \leq 0.05$. Maps were created using MAPTOOL (SEATURTLE.ORG, V. 2002, available at http://www.seaturtle.org/maptool).

Results

Loggerhead interactions and spatial distribution

A total of 323 loggerhead turtles *Caretta caretta* were examined during this study (Table 1). The majority of turtles (82%) were captured by vessels operating out of Ilo, and 99% were captured due to interactions with longline gear (Table 1).

All but 1 loggerhead (0.3%, n = 323) were reported alive when landed. Entanglement in the branchlines and main line (53.9%, n = 317) was more common than hooking (43.5%), while 2.6% of turtles were both entangled and hooked. Assessment of the degree of injury caused by hooking was only possible for a subsample (n = 51 turtles), in which turtles were categorized as severely injured (41.2%, n = 51 turtles) or lightly injured (58.8%). During the sampled trips we did not observe the sacrifice of any loggerhead for human use, possibly due to the observer's presence on board.

The location of bycatch loggerheads ranged from ca. 46.5 to 637.1 km (mean ± SD: 155.7 ± 4.95 km, n = 299 turtle locations) from the coast, between latitudes 13 and 22°S (Fig. 1). From turtles with information on depth of capture, only 1 individual was captured in the neritic zone (water depth = 125 m), while the remaining turtles (99.67%, n = 298) were caught in oceanic waters (mean ± SD depth: 4470.7 ± 86.1 m).

Size class analysis

Of the 323 loggerhead turtles caught in the present study, we obtained complete morphometric data from 307 individuals. The mean (±SD) CCL of all captured loggerheads was 57.2 ± 9.18 cm (range: 35.9 to 86.3 cm, n = 307). CCL was highly correlated with CCW (regression, CCL = 2.393 + 0.998 × CCW, r2 = 0.89, $p < 0.0001$), and therefore only CCL was examined for descriptive and comparative analyses (Fig. 2). Using our classification criteria, we found that 91.5% of the loggerheads were juveniles, 8.1% were subadults, and only 0.3% (1 individual) was a possible adult (Fig. 1). Within the individuals classified as juveniles, the majority (67.7%) corresponded to large juveniles between 50 and 70 CCL (Fig. 2).

Discussion

The present study highlights how preliminary studies aimed at describing bycatch also facilitate studies of the demography of endangered marine fauna; a viable technique when other mechanisms are unavailable for data collection. This is particularly true for elusive species such as sea turtles that spend the majority of their lives in open ocean areas that are distant from research facilities and difficult to access by other means. We acknowledge the inherent bias in this approach, since vessels target specific areas and 'sampling' is selective, as collection is affected by gear type and configuration as well as by fishing effort. However, in the absence of other fisheries-independent approaches available for studying threatened and endangered species at sea off Peru, we suggest that the collection of such data is essential for developing effective conservation programs, regardless of the potential biases. Moreover, data obtained from bycatch turtles have provided substantial information for population modeling, helping to determine key demographic and life-history components that have been vital for the development of related management policies and conservation measures for other sea turtle populations (Crouse et al. 1987, Crowder et al. 1994, Heppell et al. 1996, Chaloupka & Limpus 2001).

Using our classification criteria, we obtained only 1 *Caretta caretta* individual categorized as adult. Considering information presented in Limpus & Limpus (2003b), describing 80 cm CCL as the minimum breeding size documented for loggerheads in eastern Australia and given the variability in the relationship between size and maturity status, this apparent adult may also have been a large subadult. However, the absence of adults does not suggest that this fishery has an insignificant impact on southern Pacific loggerheads. Stage-based models of loggerhead turtles in the North Atlantic indicated that reduced survival rates of individuals ranging from 58.1 to 80 cm straight carapace length, which matches the size distribution recorded in our dataset, seriously impaired the survival or recovery of the population (Crouse et al. 1987). Heppell et al. (1996) determined similar results in a model for the eastern Australian loggerhead population.

Chaloupka (2003) modeled competing risk factors for the western South Pacific loggerhead stock across each life stage, concluding that declines in the population were probably due to chronic adult recruitment failures. Given the number of years sea turtles take to reach maturity, high and prolonged mortality of large juveniles may lead to similar recruitment failure and thus threaten population viability.

Known threats to the eastern Australian loggerhead population include fox predation on eggs, fishery bycatch by trawl, gillnet and crab trap fisheries on inter-nesting and foraging turtles, boat strikes, and ingestion of synthetic debris (Limpus & Reimer 1994, Poiner & Harris 1996, Chaloupka 2003, Limpus & Limpus 2003a). Using stochastic modeling, Chaloupka (2003) also showed how from the effects of only 3 threats or competing risk factors (egg predation by foxes, bycatch of immature and adult turtles in coastal trawlers, and bycatch of oceanic juveniles in distant water longliners), stock viability would be negatively impacted. During the present study we reported that most loggerheads were released alive (99.7%). Although a low direct mortality rate was observed (0.32%), the high incidence of severely hooked and injured turtles (41.2%) and evidence of post-hooking mortality (Chaloupka et al. 2004, Sasso & Epperly 2007), combined with the large number of fishing trips, suggest that artisanal fisheries operating in coastal waters of Peru are a major threat to juvenile loggerheads at foraging grounds in the southeastern Pacific.

Ontogenic habitat shifts were first described as 'developmental migrations' by Carr (1987) and have been shown for a number of sea turtle populations (Carr et al. 1978, Bolten et al. 1998, Lahanas et al. 1998). For example, loggerheads in waters of the eastern North Pacific near Baja California, Mexico, are exclusively immature-sized turtles (Seminoff et al. 2004, Koch et al. 2006, Peckham et al. 2007), while those in the western North Pacific are largely adults. Telemetry and tagging studies suggest that loggerheads from foraging areas in the central and northeastern Pacific eventually migrate westward to Japan (Resendiz et al. 1998, Nichols et al., 2000) and remain in the western Pacific for the remainder of their lives in breeding and foraging areas around the Japanese rookeries (Sakamoto et al. 1997, Hatase et al. 2002).

Size at recruitment to coastal neritic foraging areas in eastern Australia from oceanic juvenile life stages ranges from 66.7 to 93.9 cm CCL (mean = 78.62 cm CCL) (Limpus & Limpus 2003b). Therefore, most loggerheads from the present study were smaller than these neritic-stage juveniles and subadult recruits from eastern Australia. The preponderance of immature age classes in Peruvian waters, coupled with the absence of loggerheads between 4 and ~70 cm CCL in eastern Australian waters (Limpus & Limpus 2003b), suggests that southern Pacific loggerheads also make developmental movements, most likely in Australia and New Caledonia (P. H. Dutton et al. unpubl. data), to juvenile foraging habitat in the eastern Pacific, and back to adult foraging and nesting habitats in the western Pacific. The absence of adult size classes in the southeastern Pacific further suggests that breeders do not re-migrate to these foraging habitats.

Many of the loggerhead capture locations considered in the present study were in waters off northern Chile (Fig. 1), further highlighting the trans-boundary distribution of this species in the southeastern Pacific. Donoso et al. (2000) and Donoso & Dutton (2006) reported loggerheads in Chilean waters as bycatch in the Chilean commercial high seas longline fisheries for swordfish. The potential impacts of Chilean artisanal coastal fisheries on loggerhead turtles are currently being investigated (M. Donoso pers. comm.).

The paucity of data available on the aquatic life stages of sea turtles can be addressed, and valuable biological information obtained, in part through the use of fishing vessels (including artisanal vessels) as research platforms and the implementation of onboard observer programs with appropriate research methods. Also, the use of onboard observers has the potential added benefit of encouraging the participation of the main stakeholders (fishermen) to become actively involved in research and conservation programs. We recommend the use of similar programs in the region and globally to help describe the demographic and habitat use characteristics of protected marine species.

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Table 1. *Caretta caretta*. Ports monitored, number of trips observed, fishing method used and the number of loggerheads incidentally caught.

Port	Location	No. of trips	Fishing gear	No. of loggerheads caught
North				
Mancora	04°05'S, 81°04'W	2	Net	0
Paita	05°05'S, 81°06'W	4	Longline	0
Constante	05°35'S, 81°00'W	33	Net	0
Salaverry	08°14'S, 78°59'W	23	Longline	3
		53	Net	2
Chimbote	09°05'S, 78°36'W	3	Longline	2
Supe	10°48'S, 77°45W	1	Net	0
Center				
Ancon	11°46'S, 77°10'W	4	Longline	1
Callao	12°03'S, 77°08'W	19	Longline	29
Pucusana	12°29'S, 76°47'W	15	Longline	23
South				
Marcona	15°21'S, 75°10'W	1	Longline	0
Ilo	17°38'S, 71°20'W	170	Longline	263
Total		328		323

Fig. 1. *Caretta caretta.* At-sea locations of loggerhead turtles captured off Peru (n = 299). Loggerhead turtles were grouped by curved carapace length size classes: juveniles (<70 cm), subadult (70 to 85 cm) and apparent adults (>85 cm)

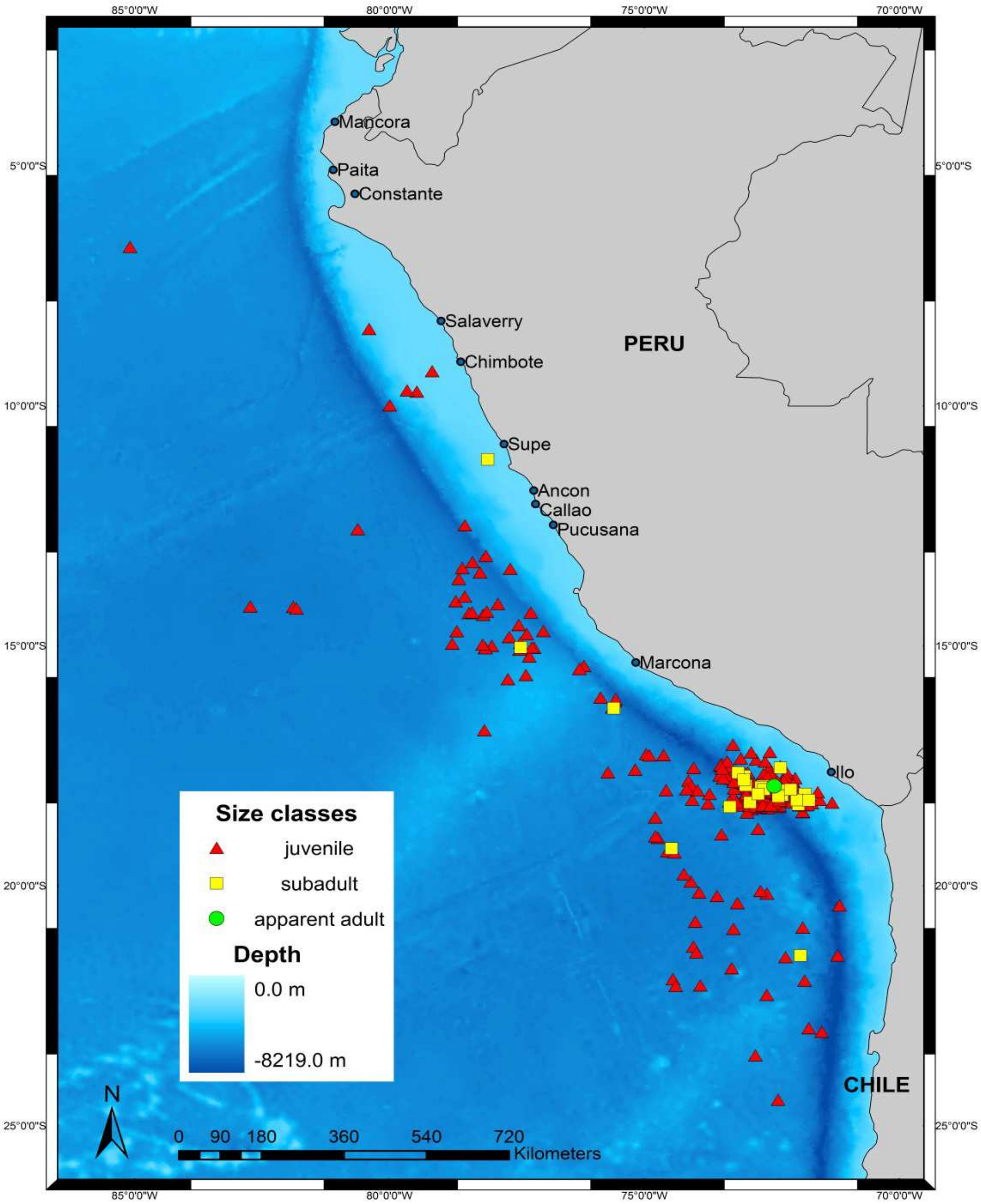
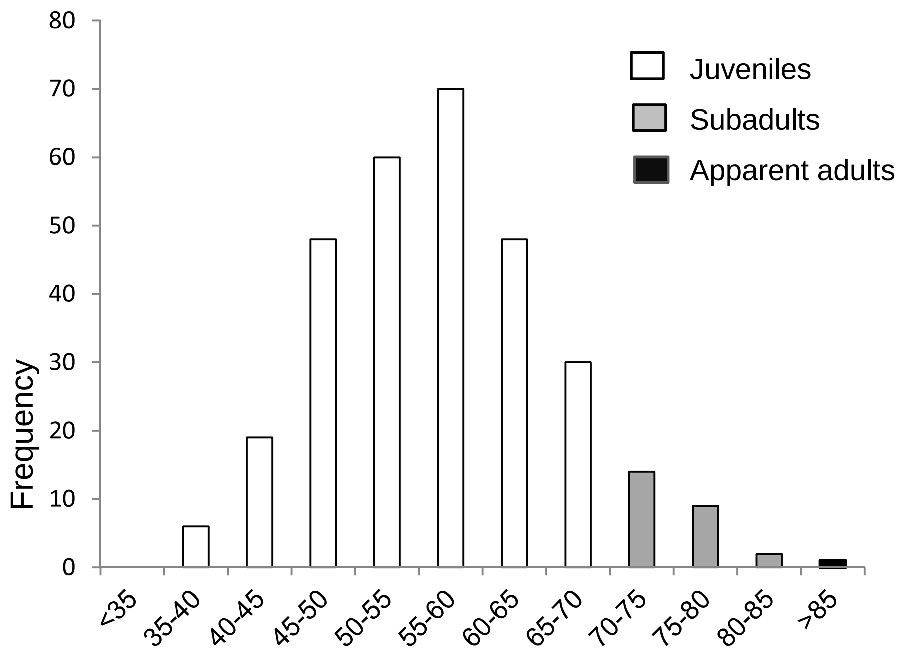


Fig. 2. *Caretta caretta.* Curved carapace length (CCL) distribution of loggerhead turtles incidentally caught in Peru (n = 307), showing the cut offs for every 10 cm of CCL, between the 3 size classes (n = 307): juveniles (<70 cm), subadults (70 to 85 cm), and apparent adults (>85 cm). Categories are based upon CCL and not internal analysis of gonads (as in Heppell et al. 1996). Size classes were adopted from values from figures for CCL and maturity stage class presented in Limpus & Limpus (2003b).



Chapter III: Small-scale fisheries of Peru: a major sink for marine turtles in the Pacific

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Abstract

1. Over the last few decades, evidence of marine vertebrate bycatch has been collected for a range of industrial fisheries. It has recently been acknowledged that large impacts may also result from similar interactions with small scale fisheries (SSF) due largely to their diffuse effort and large number of vessels in operation. Marine mammals, seabirds, turtles as well as some shark species have been reported as being impacted by SSF worldwide.

2. From 2000 to 2007, we used both shore-based and onboard observer programmes from three SSF ports in Peru to assess the impact on marine turtles of small-scale longline, bottom set nets and driftnet fisheries.

3. We reported a total of 807 sea turtles captured, 91.8% of which were released alive. For these three sites alone, we estimated ca. 5 900 turtles captured annually (3 200 loggerhead turtles *Caretta caretta*, 2 400 green turtles *Chelonia mydas*, 240 olive ridleys *Lepidochelys olivacea* and 70 leatherback turtles *Dermochelys coriacea*).

4. SSF in Peru are widespread and numerous (>100 ports, >9 500 vessels, >37 000 fishers), and our observed effort constituted ca.1% of longline and net deployments. We suggest that the number of turtles captured per year is likely to be in the tens of thousands. Thus the Peruvian SSF have the potential to severely impact sea turtles in the Pacific especially green, loggerhead and leatherback turtles.

5. Implications of the human use of turtle products as “marine bushmeat” are also raised as an important issue. Although such utilization is illegal, it is difficult to foresee how it can be managed without addressing the constraints to the livelihoods of those depending almost entirely on coastal resources.

6. *Syntheses and applications*. Our analysis demonstrates that, despite logistical challenges, it is feasible to estimate the Bycatch per Unit of Effort in small scale fisheries by combining methods that account for fishing effort and bycatch, such as using onboard and shore-based observers. We highlight sea turtle

bycatch in small scale fisheries in the southeast Pacific as a major conservation concern but also suggest possible paths for mitigation.

Introduction

Industrial fisheries have been highlighted as a major source of bycatch and mortality for a diversity of marine vertebrates such as sharks (Baum et al. 2003), sea turtles (Lewison, Freeman & Crowder 2004), seabirds (Brothers 1991) and marine mammals (Lewison et al. 2004). Indeed, high seas industrial driftnet and longline fisheries have been implicated as a key factor pushing some populations close to extirpation (Spotila et al. 2000; Baum et al. 2003; Nel & Taylor 2003). In some cases this has resulted in fishery closures (e.g. high seas driftnets were closed as a result of United Nations General Assembly Resolution 46/215). In industrial longline fisheries, concern over bycatch (here defined as unused or unmanaged catch, per Davies et al. 2009) has resulted in time-area closures (e.g. the Hawaiian longline fishery, NMFS 2000), along with the ongoing development of mitigation methods to reduce bycatch, e.g. increase fishing line weights to speed sink rates (Brothers, Cooper & Løkkeborg 1999), streamers to deter seabird capture (Løkkeborg & Robertson 2002) and the use of circle hooks to minimize turtle bycatch (Watson et al. 2005).

In recent years, it has become apparent that bycatch in small scale fisheries (SSF) is also an important source of mortality for marine vertebrates (Soykan et al. 2008; Moore et al. 2010). Small scale fisheries are mostly defined by smaller sizes of vessels, and tonnage capacity and minimal level of mechanization (Chuenpagdee et al. 2006; Jacquet & Pauly 2008); however both industrial and small scale fisheries can have a significant impact on ecosystems (Jacquet & Pauly 2008). SSF operate worldwide, and the term is often used interchangeably for ‘artisanal’ fisheries, referring to a subgroup of coastal fisheries (Chuenpagdee et al. 2006).

For marine turtles, SSF using nets have been shown to be a major source of bycatch (Frazier & Brito 1990; Chan, Liew & Mazlan 1988; Casale 2010), as have some SSF using longlines (Peckham et al. 2007; Chapter 2; Casale 2010). Although captures by individual fishers may not always be substantial, fleets can often be sizeable, particularly in developing countries where SSF are often the mainstay of the fishing sector (FAO 2005). The problem of bycatch in SSF is often accentuated by the fact that many SSF operate in nations where there are few protective measures in place and limited enforcement capabilities (Chuenpagdee et al. 2006; Dutton & Squires, 2008). Furthermore, bycatch rates are often difficult to assess due to the nature of SSF, i.e. diffuse effort, remote landing sites and social marginalization (Chuenpagdee et al. 2006; Jacquet & Pauly 2008).

Within the Peruvian fisheries sector, SSF are particularly important due to their role in food security, but also as a source of employment (Chapter 1). Operating along the entire Peruvian coastline, the SSF sector has rapidly expanded in recent decades (i.e. 34% and 54% increase in the number of fishermen and vessels, respectively; Chapter 1). The main fishing gears used include purse seines, gillnets, handlines, diving and longlines (Estrella Arellano & Swartzman 2010), with longlines exhibiting the steepest increases (Chapter 1). Given the global concern regarding bycatch in gillnets and longlines, Alfaro-Shigueto et al. (2010) sought to estimate the magnitude of the effort in these two sectors, and showed that despite their definition as small-scale, the magnitude of these fleets and their fishing effort are vast and are of concern with regard to their long term sustainability and potential interactions with large marine vertebrates.

Five species of marine turtles have been recorded as occurring in Peruvian waters. Frazier (1981) and Hays-Brown & Brown (1982) visited several landing sites and ports along the coast, from Talara (3º S) to Pisco (13º S), and reported the presence of four species including the green turtle *Chelonia mydas* Linnaeus, leatherback turtle *Dermochelys coriacea* Vandelli, olive ridley turtle *Lepidochelys olivacea* Eschscholtz and hawksbill turtle *Eretmochelys imbricata* Linnaeus. The regular presence of the loggerhead turtle *Caretta caretta* Linnaeus was not confirmed until the early 2000s, after the monitored area was extended to southern fishing ports (Alfaro-Shigueto et al. 2004).

Research suggests that the waters of Peru are primarily used as a foraging habitat, with vagrant nesting events (Hays-Brown & Brown 1982; Kelez et al. 2009). Flipper tag returns, as well as genetic and telemetry studies have begun to elaborate linkages with distant nesting rookeries, and have helped elucidate the boundaries of the putative Regional Management Units (RMUs as defined in Wallace et al. 2010b) interacting with the Peruvian fisheries. Green turtles visiting Peru are comprised, at least partly, of individuals from the Galapagos Islands (Hays-Brown & Brown 1982; Seminoff et al. 2008) and Mexico (Velez-Zuazo & Kelez 2010) while loggerhead turtles are linked to the Australian and New Caledonian nesting beaches (Alfaro Shigueto et al. 2004; Boyle et al. 2009). Genetic analyses indicate that leatherback turtles off Peru originate from rookeries both in the eastern (i.e. Mexico and Costa Rica) and the western Pacific (i.e. Papua New Guinea, Indonesia and Solomon Islands) (Dutton et al. 2010), while satellite tracking studies (Eckert & Sarti 1997; Shillinger et al. 2008), have shown the linkage between Mexican and Costa Rican nesting beaches and putative foraging grounds off Peru for this species. Tagging and genetic sampling indicate that olive ridley turtles originate from Costa Rica, Colombia and Mexico (Zeballos & Arias-Schreiber 2001; Velez-Zuazo & Kelez 2010). Little information is, as yet, available for the relatively rare hawksbill turtles found in Peru, but the closest known nesting rookery is in continental Ecuador (Gaos et al. 2010), perhaps serving as the most likely source population for individuals of this species. Of these species, the eastern Pacific RMUs for the leatherback turtle and hawksbill turtle are two of the most severely threatened (Wallace et al. 2010b).

An active turtle fishery existed in Peru until the mid-1990s. The estimated turtle take between the 1960s and the 1980s was reported as some 22 000 turtles.year^{-1}, the majority of which were green turtles (Aranda & Chandler 1989). Additionally, Pritchard & Trebbau (1984) described Peru as one of the few countries with a leatherback turtle fishery. In 1976, the Peruvian government banned the capture of all leatherback turtles and of green turtles less than 0.8 m length (Morales & Vargas 1996). In 1995 this resolution was extended to ban capture, retention and commerce of all turtle species. Furthermore, the 1995 resolution required that bycatch be reported to local authorities (Morales & Vargas 1996). Nevertheless, after the ban, information suggested that turtle take continued; indeed, it may have remained relatively unchanged in magnitude (Estrella & Guevara-Carrasco 1998; Alfaro-Shigueto et al. 2007; Chapter 2). Here we generate robust estimates of the species composition and magnitude of turtle captures in four small scale fisheries at three sites spanning the Peruvian coast. We aim to provide an insight into the impact caused by the Peruvian SSF to several turtle species, inform SSF bycatch assessment methods, and describe how this information can be used to identify areas where major conservation efforts are needed to reduce impacts.

Materials and methods

Fisheries sampled

Between 2000 and 2007, data were collected from four key fisheries: bottom set nets, driftnets and two separate longline fisheries. Bottom set nets (Constante: 05˚35'S, 80˚50'W) and driftnets (Salaverry: 08˚14'S, 78˚59'W) both targeted a variety of species including rays, sharks and dolphinfish (Chapter 1). The two longline fisheries (Ilo: 17˚38'S, 71˚20'W) seasonally targeted either dolphinfish or sharks and have season specific gear configurations (e.g. distance between and depth of branchlines, material of leader, hook sizes), and are therefore considered separately (Chapter 1). Details by fishery, sampling periods, number of trips and sets observed are summarized in Table 1. The descriptive characteristics and the modus operandi were detailed in Alfaro-Shigueto et al. (2010). The fishing areas of the vessels from the sampled ports did not overlap (Fig. 1).

Onboard observers

To obtain accurate information on the Bycatch per Unit of Effort (BPUE) of turtle bycatch, we had onboard observers operating in each of the fisheries studied (*cf* Mangel *et al.* 2010). Observers were trained in sea turtle species identification and in obtaining biometric measurements (Chapter 2). To avoid interference with data collection, observers did not participate in fisheries operations. Observers recorded the number, associated effort (km of net, number of hooks) and location of all fishing sets and turtle bycatch events during the fishing trip. Observations were spatially referenced using a handheld GPS. Using a flexible measuring tape, observers obtained the curved carapace length (CCL). Released turtles were double tagged with inconel tags (Model 681; National Band and Tag Company, Newport, Kentucky). For injured and comatose turtles, handling and resuscitation techniques were followed as described by the Southeast Fisheries Science Center, USA (www.sefsc.noaa.gov/species/turtles/observers.htm). For each capture event, observers recorded whether the turtle was (1) entangled, (2) hooked, or (3) entangled and hooked, whether it was alive or dead and whether it was released alive, discarded dead, or retained for consumption or commerce. Logistical constraints precluded the gathering of observer data for the months of February, July and

August at Constante port. For these months we used an interpolated average BPUE at this site of the month before and after.

Shore-based observers

For each fishery sampled, shore-based observers monitored the number of fishing trips at the port, length of trip, fishing area and the target species. Data collection was based upon daily interviews with fishermen and monitoring of dockside activity. From the daily information we obtained the mean monthly number of fishing trips conducted at the sampling site or port for any given gear (Table 1).

Mapping and Data analysis

All spatial analyses and maps were prepared using ESRI ArcMap 9.1 (Redlands, California, USA). All observer data were managed in a Microsoft Access relational database. Bycatch data were obtained from the onboard observer data for each species/fishery combination, generating a monthly BPUE ($BPUE_{month}$), as well as the ratio of bycatch-positive sets ($S_{positive}$). As such data are typically left skewed we followed the methodology of Mangel *et al.* (2010) in estimating the mean annual catch of small cetaceans. Monthly estimates of the total number of sets by fishery were generated from the shore-based observers (S_{month}). Monthly estimates of bycatch (B_{month}) were derived multiplying $BPUE_{month}$ by $S_{positive}$ and S_{month}. Annual estimates (B_{total}) were derived by summing all monthly estimates (B_{month}). The combination of data from shore-based observers allowed estimates to be scaled up to annual totals (see Supporting Information Appendix S1 for further information).

To make comparisons among fishing gears in terms of BPUE, we worked with basic units of turtle catch.set^{-1}; however, to facilitate comparison with other studies, catch.km of net^{-1} and catch.10^3 hooks^{-1} for longlines were also calculated. Descriptive statistics are presented as mean ± standard deviation (SD).

Results

Species composition

In a total of 264 fishing trips observed in the four fisheries studied (3446 days of fishing; 1776 sets) we recorded the capture of 807 turtles of four species (Table 2): loggerhead turtles 51.2%; green turtles 41.4%; olive ridley turtles 3.2%; leatherback turtles 2.1%; for 2.1% of the captures, positive species identification was not possible. The species composition, however, was markedly different among sites (Fig. 1), with turtle bycatch in the net fisheries in the north being dominated by green turtles (Constante 98.5%; Salaverry 84.9%; Fig. 1, Table 2); while turtle bycatch in the longline fisheries from Ilo was dominated by loggerhead turtles (dolphinfish fishery: 64.2%; shark fishery: 71.1%; Fig. 1, Table 2) followed by green turtles (dolphinfish fishery: 31%; shark fishery: 22 %). No bycatch of hawksbill turtles was observed during our sampling.

Bycatch rates

The proportion of bycatch-positive sets and mean species specific BPUE showed a marked variation among the fisheries (Table 2). Particularly notable are the high proportion of bycatch- positive sets and high BPUE for green turtles in the bottom set nets at Constante (56%; 2.78 turtle.set^{-1}) and for loggerhead turtles in the dolphinfish longline fleet (39%; 1.42 turtles.set^{-1}). Table S1 in Supporting Information shows other units of BPUE (per km, per 1000 hooks). Table S2 in Supporting Information has the monthly BPUE per species at the nets and longlines fisheries sampled.

Estimated annual bycatch

Table 2 shows the estimated average annual bycatch of turtles over the years sampled for our study harbours and fisheries. The dolphinfish longline fishery shows the highest value of mean annual estimated bycatch of turtles, followed by the driftnets, shark longlines and, finally, the bottom set nets. Based upon the shore-based observer data from these three ports and the BPUE estimated from the observed trips, the sum of the annual estimated bycatch by these four fisheries is ca. 5900 turtles (Table 2). Mortality rates differed among the fisheries, with nets showing the highest direct mortality, augmented by the retention of turtles for consumption, leading to overall mortality rates of 41% and 18.3% for bottom nets and driftnets, respectively. Conversely, in the longline fisheries, low numbers of turtles were observed dead or retained for further use (<0.5%) (Table 2). We estimated a total of 395 turtles killed: those caught dead (149) plus live individuals retained (246).

Size classes and state of maturity

We obtained curved carapace length (CCL) measurements for 619 turtles (76.7% of the total) allowing us to estimate the state of maturity inferred by the carapace length of the individuals captured. While we recognize there are several ways to categorize turtles into age classes, we used the minimum size of nesting females to differentiate between juveniles and possible adults. For green turtles the mean CCL of captured animals was 58.7 ± 8.5 cm (40.5 - 88.8, n=281). Given that the majority of the green turtles in Peru correspond genetically to the rookeries in the Galapagos (Velez-Zuazo & Kelez 2010), we used the minimum size of females nesting at Galapagos (60.7 cm CCL, Zarate, Fernie & Dutton 2003) to estimate that 34.5% of the individuals captured were possible adults (60.7 - 88.8 cm). The mean CCL of leatherback turtles captured was 139.6 ± 17.45 cm (115 - 160, n=7). The minimum CCL of nesting females is 123 cm (Costa Rica), 131 cm (Mexico) and 145.1 cm PNG (Stewart, Johnson & Godfrey 2007) suggesting as many as 71.4% could be categorized as possible adults.

Of the 24 olive ridley turtles measured, the mean CCL was 59.2 ± 9.3 cm (42 - 75.5). Minimum carapace length of females nesting in the Pacific rookeries of Costa Rica is 54 cm (NMFS & USFWS 1998) suggesting that 66.7% of animals captured were near adult size. For loggerhead turtles, the mean CCL was 57.2 ± 9.2 cm (35.9 - 86.3, n=307). Using the size categories determined by Limpus & Limpus (2003b), based upon long-term laparoscopy analyses in the corresponding stock(s) in the western Pacific (Australia), we determined that 91.5% of the loggerheads obtained in our study were juveniles, 8.1% were prepubescents and 0.3% were adult sized individuals.

Discussion

There is growing concern that SSF are impacting turtle populations worldwide (Lewison & Crowder 2007; Soykan et al. 2008; Wallace et al. 2010a). Our work provides support for this assertion. The bycatch rates reported here for gillnets are among the highest in the world (Wallace et al. 2010a). Given the level of interaction with multiple non-target species, and the amount of nets deployed each year in Peru (Chapter 1) and elsewhere in the eastern Pacific (Alvarez 2003), there is a clear need for urgent attention to SSF gillnets (i.e. driftnets, trammelnets, bottom set nets). As for the longline fisheries sampled, the highest bycatch rate was reported for the dolphinfish longline fishery (1.42 loggerhead turtles.set^{-1}). This bycatch rate was lower than those reported by other studies in small scale longlines for the eastern Pacific (e.g. Ecuador: Largacha et al. 2005; Baja California: Peckham et al. 2007). However, given the magnitude and rate of expansion of longlines in Peru in the last decade (Chapter 1), there is clearly a need to take steps to further investigate the impacts of this growing fishery. We are now using rapid assessments methods (Moore et al. 2010) elsewhere in Peru and in neighboring Ecuador and Chile in order to address the impacts of longlines and gillnets at wider geographic scales.

For longline fisheries, we recorded 635 turtles captured with an effort of ca. 900 000 hooks. The annual effort for small scale longline fisheries in Peru is estimate at 80 million hooks (Chapter 1). For net fisheries, we observed 838.3 km of nets set in which 172 turtles were caught. This compares with ca. 100 000 km of nets deployed per annum nationwide (Chapter 1). We feel therefore, although species breakdowns may vary across ports and gears, that there is a strong possibility that turtle bycatch could be at least one order of magnitude greater and likely numbers in the tens of thousands per annum with appreciable proportions, at least in some sites and fisheries, being retained for consumption. This sizeable take suggests that the protective legal status of turtles in Peru may have had a limited effect at reducing turtle take. The same lack of effectiveness has been observed for the banning of the marine mammal fishery in Peru (Mangel et al. 2010) and highlights enforcement of legislation as a key challenge in the management of SSF (Salas et al. 2007).

When compared with other research in the Pacific, our data allows us to contextualize the likely impacts to the breeding stocks of origin for sea turtles in Peruvian waters (Fig. 2). A particular cause for concern is here identified for the leatherback turtles, where both western and eastern Pacific stocks may be impacted (Eckert & Sarti, 1997; Shillinger et al. 2008; Dutton et al. 2010), and the majority of turtles affected are large individuals likely to be those of higher reproductive value (Crowder et al. 1994; Wallace et al. 2008). Although mortality from retention for human use may be low, any impact may be important (Donoso & Dutton 2010) if it is widespread given the prevailing population decline for this species, especially in the eastern Pacific where current annual nesting females number in the low hundreds (Spotila et al. 2000; Sarti-Martinez et al. 2007).

Loggerhead turtles from Australia/New Caledonia, the breeding stock impacted in Peru (Boyle et al. 2009), have also experienced a decline over the last several decades (Limpus & Limpus 2003a). Our data show that loggerheads are the main species captured in SSF longliners in southern Peru. Although this constitutes large numbers, most are captured alive and released. Nevertheless, limited information on the post-release mortality rate and the possible cumulative impacts of multiple captures complicates any attempts to fully understand the impact of this fishery (Mangel et al. in press). As for green and olive ridley turtles, tag recoveries and genetic sampling show that the stocks impacted are from within the eastern Pacific. Of concern is the fact that both species were incidentally caught in all four fisheries, and thus may be suffering impacts throughout Peru.

Bushmeat is a term generally used to describe the use of terrestrial wild animals for subsistence or commerce (Wilkie & Godoy 2001). The term “marine bushmeat” has been applied to the use of marine fauna by coastal inhabitants (Alfaro-Shigueto & Van Waerebeek 2001; Clapham & Van Waerebeek 2007) and is used here to describe the retention of live or dead turtles to be consumed or commercialized locally. Gillnet fishers in our study retained up to 30% of live turtles to be used as bushmeat. Very few other bycatch studies have detailed the use or retention of incidentally captured turtles for consumption (Alfaro-Shigueto et al. 2007; Peckham et al. 2008; Casale 2010). Brashares et al. (2004) described the correlation between the uses of terrestrial wildlife and of marine resources. In Peru, where most impoverished coastal communities rely almost exclusively on fisheries products as their main protein source, the use of marine bushmeat as a food supply, including in some cases seabirds, sea turtles and small cetaceans, has long occurred (Reitz 2001) and continues (Hays-Brown & Brown 1982; Awkerman et al. 2006; Mangel et al. 2010). It is clear therefore that bycatch research should account for this use, which could lead to alternative recommendations for management and mitigation such as alternative food sources or conservation incentives (Ferraro & Gjertsen 2009).

Current efforts to reduce bycatch of marine threatened fauna include the use of mitigation measures (Løkkeborg & Robertson 2002; Barlow & Cameron 2003; Gilman et al. 2010; Ward et al. 2008), fisheries closures (e.g. UN General Assembly Resolution 46/215; CMC versus NMFS: C.V. No. 99-00152) and the creation of Marine Protected Areas (Fallabrino & López-Mendilaharsu 2008). The high discard rate of turtles observed in Peruvian SSF longlines, suggests that much of the bycatch is unwanted and therefore may provide an opportunity to find ways to reduce turtle bycatch in longlines. Initiatives using circle hooks and dehookers could be used to reduce hooking rates and severity of injury (Largacha et al. 2005; Read 2007). As for gillnet fisheries, new mitigation measures, such as net illumination and eliminating floats from main lines, have recently been trialled (Wang, Fisler & Swimmer 2010; Gilman et al. 2010) and studies of the applicability of such schemes in the Peruvian SSF is the logical next step.

Globally, SSF are important sources of food and employment for millions of coastal inhabitants (FAO 2005; Chuenpagdee et al. 2006). In the southeastern Pacific region in particular, SSF constitute the majority of the fishers and fisheries (Alvarez 2003) and thus, it is important to recognize the need to promote their sustainability and minimize their environmental impacts. Our work here mandates that special efforts be paid to reducing bycatch of key species such as leatherback, loggerhead and green turtles. Bycatch of these taxa adds to previously described impacts on marine mammals (Mangel et al. 2010) and seabirds (Awkerman et al. 2006). It is clear that for sea turtles, there is a profound potential for SSF in the eastern Pacific to act as a population sink, negating positive initiatives being undertaken elsewhere in the region. The identification of low cost/high benefit grassroots initiatives in the region (e.g. fishing community co-management using trained fishermen: Gutiérrez, Hilborn & Defeo 2011), may contribute to ensuring the recovery of imperilled turtle populations in the Pacific.

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Table 1. Overview of the four fisheries studied. Months of operation of the fishery (season). Onboard observer: period of effort, number of trips and sets monitored, including the mean ± SD (range) of number of sets per trip, total effort observed in area of net (net fisheries) or number of hooks (longline fisheries). Shore-based observers: the number of fishing trips and estimated total sets per year (Bottom set net: 2001-2004; Driftnet: 2005-2007; Longline (dolphinfish): 2004-2006; Longline (sharks): 2004-2006).

		Onboard observers					Shore based observers				
Fishery	Season	Period	No.Trips	No.Sets	Sets.trip^{-1}	Total effort		Year 1	Year 2	Year 3	Year 4
Bottom set net	Year round	Jan 00-Dec 06	32	39	1.2 ± 0.39 (1-2)	87.6 km	Trips	300	187	272	540
							Sets	360	224	326	648
Driftnet	Year round	Jan 05-Dec 07	55	404	7.4 ± 2.2 (2-11)	750.7 km	Trips	572	593	600	
							Sets	3718	3855	3900	
Longline (dolphinfish)	Dec-Mar	Dec 03-Mar 07	88	619	7.03 ± 3.5 (1-16)	419 338 hooks	Trips	543	794	641	
							Sets	4018	5876	4743	
Longline (shark)	Apr-Nov	Apr 04-Nov 07	89	714	8.1 ± 2.8 (2-14)	533 753 hooks	Trips	236	233	224	
							Sets	1841	1817	1747	

Table 2. Turtles captured. Summary of status and fate (live/dead; retained/released) and mode of capture (H: hooked, E: entangled, H/E: both) of the turtle bycatch observed (n), per species by fishery. Proportion of bycatch-positive sets for that species (set +) and mean BPUE.set^{-1} are then used to calculate mean annual estimates (numbers caught, released, retained, dead) using multi-annual shore- based data (Table 1). Mortality per fishery obtained from animals dead at capture and those retained alive. Note: a small proportion of turtles were not identified to species in driftnets (n=3), longline for dolphinfish (n=11) and longlines for sharks (n=3).

		Fate (%)				Capture Mode (%)									
		Live		Dead											
	Species (n)	Retain	Release	Retain	Discard	H	E	H/E	Set+	BPUE/set	Mean Catch	Released	Live Retain	Dead	Mortality
Bottom set net	*C.mydas* (65)	29	60	11	_	_	100	_	0.564	2.78 ± 1.8	321 (239-395)	193 (143-237)	94 (70-116)	35 (26-43)	129
	L.olivacea (1)	100	_	_	_	_	100	_	0.026	1	47 (25-61)	0	47 (25-61)	0	47
Driftnet	*C.mydas* (90)	10	81	6	3	_	100	_	0.213	1.15 ± 0.2	881 (868-903)	723 (712-741)	88 (78-89)	79 (78-81)	167
	L.olivacea (7)	14	72	14	_	_	100	_	0.017	1	60 (55-63)	43 (40-45)	9 (8-9)	9 (8-9)	18
	C.caretta (1)	_	_	100	_	_	100	_	0.003	1	15 (10-22)	0	0	15 (5-15)	15
	D.coriacea (5)	20	80	_	_	_	100	_	0.012	1	40 (37-44)	32 (30-35)	8 (7-9)	0	8
Longline (dolphin fish)	*C.mydas* (135)	_	100	_	_	54	41	4	0.155	1.3 ± 0.2	1061 (801-1313)	1061 (801-1313)	0	0	0
	L.olivacea (16)	_	94	_	6	56	44	_	0.026	1	133 (116-158)	125	0	8 (7-10)	8
	C.caretta (272)	_	100	_	_	52	46	2	0.391	1.42 ± 0.2	2613 (2104-3066)	2613 (2104-3066)	0	0	0
	D.coriacea (1)	_	100	_	_	_	100	_	0.002	1	6 (3-9)	6 (3-9)	0	0	0
Longline (shark)	*C.mydas* (44)	_	98	2	_	45	52	2	0.055	1.14 ± 0.1	131 (100-163)	128 (98-159)	0	3 (2-4)	3
	L.olivacea (2)	_	100	_	_	50	50	_	0.003	1	7 (5-9)	7 (5-9)	0	0	0
	C.caretta (140)	_	100	_	_	33	66	1	0.155	1.23 ± 0.2	589 (545-646)	589 (545-646)	0	0	0
	D.coriacea (11)	_	100	_	_	27	55	18	0.015	1	26 (24-27)	26 (24-27)	0	0	0
Totals		_	_	_	_	_	_	_	_	_	5930	5546	246	149	395

Figure 1. Fisheries sampled (N to S): Constante (bottom set nets), Salaverry (driftnets) and Ilo (longlines). Fishing areas are indicated by polygons and represent each of the grounds used by each fishery based on set locations (represented by dots). Species composition of turtle bycatch for each fishery is indicated in a pie chart.

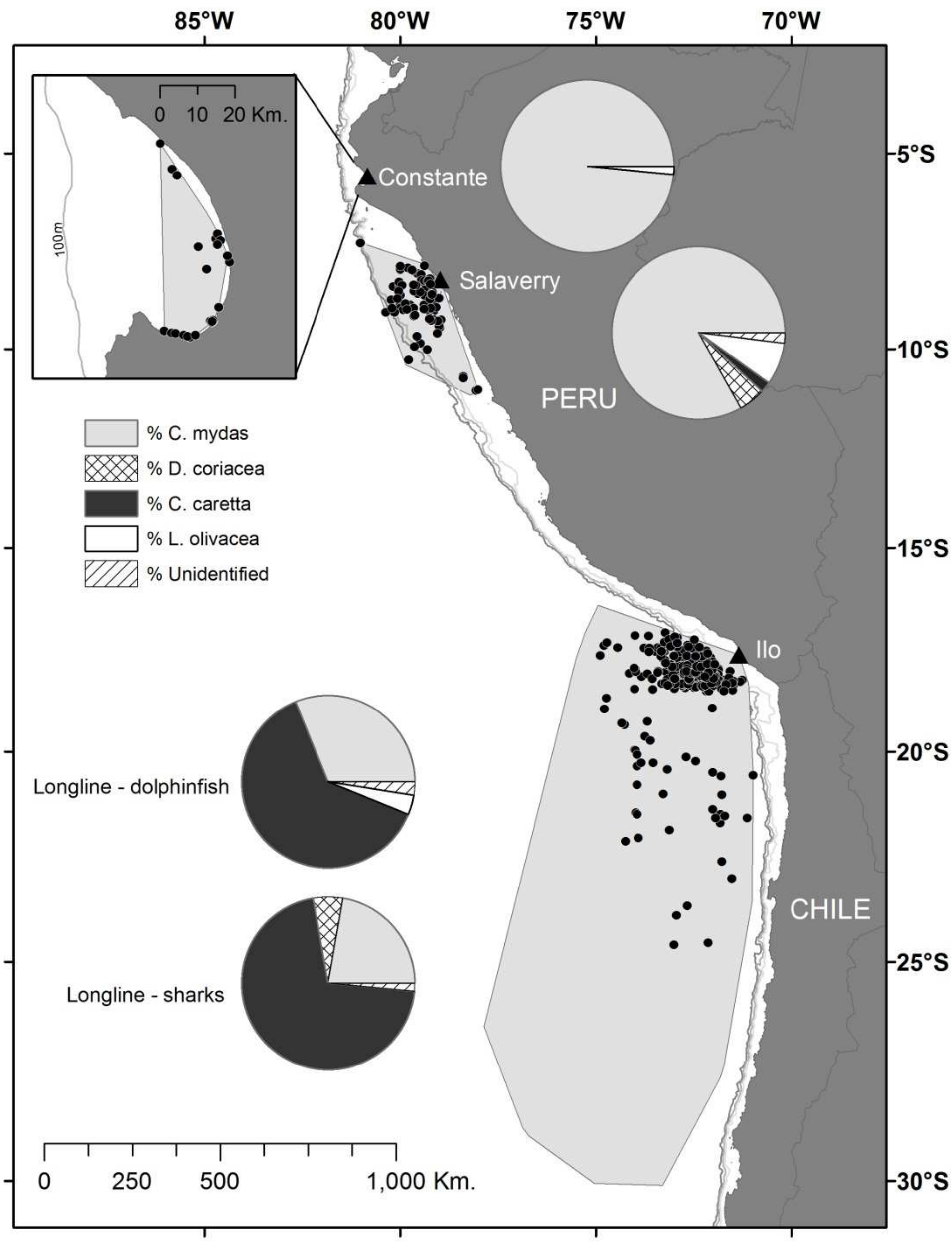
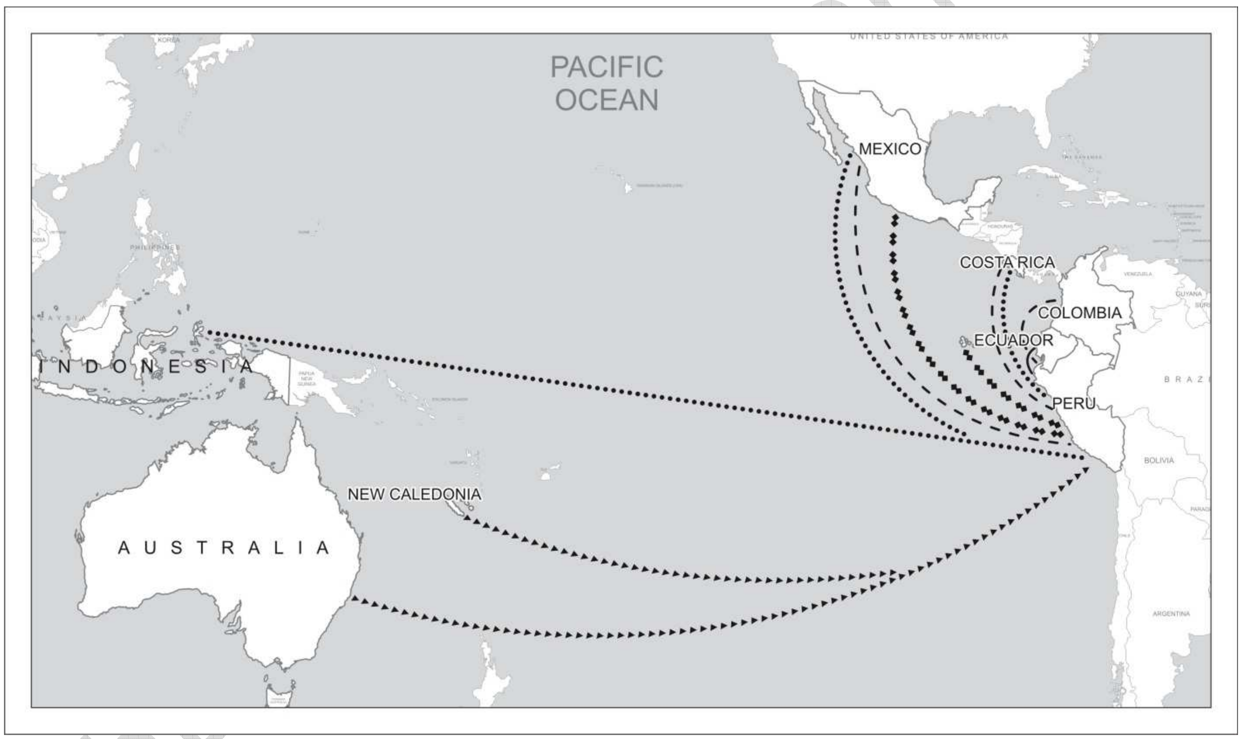


Figure 2. Schematic view of linkages of turtles breeding stocks to Peruvian foraging grounds. Leatherback turtles (●): western and eastern Pacific rookeries (Eckert and Sarti, 1997; Shillinger et al. 2008; Dutton et al. 2010). Olive ridleys (▬ ▬): Colombia, Mexico and Costa Rica (Zeballos & Arias-Schreiber, 2001; Velez-Zuazo & Kelez 2010). Green turtles (♦♦): Galapagos Islands and Mexico (Hays-Brown & Brown, 1982; Velez-Zuazo & Kelez, 2010). Loggerhead turtles (►►): Australia and New Caledonia (Alfaro-Shigueto et al. 2004; Boyle et al. 2009). Hawksbill turtles (▬): Mainland Ecuador as the closest nesting rookery for the species.



Appendix S1. Supplemental methods

Equation to estimate Bycatch per unit of effort BPUE and mean estimated catch of turtles

$$B_{month} = BPUE_{month} * S_{positive} * S_{month}$$

$$B_{total} = \Sigma\, B_{month}\ \text{year 1} + B_{month}\ \text{year 2} + \ldots / Y$$

Where

$BPUE_{month}$ = Bycatch per unit of effort per month

$S_{positive}$ = proportion of monthly bycatch-positive sets

S_{month} = sets per month (from shore based observers data)

B_{month} = monthly bycatch estimate

B_{total} = mean annual bycatch estimate

Y = Number of years sampled

Table S1. Other units of BPUE: Mean BPUE.$trip^{-1}$, BPUE.km^{-1} for bottom set nets and driftnets. BPUE.$trip^{-1}$ and BPUE.10^3 $hooks^{-1}$ for dolphinfish and sharks longliners. Confidence intervals and low and high values are given for all turtle species (overall) and by species.

Fishery	Mean	SD	Low	High
Bottom set nets.$trip^{-1}$				
Overall spp.	2.11	1.50	0.91	3.32
C.mydas	2.10	1.59	0.88	3.32
L.olivacea	0.01	0.04	0.00	0.05
Bottom set net.km^{-1}				
Overall spp.	0.80	0.61	0.33	1.27
C.mydas	0.66	0.49	0.28	1.04
L.olivacea	0.01	0.00	0.00	0.02
Driftnets.$trip^{-1}$				
Overall spp.	1.71	1.25	0.92	2.51
C.mydas	1.46	1.16	0.71	2.20
D.coriacea	0.06	0.13	0.00	0.14
L.olivacea	0.11	0.12	0.03	0.19
Driftnet.km^{-1}				
Overall spp.	0.13	0.08	0.08	0.18
C.mydas	0.11	0.08	0.06	0.16
D.coriacea	0.00	0.01	0.00	0.01
L.olivacea	0.01	0.01	0.00	0.01
Longline (dolphin fish).$trip^{-1}$				
Overall spp.	4.38	2.27	0.78	7.99
C.mydas	2.61	1.41	0.36	4.85
C.caretta	3.61	1.39	1.41	5.82
L.olivacea	1.00	0.72	0.00	2.15
Longline (dolphin fish).10^3 $hooks^{-1}$				
Overall spp.	1.01	0.56	0.12	1.91
C.mydas	0.32	0.29	0.00	0.79
C.caretta	0.63	0.34	0.10	1.16
L.olivacea	0.03	0.04	0.00	0.09
Longline (shark).$trip^{-1}$				
Overall spp.	2.30	0.80	1.63	2.97
C.mydas	1.71	0.85	1.00	2.42
C.caretta	2.56	0.81	1.88	3.24
D.coriacea	0.51	0.65	0.00	1.06
Longline (shark).10^3 $hooks^{-1}$				
Overall spp.	0.47	0.24	0.27	0.67
C.mydas	0.11	0.08	0.05	0.18
C.caretta	0.33	0.21	0.16	0.51
D.coriacea	0.02	0.03	0.00	0.04
L.olivacea	0.01	0.01	0.00	0.02

Table S2. BPUE.set^{-1} values given per month by fishery and by species, number of sets (N.sets) and number of sets with bycatch (set +).

			C. mydas			*C.caretta*			*D. coriacea*			*L. olivacea*		
Fishery	Month	N.sets	Mean	SD	Set +	Mean	SD	Set +	Mean	SD	Set +	Mean	SD	Set +
Bottom set net	Jan	7	1.8	1.3	5.0	0.0		0.0	0.0		0.0	0.0	-	0.0
	Feb	-	1.8	-	-	0.0		0.0	0.0		0.0	0.0	-	-
	Mar	8	1.8	0.5	4.0	0.0		0.0	0.0		0.0	1.0	-	1.0
	Apr	2	0.0	-	0.0	0.0		0.0	0.0		0.0	0.0	-	0.0
	May	2	1.0	-	1.0	0.0		0.0	0.0		0.0	0.0	-	0.0
	Jun	2	2.0	1.4	2.0	0.0		0.0	0.0		0.0	0.0	-	0.0
	Jul	-	1.5	-	-	0.0		0.0	0.0		0.0	0.0	-	-
	Aug	-	1.5	-	-	0.0		0.0	0.0		0.0	0.0	-	-
	Set	1	1.0	-	1.0	0.0		0.0	0.0		0.0	0.0	-	0.0
	Oct	6	4.7	5.5	3.0	0.0		0.0	0.0		0.0	0.0	-	0.0
	Nov	5	4.3	3.5	3.0	0.0		0.0	0.0		0.0	0.0	-	0.0
	Dec	6	5.7	3.8	3.0	0.0		0.0	0.0		0.0	0.0	-	0.0
Driftnet	Jan	26	1.3	0.8	6.0	0.0		0.0	0.0		0.0	1.0	-	1.0
	Feb	38	1.5	0.7	10.0	0.0		0.0	0.0		0.0	0.0		0.0
	Mar	57	1.6	1.1	16.0	0.0		0.0	1.0	-	1.0	1.0	-	2.0
	Apr	57	1.0	-	9.0	0.0		0.0	1.0	-	1.0	1.0	-	1.0
	May	55	1.2	0.4	10.0	0.0		0.0	1.0	-	3.0	0.0		0.0
	Jun	15	1.0	-	2.0	1.0	-	1.0	0.0		0.0	0.0		0.0
	Jul	23	1.0	-	8.0	0.0		0.0	0.0		0.0	0.0		0.0
	Aug	31	1.0	-	2.0	0.0		0.0	0.0		0.0	1.0	-	1.0
	Set	24	1.0	-	3.0	0.0		0.0	0.0		0.0	0.0		0.0
	Oct	35	1.0	-	3.0	0.0		0.0	0.0		0.0	1.0	-	1.0
	Nov	34	1.0	-	2.0	0.0		0.0	0.0		0.0	1.0	-	1.0
	Dec	9	0.0	-	0.0	0.0		0.0	0.0		0.0	0.0		0.0
Longline (dolphin fish)	Jan	221	1.4	0.7	37.0	1.3	0.6	55.0	0.0		0.0	1.0	-	2.0
	Feb	124	1.6	0.9	34.0	1.4	0.7	45.0	0.0		0.0	1.0	-	4.0
	Mar	62	1.0	-	2.0	1.3	0.5	67.0	1.0	-	1.0	0.0		0.0
	Dec	212	1.3	0.5	23.0	1.8	1.5	75.0	0.0		0.0	1.0	-	10.0
Longline (shark)	Apr	63	1.3	0.5	4.0	1.1	0.5	16.0	1.0	-	3.0	1.0	-	1.0
	May	107	1.3	0.5	6.0	1.0	-	8.0	1.0	-	4.0	0.0		0.0
	Jun	89	1.3	0.6	3.0	1.1	0.3	16.0	0.0		0.0	0.0		0.0
	Jul	79	1.0	-	3.0	1.7	0.9	9.0	1.0	-	2.0	0.0		0.0
	Aug	123	0.0	-	0.0	1.2	0.4	10.0	0.0		0.0	0.0		0.0
	Set	58	1.0	-	5.0	1.0	-	8.0	0.0		0.0	0.0		0.0
	Oct	104	1.1	0.3	12.0	1.3	0.8	21.0	1.0	-	2.0	0.0		0.0
	Nov	91	1.0	-	6.0	1.5	1.0	23.0	0.0		0.0	1.0	-	1.0

Chapter IV: Untangling the impacts of nets in the Pacific: use of rapid assessments of turtle bycatch to set conservation priorities in small-scale fisheries

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Abstract

There is growing global concern regarding the incidental capture, or bycatch, of marine fauna, such as sea turtles, by small-scale fisheries. The nations of the southeastern Pacific Ocean hold large fisheries that are important sources of food and livelihoods for millions of people. Using survey questionnaires to assess the impact on sea turtles of small-scale gillnet fisheries in Ecuador, Peru and Chile we identified priority areas for future conservation work. A total of 793 surveys from 43 index small-scale fishing ports were obtained for these three countries: Ecuador: n=407, 7 ports; Peru: n=342, 30 ports; Chile: n=44, 6 ports). The survey coverage per harbour varied but was, on average, 31.1% for Ecuador, 37.0% for Peru and 62.7% for Chile. When the survey data for the three countries are combined with data on gillnet fleet sizes the resulting estimate of annual bycatch in the study harbours is 57 653 turtles, with 35.8% (20 658 turtles) estimated as fatal take. Based on these results we highlight geographic areas of key concern in which future conservation efforts are needed. We identify opportunities for conservation progress, demonstrate the effectiveness of survey questionnaires at assessing sea turtle bycatch and provide insights into the complexity of human use of sea turtles. The latter is particularly important given the conservation status of certain regional turtle populations and due also to the magnitude of small-scale fisheries in the region and their central importance to livelihoods in many coastal communities.

Introduction

Incidental take, or bycatch (Davies et al. 2009), poses a major threat to marine vertebrates at a global level (Anderson et al. 2011; Baum et al. 2003; Lewison et al. 2004). This is certainly the case 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). However sea turtle bycatch also occurs in small-scale fisheries (Chapter 3; Lewison and Crowder 2007; Peckham et al. 2007).

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 challenges to implementing 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 the magnitude of the bycatch issue (D'Agrosa et al. 2000; López et al. 2003).

Survey questionnaires, group discussions and semi-directive interviews have been methods used by social scientists to assess both terrestrial and marine biodiversity (Huntington 2000; Jones et al. 2008; White et al. 2005). These techniques are based on the use of local ecological knowledge LEK (Olsson and Folke 2001) as a useful source of information, especially when the ability to use other sampling methods is limited (e.g. cost prohibitive, extensive geographic regions) (Anadon et al. 2008).

In the Pacific Ocean, sea turtle populations extend over large spatial scales. For the southeastern Pacific, 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 (Dutton et al. 2010; Eckert and Sarti 1997; Shillinger et al. 2008) as well as the western Pacific (Papua New Guinea, Indonesia and Solomon Islands) (Dutton et al. 2010). Loggerhead turtles

Caretta caretta foraging in Peru and Chile originate in Australia and New Caledonia (Alfaro-Shigueto et al. 2004; Boyle et al. 2009). Olive ridley turtles *Lepidochelys olivacea* inhabiting Peruvian waters, originate from Costa Rica, Colombia and Mexico (Velez-Zuazo and Kelez 2010; Zeballos and Arias-Schereiber 2001). The hawksbill turtle *Eretmochelys imbricata* is relatively rare in Peru, but when found is likely to be linked to the closest rookery in Ecuador (Chapter 3; Gaos et al. 2010). These inter-relations highlight how bycatch occurring in foraging areas in the southeastern Pacific can have wide ranging detrimental impacts (Chapter 3).

The use of regional management units RMUs has been described as a means to define priorities for sea turtle conservation (Wallace et al. 2010a). Two of the eleven most endangered putative RMUs are located in the eastern Pacific: those for leatherback and hawksbill turtles (Wallace et al. 2011), stressing once again the importance of the eastern Pacific region for turtle conservation.

Empirical information suggests that within small-scale fisheries, gillnets play a major role in the bycatch of sea turtles (Echwikhi et al. 2010; Eckert and Sarti 1997; Wallace et al. 2010b). Levels of fishing effort of small-scale fisheries in the eastern tropical Pacific are among the highest worldwide (Stewart et al. 2010). Within this vast region, the waters of Ecuador, Peru and Chile, form the Major Fishing Area 87 (FAO Major Fishing Areas). Gillnets are in widespread use, especially in Ecuador by 1999, 84.7% of 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). Also in Peru, where, by 2005 the number of small-scale fishing vessels was estimated as 9 667 run by 37 727 fishers, gillnets are the main fishing gear used at the small-scale fisheries (Estrella and Swartzman 2010), and effort has been estimated at ca. 100,000 km of nets deployed each year (Chapter 1). 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 very limited and includes a swordfish *Xiphias gladius* fishery currently categorized as experimental (DecretoNo.657 2002).

Landing sites for these three countries total ca. 500 ports in Ecuador (Solis-Coello and Mendivez 1999), 106 ports in Peru (Chapter 1) and 230 landing sites in Chile (Bernal et al. 1999). Here, with a rapid survey approach using survey instruments modified from those developed and trialed by Project Global (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 in the southeastern Pacific Ocean region.

Materials and methods

Survey design and planning

Surveys were conducted in Ecuador, Peru and Chile (Figure 1; Supplementary Table 1). Surveys were completed in Ecuador and Chile from August 2010 to November 2010 and in Peru from November 2010 to March 2011. Survey forms were tested in the three countries prior to full-scale implementation to help avoid ambiguous terms and to ensure wording would mean the same in the three countries. 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 but 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 fishing captains. In Ecuador and Chile, gillnets were separated into surface nets (made of multifilament or monofilament material), midwater nets, trammelnets and bottom set nets whilst in Peru, surveys addressed gillnets as a single category.

Survey coverage was estimated based upon the number of surveys completed in a given port and the number of vessels per fishing gear estimated to be operating in that port. The coverage for individual countries was estimated by taking the average percent coverage for all ports and fisheries of each nation.

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 material for survey form). Surveys were initiated by specifying the purpose of the surveys 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 an 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 Chapter 3 (i.e. released live, dead at capture or retained to be commercialized, used as food, bait or for medicinal purposes). Other bycatch taxa such as marine mammals (sealions and cetaceans) and seabirds were also included. Questions also enquired as to the interviewee's knowledge of legislation pertaining to marine turtles. The final few questions were completed by the interviewer and were an assessment of the respondent's degree of confidence and honesty during interview.

Fisheries description

As in Chapter 1, we obtained general information about each port from the local officers of the National Marine Authority or the local Ministry of Fisheries representative and from the 'beach sergeant', a local authority present at each fishing port. This information included the total number of boats and the number of boats using gillnets at each sample site. Supplemental Table 1 summarizes this information per port and per country.

Bycatch estimates

For each site and for the three countries, we calculated bycatch estimates by fishery, based on the median survey responses for bycatch per year (e.g. 0 turtles per year, 1-3 turtles per year, 4-10 turtles per year). These data were scaled according to the fleet size using the same gear for a given port to obtain the estimate of annual turtle bycatch. Using data gathered on the fate of turtles we were then able to estimate the total take (herein 'take' is defined as the number of turtles killed as a consequence of fisheries). Turtle take is obtained from captured dead individuals and those retained to be sold, eaten or otherwise used.

Results

A total of 793 surveys from 43 index fishing ports were obtained for the three countries (Ecuador: n=407, 7 ports; Peru: n=342, 30 ports; Chile: n=44, 6 ports; Figure 1). Survey coverage by gear across the ports varied between 3.8-100% but was on average 31.1% for Ecuador, 37.0% for Peru and 62.7% for Chile. In general fishermen who declined to participate were few (125), constituting 15.8% of all skippers approached (31 in Ecuador, 94 in Peru and 0 in Chile). Supplemental Tables 2 and 3 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 was reported.

Gillnet fisheries magnitude

There was a general latitudinal pattern to the abundance and prevalence of gillnet fishing with numbers much higher in Ecuador than Peru which were, in turn, higher than those in Chile (Figure 1, Supplemental Table 1). These patterns are driven by both the number of fishing vessels per port (Spearman $R_s=0.308$: $p=0.045$) and the proportion of vessels using gillnets (Spearman $R_s=0.359$: $p=0.018$) correlated with latitude.

Bycatch occurrence in the region

Bycatch was broadly reported throughout the region for seabirds, marine mammals and sea turtles. (Table 1 and Supplementary Table 4).

Seabirds

Seabird bycatch in Ecuador was reported in 42.9% of fishing ports (by 4.9% of respondents in those harbours). In Peru, seabirds were reported as being caught at 86.7% of the Peruvian ports (by 28.4% respondents in those harbours). In Chile 66.7% of ports (20.5% of respondents in those harbours) reported seabird bycatch (Supplementary Table 4).

Marine mammals

Marine mammal bycatch was reported from all Ecuadorian ports and all but one Peruvian harbor (59.2% and 49.1% of interviewees at these sites in Ecuador and Peru, respectively). In Chile, the reported level was considerably lower with only 67% of ports (63.6% interviews at these sites) responding affirmatively (Supplemental Table 4).

Turtle bycatch

The vast majority (83.9%) of respondents reported having at least some level of sea turtle bycatch and this did not vary markedly by country (Ecuador: 82.7%; Peru: 82.6%; Chile fishermen 86.5%).

Turtle species distribution

There were clear differences in the relative frequencies at which the sea turtle species were recorded as captured (Supplemental Table 4). The most commonly noted species bycaught in Peru and Chile was the green turtle which was captured across the study region. Olive ridley turtles were the most commonly reported species in Ecuador, although it was also reported captured 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. Hawksbill turtle captures were reported in low numbers in Ecuador and Peru only.

Regional turtle take levels

Survey data allow us to model the total take of marine turtles and their fate per harbour (Table 2, Figure 2). It is clear that the magnitude of turtle take in Ecuador is very high with 13 994 turtles taken per year in the 7 study harbours, although an estimated two thirds (67.2%) are released alive. Turtle consumption was acknowledged in 100% of Ecuadorian harbours. Across the 30 Peruvian study harbours, although marine turtle captures were still widespread, the magnitude was lower than Ecuador with an estimated total of 6 620 turtles taken, with 55.3% being released alive. Turtle consumption was reported for 76.1% of Peruvian harbours. Captures were lower again in Chilean fisheries, with surveys in 6 harbours indicating an estimated 238 turtles captured annually, with 81.5% released alive. No turtle consumption was reported in Chile.

When data from three countries are combined the resulting estimate of annual turtle incidental captures is 57 653 turtles, with 35.8% (20 658 turtles) taken as a consequence of net fishery activity (Table 2).

There was, in general, quite a high level of awareness of the protected status of marine turtles (Ecuador 71.3%, Peru 77.9% Chile 64.9% of interviewees), although this varied from site to site (Supplementary Table 4).

The honesty score rates obtained based on the level of reliability of the fishermen interviewed varied from 66.7 % for Huarmey port in Peru, to a 100 % obtained for most of the fisheries (90 %) at the three countries (Supplementary Table 4).

Discussion

There is a recent and 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 provide this information for the southeastern Pacific Ocean by developing a first rapid regional assessment of turtle bycatch in small-scale gillnet fisheries. Study results indicate that the annual take from bycatch of five species of turtles is in the tens of thousands. To further contextualize our data, it is important to note that we estimate that the vessels in the survey harbours constitute 50%, 40.8% and 87.2% of the small-scale gillnet fishing fleet in Ecuador, Peru and Chile, respectively (Barria et al. 2006; Estrella 2007; Martinez et al. 1991). As a result, it is likely that bycatch in this region is one of the largest in the world, particularly Ecuador and Peru. For example, numbers of turtles taken appear to dwarf that of the entire Mediterranean, a major bycatch hotspot, where 23 000 turtles were estimated as the bycatch produced by small-scale fisheries using set nets (Casale 2011).

Surveys as a tool to assess turtle bycatch in small-scale fisheries

Although limitations of LEK methods are acknowledged (Huntington 2000; White et al. 2005), they 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 in marine turtles. Similar studies have also has been used in several other geographic regions (Carreras et al. 2004; Godley et al. 1998; Moore et al. 2010). The validation of results obtained from LEK methods with other empirical research has been highly 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) (Álvarez de Quevedo et al. 2012; Carreras et al. 2004). While previous bycatch studies in gillnets in the southeast Pacific region are currently largely limited to Peru (Chapter 3), when comparing previous results with two ports where survey questionnaires were also applied, similar estimates of both bycatch and the take were obtained (Constante: 368 using direct observers, 286 in this study; Salaverry: 996 using direct observers, 924 in this study).

Species distribution

Information obtained from these surveys aligned well with existing empirical information on species distributions in the southeast Pacific i.e. olive ridley turtles are present in tropical waters off Ecuador to Peru (Chapter 3; Largacha et al. 2006) and becoming rare towards the south; green turtles are distributed from Ecuador to Chile (Chapter 3; Donoso and Dutton 2010; Largacha et al. 2006); leatherback turtles are present in the entire region (Shillinger et al. 2008), loggerhead turtles from Ecuador to Chile (Alava 2008; Chapter 2; Donoso and Dutton 2010) and hawksbill turtles are rare and perhaps even rarer with increasing latitude (Alfaro-Shigueto 2010a; Gaos et al. 2010).

Spatial use of gillnets in the region

Due to their simplicity and relatively low cost, gillnets have become 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, 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 (DecretoNo.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 new coastal net fishery for hake employing surface monofilament has recently developed: however, there are as of now no reports of turtle bycatch (ProyectoFIP2009-23 2011).

Setting of regional priorities

Our work has highlighted several Ecuadorian net ports as important potential sources of sea turtle bycatch. However, captures of leatherback and loggerhead turtles in all three nations were reported and thus should not be overlooked, especially if other fisheries also have an impact on these particular threatened stocks (Donoso and Dutton 2010; Frazier and Brito Montero 1990).

Sea turtles as marine bushmeat

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 ((Chapter 3). This situation, in which protective legislation is acknowledged but ignored, likely relates to the socio-economic characteristics of fishing communities themselves (e.g. impoverished, highly dependent on fishing for food, limited environmental information). Given that most fishermen surveyed reported that fisheries are their main economic activity, these socio-economic concerns should be factored into future conservation projects with coastal communities which seek to understand the causes and potential solutions to sea turtle catch and consumption.

Opportunities for conservation

From the total estimated turtle bycatch, a great many are released back to the sea, likely causing subsequent net damage or lost fishing time. This highlights an opportunity for the use of mitigation measures in net fisheries (Gilman et al. 2010) such as increasing net visibility (Wang et al. 2010), reducing net profile (Price and Van Salisbury 2007), using buoyless float lines (Gilman et al. 2010), tiedown modification (Eckert et al. 2008); or promotion of the use of tools and guidelines to safely release animals (NMFS-SEFSC 2008). Apart from reducing negative impacts to sea turtles, 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, mostly from Peru, how to avoid fishing in areas with high bycatch and how to more safely release bycatch (Chapter 5).

Conclusions

The use of questionnaire-based surveys has been shown here to be a useful tool for assessing turtle bycatch in small-scale fisheries and a method capable of overcoming some of the logistical and funding constraints of researching such fisheries.

Recent worldwide estimations of turtle bycatch are ca. 85,000 turtles for circa two decades, although this is likely 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). The putative RMU of the eastern Pacific has been identified as one area of conservation priority for turtles (Wallace et al. 2010a). Our results support this high priority designation given the high turtle mortality from fisheries and the presence of highly threatened stocks such as the loggerhead, leatherback and hawksbill turtles.

Small-scale fisheries are the main protein provider for an estimated 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 ca. 1 million small-scale fishermen (CPPS 2003) and there is therefore a clear need to identify conservation opportunities that promote the long-term sustainability of these fisheries, both for the communities they serve and the marine fauna with which they interact.

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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 numbers of animals incidentally captured, released alive and taken, is also provided by country (presented in detail in Table 2).

Taxa	Ecuador		Peru		Chile	
	% Harbours	% Surveys	% Harbours	% Surveys	% Harbours	% 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
Bycatch	42706.9		14813.3		237.8	
Released	28712.8		8192.6		194.3	
Taken	13994.1		6620.7		43.5	

Table 2. Estimates of turtle take from surveys by port and country (north to south) and fishing gear (S = surface gillnets, M = surface monofilament, Md = midwater nets, T = trammelnets, B = bottomset nets and G = gillnets). Data obtained by combining median of the low and high estimates from surveys with fishing effort in the port (given in number of boats) and the final fate of the bycatch (Released alive, Discard dead, Sold, Eat, Medicine use). T% = percentage and numbers (Take) of mortality estimated from adding turtles retained and those discarded dead.

Port	Gear	Bycatch	Released	Dead	Sold	Eat	Medicine	T%	Take
Ecuador									
Esmeraldas	S	2361.2	1291.8	1024.8			44.6	43.4	1069.4
	M	52.0	34.7	17.3				33.3	17.3
	T	35.0	17.5	17.5				50.0	17.5
	B	220.0	122.2	97.8				44.4	97.8
Subtotal		2668.2	1466.2	1157.4			44.6	0.5	1202.0
Manta	S	9275.4	6090.2	2997.8		187.4		34.3	3185.2
	M	30.0	22.5	7.5				25.0	7.5
	T	124.0	62.0	62.0				50.0	62.0
	B	0.0	0.0					50.0	0.0
Subtotal		9429.4	6174.7	3067.3		187.4		0.3	3254.7
Pto.Lopez	S	2293.3	1490.6	649.7		153.0		35.0	802.7
	M	315.0	225.0	67.5		22.5		28.6	90.0
	T	105.0	52.5	52.5				50.0	52.5
	B	530.0	397.5	132.5				25.0	132.5
Subtotal		3243.3	2165.6	902.2		175.5		0.3	1077.7
Sta.Rosa	S	18257.5	13419.3	3901.6		936.6		26.5	4838.2

	M	83.4	54.2	29.2			35.0	29.2
	T	42.0	21.0	21.0			50.0	21.0
	B	44.0	33.0	11.0			25.0	11.0
Subtotal		18426.9	13527.5	3962.8	936.6		0.3	4899.4
Anconcito	S	717.1	478.1	239.0			33.3	239.0
	M	766.9	524.7	201.8	40.3		31.6	242.2
	T	133.8	66.9	58.5	8.4		50.0	66.9
	B	147.5	105.4	42.1			28.6	42.1
Subtotal		1765.3	1175.1	541.5	48.7		0.3	590.2
Chanduy	S	124.0	124.0				0.0	0.0
	M	745.3	416.5	285.0	43.8		44.1	328.8
	T	787.5	350.0	350.0	87.5		55.6	437.5
	B	310.0	62.0	248.0			80.0	248.0
Subtotal		1966.8	952.5	883.0	131.3		0.5	1014.3
Pto.Bolivar	S	273.5	136.7	121.5	15.2		50.0	136.8
	M	3200.0	2240.0	896.0	64.0		30.0	960.0
	T	1225.0	612.5	612.5			50.0	612.5
	B	508.5	262.0	215.7	30.8		48.5	246.5
Subtotal		5207.0	3251.2	1845.7	110.0		178.5	1955.8
Subtotal Ec		42706.9	28712.8	12359.9	1589.5	44.6	0.3	13994.1
Peru								
Pizarro	G	2024.9	736.3	782.4	506.2		63.6	1288.6

Zorritos	G	1113.6	651.9	353.1		108.6		41.5	461.7
Cancas	G	105.0	84.0	10.5		10.5		20.0	21.0
Mancora	G	2759.4	862.3	1724.6	86.2	86.2		68.8	1897.1
Talara	G	14.0	10.0			4.0		28.6	4.0
Paita	G	1240.0	1240.0					0.0	0.0
Constante	G	286.0	76.3		76.3	133.5		73.3	209.7
Delicias	G	45.0	22.5	22.5				50.0	22.5
Parachique	G	216.6	162.5	27.1		27.1		25.0	54.1
Bayovar	G	817.5	654.0				163.5	20.0	163.5
Pimentel	G	77.5	77.5					0.0	0.0
San Jose	G	703.0	461.0	11.5		230.5		34.4	242.0
Malabrigo	G	15.8	15.8					0.0	0.0
Salaverry	G	924.4	561.3	231.1		132.1		39.2	363.1
Chimbote	G	293.8	207.4	34.6		51.8		29.4	86.4
Culebras	G	14.0	7.6		1.3	5.1		45.5	6.4
Supe	G	480.0	240.0	120.0		120.0		50.0	240.0
Huarmey	G	70.0	35.0	23.3		11.7		50.0	35.0
Huacho	G	103.6	79.7	15.9		8.0		23.1	23.9
Ancon	G	725.0	414.3	103.6		207.1		42.9	310.7
Callao	G	90.0	64.3			25.7		28.6	25.7
Pucusana	G	717.3	377.5			339.8		47.4	339.8
Tbo.Mora	G	216.8	104.9	14.0	7.0	90.9		51.6	111.9
Sn.Andres	G	1404.8	819.5	175.6		409.7		41.7	585.3

Marcona	G	29.2	11.0			18.2		62.5	18.2
Atico	G	0.0	0.0			0.0		0.0	0.0
Planchada	G	70.0	35.0			35.0		50.0	35.0
Matarani	G	30.8	30.8					0.0	0.0
Ilo	G	225.3	150.2	25.0		50.1		33.3	75.1
Morro	G	0.0	0.0					0.0	0.0
Subtotal Pe		14813.3	8192.6	3674.7	170.8	2611.8	163.5	0.4	6620.7
Chile									
Caldera	S	28.6	28.6					0.0	0.0
Coquimbo	S	12.0	12.0					0.0	0.0
Quintero	S	4.0	4.0					0.0	0.0
Valparaiso	S	19.3	19.3					0.0	0.0
Sn.Antonio	S	77.0	38.5	38.5				50.0	38.5
	Md	12.5	7.5	5.0				40.0	5.0
Lebu	S	84.4	84.4					0.0	0.0
Subtotal Ch		237.8	194.3	43.5	0.0	0.0	0.0	0.2	43.5
Total SUM		57758.0	37099.7	16078.2	170.8	4201.2	208.1	0.4	20658.3

Figure 1. Distribution of gillnet use at small-scale ports 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).

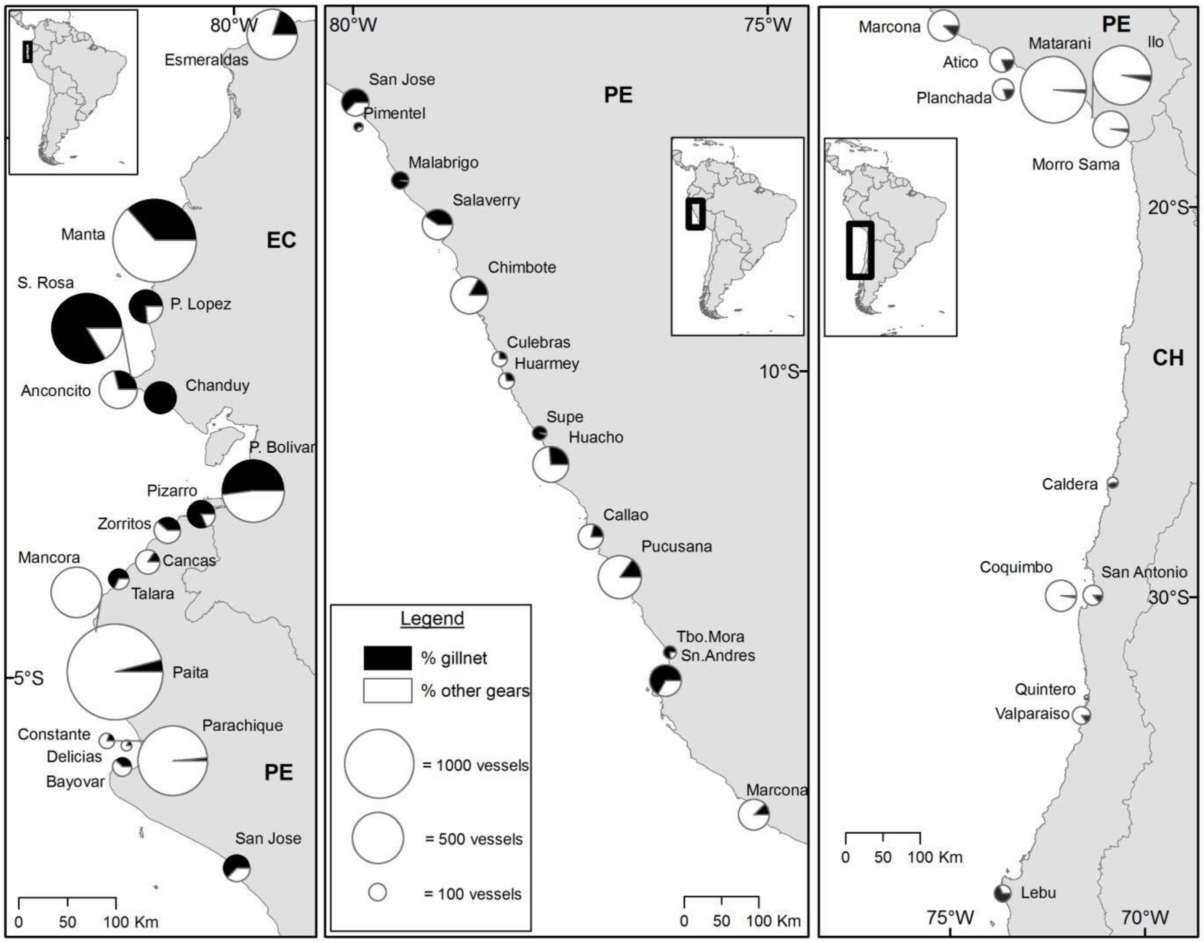
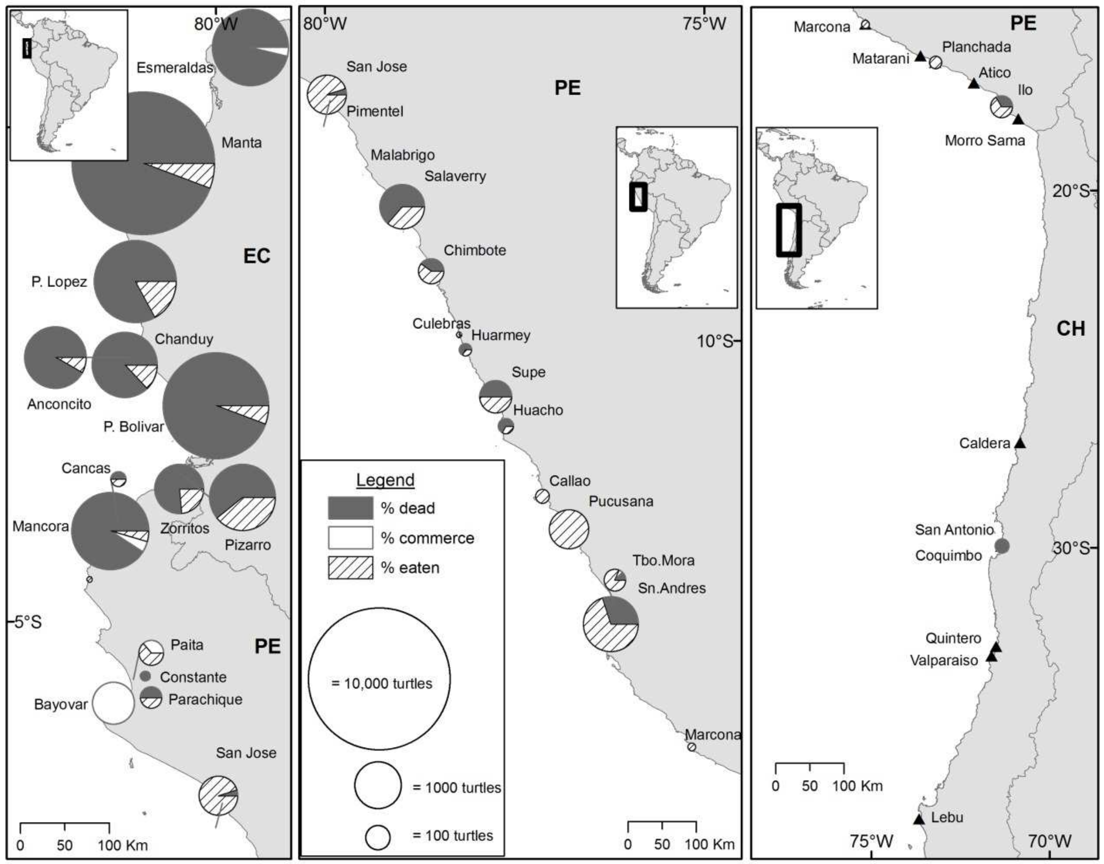


Figure 2. Distribution of estimated bycatch take caused by gillnets from Ecuador to Chile. From left to right (north to south: EC=Ecuador, PE=Peru, CH=Chile), circle size indicate the magnitude of the take in number of turtles, shaded area show turtles found dead, blanks show turtles commercialized and stripes were used for turtles that were eaten (from Table 2). Santa Rosa port does not show, values showed in Table 2.



Supplemental Table 1. Summary of ports surveys, from North to South, divided by country. Gillnet composition (S = surface gillnets, M = surface monofilament, Md = midwater nets, T = trammelnets, B = bottomset nets and G = gillnets), in numbers and in percentages from the total of small-scale vessels, number and percentage of surveys covered, and declined number and percentage of surveys. Target species for each fishery from Supplemental Table 2.

Port	Boats	Gillnets	Gear	% Fleet	Surveys	% Coverage	Declined	% Declined	Target
Ecuador									
Esmeraldas	545	76	S	13.9	29	38.2	4	9.8	7,1,50,47
		20	M	3.7	6	30.0			37,22,40,3
		5	T	0.9	1	20.0			59,22,44,3
		8	B	1.5	5	62.5			9,44,37,48
Manta	1500	495	S	33.0	65	13.1	4	5.6	6,1,50,8,28
		15	M	1.0	3	20.0			31,22,2,24
		8	T	0.5	2	25.0			60,9,6,1
		30	B	2.0	1	3.3			31,37
Pto.Lopez	255	80	S	31.4	39	48.8	7	13.0	6,47,1,50,63
		70	M	27.5	10	14.3			12,44,61,49,37,22
		15	T	5.9	2	13.3			44,1,41
		30	B	11.8	3	6.7			61,37,1,63,50,44
Sta.Rosa	1100	880	S	80.0	92	10.5	5	4.5	6,63,1,50
		14	M	1.3	14	100.0			37,44,26,14,61,3,33
		6	T	0.5	2	33.3			16
		22	B	2.0	3	13.6			53,37,26,61
Anconcito	315	20	S	6.3	8	40.0	2	5.9	62,31,6,50,63,1,29,44,51
		45	M	14.3	13	28.9			16,31,37,32,43,50,62,29
		10	T	3.2	8	80.0			16,31,32,22
		15	B	4.8	5	33.3			33,17,32,37,16
Chanduy	238	8	S	3.4	2	25.0	1	3.3	6,50,47
		140	M	58.8	19	13.6			16,37,22,44,62,29,31,58,49

		70	T	29.4	4	5.7			16,22,37,44
		20	B	8.4	5	25.0			37,32,44,31
Pto.Bolivar	855	10	S	1.2	10	100.0	8	12.1	1,72,28,50,62,6,22,54,14,58,3
		350	M	40.9	35	10.0			14,16,48,62,58,22,37
		50	T	5.8	3	6.0			14,44,58,3,59,22
		35	B	4.1	18	51.4			16,14,22,37
Peru									
Pizarro	174	142	G	81.6	25	17.6	16	64.0	15,4,45,13,28,42,62
Zorritos	150	59	G	39.3	24	40.7	0	0.0	1,42,64
Cancas	127	20	G	15.7	8	40.0	0	0.0	25,14,62,42,15,38,2
Mancora	96	65	G	67.7	21	32.3	0	0.0	1,28,68,67
Talara	554	5	G	0.9	5	100.0	9	180.0	1,28,38,13,14,69
Paita	1980	80	G	4.0	3	3.8	6	200.0	34,14,19
Constante	50	10	G	20.0	10	100.0	0	0.0	57,55,33
Delicias	25	4	G	16.0	2	50.0	2	100.0	14,69
Parachique	1050	15	G	1.4	8	53.3	2	25.0	14,19,34,57,55
Bayovar	80	30	G	37.5	4	13.3	0	0.0	34,14
Pimentel	18	12	G	66.7	12	100.0	0	0.0	55,69,14,33,19,67
San Jose	160	100	G	62.5	50	50.0	0	0.0	69,14,55,19
Malabrigo	65	63	G	96.9	28	44.4	0	0.0	35,19,14,33,34
Salaverry	200	81	G	40.5	17	21.0	1	5.9	19,35,14,64,67,69,55
Chimbote	300	50	G	16.7	12	24.0	29	241.7	69,28,70,13,35,19,18,10
Culebras	48	12	G	25.0	6	50.0	2	33.3	35,46,11,21
Supe	42	40	G	95.2	6	15.0	0	0.0	35,46,28,70,36,55,7
Huarmey	55	15	G	27.3	3	20.0	3	100.0	11,35,46,23
Huacho	279	74	G	26.5	10	13.5	2	20.0	46,35,28,47,55,7
Ancon	200	50	G	25.0	4	8.0	7	175.0	7,34,11,1,28
Callao	134	28	G	20.9	7	25.0	0	0.0	11,36,65,66,35,52,46,34
Pucusana	400	60	G	15.0	11	18.3	4	36.4	7,47,28,46,65,34,66,35
Tbo.Mora	35	27	G	77.1	16	59.3	1	6.3	57,56,69,5,35,5,39,11,14

Sn.Andres	214	143	G	66.8	17	11.9	5	29.4	7,55,23,34,46,11,30,28
Marcona	208	25	G	12.0	6	24.0	5	83.3	7,13,20,11,34,52
Atico	130	25	G	19.2	1	4.0	0	0.0	13,52,11,30
Planchada	101	20	G	19.8	2	10.0	0	0.0	23,7,69,55
Matarani	940	15	G	1.6	15	100.0	0	0.0	71,23,14
Ilo	744	26	G	3.5	6	23.1	0	0.0	71,23,20
Morro	284	8	G	2.8	3	37.5	0	0.0	23,7,69,55,20
Chile									
Caldera	25	11	S	44.0	5	45.5	0	0.0	28
Coquimbo	211	6	S	2.8	2	33.3	0	0.0	28
Quintero	5	2	S	40.0	2	100.0	0	0.0	28
Valparaiso	70	11	S	15.7	10	90.9	0	0.0	28
Sn.Antonio	86	2	S	2.3	1	50.0	0	0.0	28
		9	Md	10.5	7	77.8	0		28
Lebu	60	41	S	68.3	17	41.5	0	0.0	28
SUM	14108	3933		27.9	793	20.1	125	15.8	

Supplemental Table 2. Target species list, with common name in Spanish, common name in English and scientific name. Synonymous common names: Ec = species in Ecuador, Pe = species in Peru.

	Common name Spanish	Common name English	Scientific name
1	Albacora, tuno, atun	Yellowfin tuna/ Albacore	*Thunnus spp.*
2	Angelote	Angel fish	*Squatina californica, S. armata*
3	Bagre	Catfish	*Bagre spp., Galeichthys spp.*
4	Bereche	Pacific drum	*Larimus pacificus*
5	Bobo, mismis	Snakehead kingcroaker	*Menticirrhus ophicephalus*
6	Bonito (Ec)	Skipjack tuna, striped bonito, black skipjack	*Katsuwonus pelamis, Sarda orientalis, Euthynnus lineatus*
7	Bonito (Pe)	Eastern Pacific Bonito	*Sarda chiliensis chiliensis*
8	Botellita	Frigate tuna	*Auxis thazard thazard*
9	Caballa (Ec)	Thread herring, green jack, chub mackerel	*Opisthonema spp., Caranx caballu, Scomber japonicus*
10	Caballa (Pe)	Chub mackerel	*Scomber japonicus*
11	Cabinza	Cabinza grunt	*Isacia conceptionis*
12	Cabezudo	Bighead tilefish	*Caulolatilus affinis*
13	Cabrilla	Southern rock seabass	*Paralabrax callaensis*
14	Cachema, ayanque	Peruvian weakfish	*Cynoscion analis*
15	Cagalo, cabrilla	Peruvian rock seabass	*Paralabrax callaoensis*
16	Camaron	Pacific white shrimp	*Litopenaeus vannamei*
17	Cherna	Grouper	*Mycteroperca spp.*
18	Chita	Peruvian grunt	*Anisotremus scapularis*
19	Coco, suco	Peruvian banded croaker	*Paralonchurus peruanus*
20	Cojinova	Palm ruff	*Seriorella violacea*
21	Congrio	Cusk eel	*Genipterus spp.*
22	Corvina (Ec)	Corvina drum	*Cilus gilberti*
23	Corvina (Pe)	Weakfish	*Cynoscion spp.*
24	Culon	Cusk-eel	*Lepophidium spp.*
25	Doncella	Splittail bass	*Hemanthias peruanus*
26	Dormilon	Giant electric ray	*Narcine entemedor*
27	Espada	Swordfish	*Xiphias gladius*
28	Gallo, pejegallo	Plownose chimaera	*Callorhinchus callorynchus*
29	Huayaipe	Longfin yellowtail	*Seriola rivoliana*
30	Jurel	Chilean jack mackerel	*Trachurus picturatus murphyi*
31	Langosta	Green spiny lobster	*Panulirus gracilis*
32	Langostino	Prawn	*Callinasa islagrande*
33	Lenguado	Flounder	*Paralichthys spp*
34	Lisa	Mullet	*Mugil cephalus*

35	Lorna	Lorna drum	*Sciaena deliciosa*
36	Machete	Pacific thread herring	*Opisthonema libertate*
37	Menudo	Small catch	Various small fish
38	Merluza	South Pacific hake	*Merluccius gayi peruanus*
39	Mojarrilla	Minor stardrum	*Stellifer minor*
40	Ojon	Grape-eye seabass	*Hemilutjanus macrophthalmos*
41	Pampano, chazu (Ec)	Pompano, Pacific harvestfish	*Peprilus medius*
42	Pampano (Pe)	Pampano	*Trachinotus paitensis/Peprilus medius*
43	Pampanito	Starry butterfish	*Stromateus stellatus*
44	Pargo, chino, rojo	Snapper	*Lutjanus spp.*
45	Peje blanco	Bighead tilefish	*Caulolatilus affinis*
46	Pejerrey	Chilean silverside	*Odontesthes regia regia*
47	Perico, dorado	Common dolphinfish	*Coryphaena hippurus*
48	Pesca blanca	Various catch	Various species 20-40cm
49	Pez sol/luna	Ocean sunfish, sharptail mola	*Mola mola, Masturus lanceolatus*
50	Picudo	Indo-Pacific blue marlin, Striped marlin	*Makaira mazara, Tetrapturus audax*
51	Pinchagua	Thread herring	*Opisthonema spp.*
52	Pintadilla	Peruvian morwong	*Cheilodactylus variegatus*
53	Rabon	Pelagic thresher	*Alopias pelagicus*
54	Raya (Ec)	Rays	*Dasyatis spp., Gymnura spp. , Raja spp., Aetobatus sp., Narcina sp., Rhinobatus sp.*
55	Raya (Pe)	Rays	*Myliobatis peruvianus, Rhinobatus spp, other rays*
56	Raya batana	Diamond stingray	*Dasyatis spp.*
57	Raya guitarra	Pacific guitar fish	*Rhinobatos planiceps*
58	Rayado	Suco croaker	*Paralonchurus dumerilii*
59	Robalo	Snook	*Centropomus spp.*
60	Sardina	South American pilchard	*Sardinops sagax sagax*
61	Selemba	Creole fish	*Paranthias spp.*
62	Sierra	Pacific sierra	*Scomberomorus sierra*
63	Tiburon (Ec)	Shark	*Alopias pelagicus, Alopias superciliosus, Sphyrna zygaena*
64	Tiburon (Pe)	Sharks	*Alopias spp., Carcharhinidae, Sphyrna zygaena, Prionace glauca, Isurus oxyrinchus*
65	Tiburon azul	Blue shark	*Prionace glauca*
66	Tiburon diamante	Shortfin mako	*Isurus oxyrinchus*
67	Tiburon cacho, martillo	Hammerhead	*Sphyrna zygaena*
68	Tiburon zorro	Thresher shark	*Alopias vulpinus*
69	Tollo	Sharks, smooth-hounds	*Carcharhinidae, Mustelus spp., Triakis spp.*
70	Vela	Indo-Pacific sailfish	*Istiophorus platypterus*
71	Volador	Longjaw leatherjacket	*Exocoetus spp.*
72	Wahoo	Wahoo	*Acanthocybium solandri*

Supplemental Table 3. Summary of fisheries descriptions by port and country (North to South). Number of surveys, age of fishermen, years fishing, if fisheries is their main job, other economic activities, fishing year round or seasonal, boat owner, length of vessel, % with motor if positive, % with inboard or offboard, and motor power. Results are given by mean (range, ±SD). *values from one survey.

Ports	No. Surveys	Age (years)	Years fishing	Main	Other job	Year round fishing	Boat owner	Boat length (m)	No motor	Off board	In board	Motor power (hp)
Ecuador												
Esmeraldas	41	46.2 (25-73, 12.4)	25.2 (10-60, 10.2)	100.0	4.9	100.0	70.7	7.9 (7-8.5, 0.7)		100.0		69.2 (40-75, 13)
Manta	71	37.1 (19-65,10.2)	20.2 (5-50, 9.1)	96.0	9.9	90.1	23.9	8.7 (7.2-9.5, 0.5)		100.0		74.2 (40-85, 6.5)
Pto.Lopez	54	39.7 (21-65, 11.1)	23.4 (5-48,10.7)	100.0	3.8	98.0	50.0	8.3 (6.5-8.5, 0.5)		100.0		71.7 (40-75,9.2)
Sta. Rosa	111	38 (17-75, 11.1)	18.6 (4-55, 9.8)	99.2	19.5	93.2	38.6	9.1 (7-85, 7.1)		100.0		73.5 (40-85, 6.9)
Anconcito	34	45.8 (25-66, 9.2)	26.9 (10-43, 7.9)	100.0	17.6	94.1	47.1	7.9 (6-9.5, SD1)		91.2	8.8	55.1 (2-85, 19.2)
Chanduy	30	45.7 (20-59, 11.1)	29 (4-44, 10)	100.0	10.0	100.0	63.3	7.5 (6.5-8.5, 0.6)		100.0		52.8 (8-75, 14.8)
Pto.Bolivar	66	42 (22-78, 10.7)	23 (7-58, 10.6)	100.0	20.0	95.5	50.8	7.8 (6.2-12, 1.4)		86.4	13.6	47.3 (4-75, 23.7)
Peru												
Pizarro	25	39 (20-60, 10.4)	18 (3-40, 9.5)	100.0	20.0	92.0	48.0	6.8 (5-8.5, 0.7)			100.0	19.8 (16-80, 12.7)
Zorritos	24	43.2 (34-55, 6.4)	23.8 (12-41, 8.4)	100.0	41.7	54.2	45.8	6.7 (3.6-10, 2)	4.2	17.4	78.3	75 (14-135, 51.9)
Cancas	8	47 (29-65, 10.6)	32.3 (17-50, 11.2)	100.0	0.0	50.0	87.5	5.3 (3-6.7, 1.1)		12.5	87.5	25.5 (16-35, 7.3)
Mancora	21	38.5 (29-54, 6.4)	19.6 (11-30, 6.2)	100.0	0.0	62.0	38.0	9.5 (6.3-12, 1.4)			100.0	120.3 (35-180, 37.9)
Talara	5	40.8 (32-49, 7.2)	24.4 (15-39, 9.1)	100.0	20.0	100.0	60.0	6.1 (3-8.5, 2.8)		20.0	80.0	64.3 (8-190, 84.6)
Paita	3	45.3 (44-47, 1.5)	29 (27-32, 2.6)	100.0	0.0	100.0	67.0	7.8 (7-8.8, 0.9)			100.0	38.3 (25-50, 12.6)
Constante	10	32.3 (22-55, 12.8)	20.9 (6-43, 11.8)	100.0	10.0	80.0	90.0	8.2 (5.2-27, 6.6)			100.0	143.4 (87-170, 38.2)
Delicias	2	34.5 (29-40, 7.8)	15 (10-20, 7.1)	100.0	50.0	100.0	100.0	34.5 (11-15, 7.8)			100.0	105 (100-110, 7.1)
Parachique	8	40 (22-48, 8.5)	23.1 (10-30, 63)	100.0	0.0	100.0	62.5	8.7 (5.2-20, 4.7)		12.5	87.5	38.6 (22-60, 16.2)
Bayovar	4	33 (28-36, 3.6)	16.8 (13-20, 2.9)	100.0	25.0	50.0	25.0	9.6 (7.9-10.9, 1.6)			100.0	25.3 (8-35, 15.3)
Pimentel	12	42.4 (32-57, 7.7)	26.1 (14-44, 7.9)	100.0	8.3	91.7	25.0	7.8 (6.5-10, 1.1)		67.0	33.0	70.8 (40-180, 46.6)
San Jose	50	40.7 (25-65, 10.4)	24.1 (6-50, 10.3)	100.0	16.0	84.0	44.0	8.9 (2-14, 2.1)	2.0	66.0	32.0	85.8 (32-250, 64.7)
Malabrigo	28	43.2 (27-60, 8.3)	9.5 (4-24, 4.3)	100.0	17.9	75.0	50.0	5.7 (3-7, 0.8)		96.4	3.6	16.6 (15-25, 3.6)
Salaverry	17	48.4 (32-70, 10.9)	24.7 (5-60, 13)	88.2	17.6	70.6	64.7	5.9 (3-9.8, 2.5)	35.3	23.5	41.2	30.1 (15-90, 23.2)

Chimbote	12	47.3 (27-67, 10.8)	23.4 (13-35, 7.7)	100.0	0.0	91.7	41.7	7.9 (4-18, 4.1)			100.0	72.1 (8-180, 74.8)
Culebras	6	46.2 (28-70, 14.8)	26.2 (10-40, 10.9)	100.0	0.0	100.0	67.0	5.6 (3.1-7.6, 2)	16.7		83.3	13.8 (8-23, 6.2)
Supe	6	42 (31-59, 9.4)	25.2 (17-42, 9.4)	83.3	16.7	83.3	50.0	8.48 (6.8-10, 1.4)		16.7	83.3	40.8 (16-90, 29.5)
Huarmey	3	42 (30-60, 15.9)	24.7 (11-45, 17.9)	100.0	33.3	100.0	67.0	4.9 (3.3-7.3, 2.1)	33.3	33.3	33.3	26 (16-36, 14.1)
Huacho	10	47.2 (29-66, 11.8)	30.8 (14-47, 10.6	100.0	20.0	100.0	60.0	5.3 (3-7, 1.5)	60.0		40.0	38 (16-70, 28.4)
Ancon	4	51.3 (45-60, 6.3)	34.3 (27-45, 7.9)	100.0	25.0	100.0	25.0	8.4 (6.4-9.8, 1.8)		75.0	25.0	48.5 (9-65, 26.4)
Callao	7	57.1 (43-65, 1.8)	40.1 (18-52, 12.2)	100.0	0.0	100.0	28.6	5.6 (4.6-6.7, 1.5)		14.3	85.7	26.6 (6-60, 23.1)
Pucusana	11	44.5 (26-81, 14.2)	27.7 (11-60, 13.9)	90.9	36.4	72.7	63.6	10.5 (7-34, 7.8)		81.8	18.2	59.6 (16-160, 36.2)
Tbo.Mora	16	55.4 (38-73, 12.1)	35.5 (15-53, 12.1)	100.0	6.3	81.3	68.8	7.7 (4.3-20, 3.9)	6.2	87.5	6.2	27.1 (8-40, 11.6)
Sn.Andres	17	52.5 (32-72, 12.7)	33.7 (17-50, 11.9)	100.0	11.8	76.5	58.8	8.2 (5.2-23, 4)		100.0		38.2 (25-40, 4.9)
Marcona	6	44.5 (27-71, 15.5)	28.5 (10-50, 13.8)	100.0	0.0	100.0	33.3	6.9 (4.6-8.2, 1.4)		100.0		42.5 (15-60, 16.7)
Atico*	1	43.0	23.0	100.0	0.0	100.0	0.0	8.5		100.0		40.0
Planchada	2	46 (40-52, 8.5)	30 (28-32, 2.8)	100.0	0.0	0.0	50.0	6.3 (5.8-6.7, 0.7)		50.0	50.0	28 (16-40, 16.9)
Matarani	15	48.2 (28-55, 7)	27.4 (8-35, 7.7)	100.0	13.3	0.0	46.7	8.1 (7-9, 0,8)		100.0		52 (40-60, 10.1)
Ilo	6	45.8 (37-64, 10.3)	26 (15-50, 13.2)	100.0	16.7	66.7	50.0	9.1 (7-12, 1.8)		100.0		44.2 (25-60, 13.6)
Morro	3	47.7 (32-58, 13.8)	32 (12-44, 17.4)	100.0	0.0	0.0	0.0	9.3 (7-12, 2.5)		100.0		46.7 (40-60, 11.5)
Chile												
Caldera	5	46.4 (38-58, 7.7)	25.2 (18-32, 6.3)	100.0	100.0	0.0	40.0	14.6 (13-16, 1.1)			100.0	140 (100-155, 22.6)
Coquimbo	2	43.5 (41-46,3.5)	20.5 (20-21,0.7)	100.0	100.0	0.0	50.0	17.5 (17-18, 0.7)			100.0	245 (140-350, 148.5)
Quintero	2	61 (55-67, 8.5)	35.5 (19-52, 23.3)	100.0	50.0	0.0	100.0	13.5 (12-15, 2.1)			100.0	130 (120-140, 14.1)
Valparaiso	10	47.9 (28-57,9.5)	29.2 (10-44, 10.3)	100.0	0.0	0.0	40.0	16.4 (14-18, 1.3)			100.0	219 (100-400, 103.7)
Sn.Antonio	8	48.8 (32-58, 8.3)	29.4 (14-42, 9.2)	100.0	12.5	0.0	33.3	17.3 (15-18, 1)			100.0	346.3 (280-480, 61.9)
Lebu	17	53.8 (35-75, 10.2)	34.5 (20-63, 11)	100.0	94.1	0.0	47.1	17.4 (15-18, 0.9)			100.0	402.4 (320-480, 53.3)

Supplemental Table 4. Summary of bycatch information by port and country (north to south) per gear type (S = surface gillnets, M = surface monofilament, Md = midwater nets, T = trammelnets, B = bottomset nets and G = gillnets), all given in percentages. Turtles = respondents that acknowledge having turtle bycatch. Turtle species composition: Cc = *Caretta caretta*, Dc = *Dermochelys coriacea*, Cm = *Chelonia mydas*, Lo = *Lepidochelys olivacea*, Ei = *Eretmochelys imbricata*. Turtles/y = median of turtles caught per year according to survey category. M = marine mammals bycatch, S = seabirds bycatch. Final fate: E=eat, D=discard dead, S= sold, M = used for medicine, R=release alive. Law = % of fishermen aware of the protected status of turtles. Score = % of score surveys. Column 'Score' indicates the percent of surveys for a given port that were considered reliable based upon three post-interview questions completed by the interviewer to assess their confidence in the survey responses. Two decimals used only at species composition. *values from one survey.

Ports	Gear	Turtles	Cc	Dc	Cm	Lo	Ei	Turtles/y	M	S	Final fate	Law	Score
Ecuador													
Esmeraldas	S	100.0	6.38	4.26	31.92	51.06	6.38	21-50	96.6	0.0	43.4 D, 54.7 R, 1.8 M	65.5	100.0
	M	100.0	0.00	14.30	14.30	71.40	0.00	11-20	0.0	0.0	33.3 D, 66.7 R	50.0	100.0
	T	100.0	0.00	0.00	100.00	0.00	0.00	11-20	0.0	0.0	50 D, 50 R	100.0	100.0
	B	100.0	0.00	0.00	25.00	50.00	25.00	>51	0.0	0.0	44.4 D, 55.6 R	60.0	100.0
Manta	S	96.9	1.85	6.48	44.44	35.19	12.04	21-50	95.4	1.5	2 E, 32.3 D, 65.7 R	75.0	100.0
	M	33.3	0.00	0.00	50.00	0.00	50.00	0	0.0	0.0	25 D, 75 R	100.0	100.0
	T	50.0	0.00	0.00	0.00	0.00	100.00	4-10	50.0	0.0	50 D, 50 R	50.0	100.0
	B*	0.0						0	0.0	0.0	50 D, 50 R	100.0	100.0
Pto.Lopez	S	100.0	1.40	2.80	35.20	47.90	12.70	>51	97.4	0.0	6.7 E, 28.3 D,65 R	92.3	100.0
	M	80.0	0.00	0.00	35.71	57.14	7.14	11-20	10.0	0.0	7.1 E, 21.4 D, 71.4 R	70.0	100.0
	T	100.0	0.00	0.00	33.30	66.70	0.00	11-20	0.0	0.0	50 D, 50 R	50.0	100.0
	B	100.0	0.00	0.00	33.33	33.33	33.33	21-50	33.3	0.0	25 D, 75 R	66.7	100.0
Sta.Rosa	S	96.7	2.60	4.50	36.10	48.40	8.40	21-50	94.6	18.5	5.1 E, 21.4 D, 73.5 R	73.0	96.7
	M	85.7	0.00	0.00	23.50	70.60	5.90	11-20	35.7	0.0	35 D,65 R	86.0	100.0
	T	100.0	50.00	0.00	0.00	50.00	0.00	11-20	0.0	0.0	50 D, 50 R	100.0	100.0
	B	33.3	0.00	0.00	0.00	100.00	0.00	11-20	0.0	0.0	25 D, 75 R	100.0	100.0
Anconcito	S	87.5	6.25	12.50	43.75	31.25	6.25	>51	25.0	0.0	33.3 D, 66.7 R	50.0	100.0
	M	92.3	0.00	12.00	20.00	40.00	28.00	21-50	0.0	0.0	5.3 E, 26.3 D, 68.4 R	46.2	100.0

	T	100.0	0.00	0.00	33.30	50.00	16.70	11-20	0.0	0.0	6.2 E, 43.8 D, 50 R	75.0	100.0
	B	60.0	0.00	0.00	50.00	50.00	0.00	11-20	0.0	0.0	28.6 D, 71.4 R	40.0	100.0
Chanduy	S	50.0	0.00	0.00	50.00	50.00	0.00	4-10	50.0	0.0	100 R	50.0	100.0
	M	89.5	0.00	0.00	32.14	57.14	10.71	21-50	26.3	0.0	5.9 E, 55.9 R, 38.2 D	71.4	92.9
	T	100.0	0.00	0.00	25.00	75.00	0.00	11-20	0.0	0.0	11.1 E, 44.5 D, 44.4 R	100.0	100.0
	B	80.0	0.00	12.50	50.00	12.50	25.00	21-50	20.0	0.0	50 D, 50 R	80.0	100.0
Pto.Bolivar	S	100.0	0.00	0.00	30.00	70.00	0.00	>51	60.0	10.0	5.6 E, 44.4 D, 50 R	50.0	100.0
	M	85.7	4.20	6.40	36.20	44.70	8.50	21-50	2.9	0.0	2 E, 28 D, 70 R	51.0	100.0
	T	100.0	0.00	0.00	67.00	33.00	0.00	21-50	0.0	0.0	50 D, 50 R	66.7	100.0
	B	94.0	0.00	0.00	28.60	66.70	4.70	11-20	11.1	5.6	6 E, 42 D, 52 R	77.8	100.0
Mean		82.7	2.69	2.81	34.40	46.74	13.36		25.3	1.3		71.3	
Peru													
Pizarro	G	80.0	0.00	28.00	34.00	38.00	0.00	11-20	12.0	24.0	25 E, 39 D, 36 R	60.0	80.0
Zorritos	G	90.0	13.64	4.55	38.63	43.18	0.00	4-10	79.2	4.2	9.8 E, 31.7 D, 58.5 R	75.0	100.0
Cancas	G	37.5	0.00	0.00	62.50	37.50	0.00	4-10	25.0	25.0	10 E, 10 D, 80 R	100.0	100.0
Mancora	G	95.2	0.00	30.00	44.00	21.00	5.00	>51	90.5	23.8	3.1 E, 3.1 S, 62.5 D, 31.3 R	90.5	100.0
Talara	G	40.0	0.00	0.00	100.00	0.00	0.00	4-10	20.0	0.0	28.6 E, 71.4 R	80.0	100.0
Paita	G	100.0	0.00	0.00	100.00	0.00	0.00	11-20	33.3	0.0	100 R	100.0	100.0
Constante	G	100.0	8.33	0.00	83.33	8.33	0.00	11-20	60.0	40.0	46.6 E, 26.7 S, 26.7 R	80.0	100.0
Delicias	G	100.0	0.00	33.00	67.00	0.00	0.00	11-20	100.0	100.0	50 D, 50 R	50.0	100.0
Parachique	G	100.0	12.50	0.00	75.00	12.50	0.00	11-20	50.0	75.0	12.5 E, 12.5 D, 75 R	87.5	100.0
Bayovar	G	75.0	0.00	0.00	40.00	60.00	0.00	11-20	75.0	75.0	80 R, 20 M	75.0	100.0
Pimentel	G	41.7	0.00	0.00	0.00	100.00	0.00	0	41.7	25.0	100 R	75.0	100.0
San Jose	G	44.0	4.54	25.00	43.18	20.45	6.82	0	46.0	10.0	32.8 E, 1.6 D, 65.6 R	82.0	100.0
Malabrigo	G	6.0	0.00	66.67	33.33	0.00	0.00	0	12.0	3.6	100 R	71.4	100.0
Salaverry	G	47.1	15.00	23.00	46.00	8.00	8.00	0	58.8	52.9	14.3 E, 25 D, 60.7 R	76.5	100.0
Chimbote	G	58.3	9.00	9.00	55.00	27.00	0.00	1-3	75.0	33.3	17.6 E, 11.8 D, 70.6 R	66.7	100.0
Culebras	G	33.3	33.00	0.00	67.00	0.00	0.00	0	50.0	50.0	36.3 E, 9.1 S, 54.5 R	66.7	100.0
Supe	G	66.7	20.00	0.00	60.00	20.00	0.00	4-10	50.0	66.7	25 E, 25 D, 50 R	100.0	100.0

Huarmey	G	66.7	0.00	0.00	66.70	33.30	0.00	4-10	66.7	0.0	16.7 E, 33.3 D, 50 R	33.3	66.7
Huacho	G	40.0	20.00	0.00	40.00	20.00	20.00	0	50.0	50.0	7.7 E, 15.4 D, 76.9 R	70.0	100.0
Ancon	G	100.0	0.00	20.00	20.00	40.00	20.00	1-3	75.0	75.0	28.6 E, 14.3 D, 57.1 R	75.0	100.0
Callao	G	75.0	0.00	0.00	100.00	0.00	0.00	0	85.7	28.6	28.6 E, 71.4 R	85.7	100.0
Pucusana	G	72.7	6.25	6.25	43.75	25.00	18.75	4-10	90.9	45.5	47.4 E, 52.6 R	72.7	100.0
Tbo.Mora	G	56.3	7.14	14.29	57.14	21.42	0.00	4-10	56.3	43.8	41.9 E, 3.2 S, 6.5 D, 48.4 R	87.5	100.0
Sn.Andres	G	47.1	7.14	21.43	57.14	14.29	0.00	0	23.5	35.3	29.2 E, 12.5 D, 58.3 R	94.1	100.0
Marcona	G	66.7	0.00	0.00	50.00	25.00	25.00	0	83.3	66.7	62.5 E, 37.5 R	83.3	100.0
Atico	G*	0.0						0	0.0	100.0	_	100.0	100.0
Planchada	G	50.0	0.00	50.00	0.00	50.00	0.00	1-3	100.0	100.0	50 E, 50 R	50.0	100.0
Matarani	G	6.7	0.00	100.00	0.00	0.00	0.00	0	6.7	0.0	100 R	100.0	100.0
Ilo	G	83.3	14.28	0.00	57.14	14.29	14.29	4-10	50.0	33.3	22.2 E, 11.1 D, 66.7 R	83.3	100.0
Morro	G	0.0	0.00	0.00	100.00	0.00	0.00	0	67.0	66.7	100 R	66.7	100.0
Mean		82.6	5.89	14.87	53.13	22.04	4.06		54.5	41.8		77.9	
Chile													
Caldera	S	80.0	20.00	0.00	80.00	0.00	0.00	4-10	0.0	0.0	100 R	40.0	100.0
Coquimbo	S	100.0	25.00	50.00	25.00	0.00	0.00	4-10	0.0	0.0	100 R	100.0	100.0
Quintero	S	100.0	0.00	50.00	50.00	0.00	0.00	4-10	50.0	100.0	100 R	33.3	100.0
Valparaiso	S	80.0	50.00	0.00	50.00	0.00	0.00	4-10	80.0	20.0	100 R	60.0	100.0
Sn.Antonio	S*	100.0	0.00	0.00	100.00	0.00	0.00	4-10	100.0	100.0	50 D, 50 R	100.0	100.0
	Md	57.1	18.00	27.00	55.00	0.00	0.00	4-10	100.0	0.0	40 D, 60 R	85.7	71.4
Lebu	S	88.2	35.00	40.00	25.00	0.00	0.00	4-10	58.8	23.5	100 R	35.0	88.2
Mean		86.5	21.14	23.86	55.00	0.00	0.00		55.5	34.8		64.9	
Total Mean		83.9	9.91	13.84	47.51	22.93	5.81		45.1	25.9		71.4	

Supplemental document. Survey form for bycatch used in Ecuador, Peru and Chile.

Numero de ficha:

Nombre de entrevistador:________________ **Fecha**:_________________ **Lugar**:___________

PARA LOS PESCADORES

Al inicio se menciona a los entrevistados:

Me llamo __________. Hago un estudio en pesca artesanal. Esta es una entrevista voluntaria y anónima. No necesitamos su nombre o ninguna información de contacto personal ni compartiremos su respuesta personal con alguna persona fuera del equipo de investigación. Usted no tiene que responder alguna pregunta que no quiera.

El objetivo principal es aprender sobre las tortugas, delfines y aves marinas en la pesca costera artesanal. Estamos agradecidos por su participación en este estudio, y confiamos que nos ayudará a aprender más sobre el tema.

ANTECEDENTES

1. ¿Ha participado previamente en entrevistas o investigaciones relacionadas a (marque):
   ☐ Pesca? ☐ Tortugas marinas? ☐ Mamíferos marinos? ☐ Aves marinas? ☐ Nunca participe
   Describa: ____
2. ¿Qué edad tiene? ____________
3. ¿Por cuántos años la pesca ha sido su ocupación? ____________
4. ¿La pesca es su principal ocupación? ☐ Sí ☐ No
5. ¿La pesca es su única ocupación? ☐ Sí ☐ No
6. (***Si la respuesta es No***): ¿Cuáles son sus otras ocupaciones?: ______________
7. ¿Durante cuáles meses ha pescado (**de los últimos 12**)? E F M A M J J A S O N D
8. ¿Es usted dueño de un bote? ☐ Sí ☐ No
9. ¿Cuál es su puerto de matrícula? _____________
10. De que puerto operó principalmente en el último año? ______________

DESCRIPCIÓN DEL BOTE

11. ¿Qué tan largo (en metros) es el bote donde pesca? ________________
12. ¿Es el bote motorizado? ☐ Sí ☐ No
13. (***Si la respuesta es Sí***): ☐ Motor interior estacionario? ☐ Fuera de borda?
14. ¿Cuántos caballos de fuerza tiene el motor?: ________________

APAREJOS 1: PREGUNTAS DE PESCA Y CAPTURA
(Responda las preguntas describiendo **su experiencia personal**, no de la comunidad.)

15. ¿Qué tipo de aparejo (u arte) de pesca usa **más seguido** durante el curso de un año? **Marque UNO**:
- ☐ Red de superficie ☐ Red electrónicas (chinas)
- ☐ Red de media agua ☐ Redes de trasmallo
- ☐ Red de fondo ☐ Otra (describa): ________________

16. ¿Cuántos pescadores, incluyéndose, van en el bote a pescar con ese tipo de arte? ____________________

17. ¿Durante cuáles meses del año utiliza este arte? E F M A M J J A S O N D

18. ¿Cuál es tu principal especie objetivo con este arte? ____

19. ¿Cuántos días al mes pesca cuando está usando este arte?
☐ 1-7 ☐ 8-14 ☐ 15-21 ☐ 22-31

20. ¿Captura ocasionalmente tortugas cuando utiliza este arte? ☐ Sí ☐ No
Si la respuesta es Sí:

21. ¿Qué especies de **tortugas** captura cuando utiliza este arte? (***use ilustraciones***) y qué tan seguro está de la identificación de estas especies? Liste las especies de mayor a menor frecuencia.
- ________________ ☐ muy seguro ☐ parcialmente seguro ☐ no estoy seguro
- ________________ ☐ muy seguro ☐ parcialmente seguro ☐ no estoy seguro
- ________________ ☐ muy seguro ☐ parcialmente seguro ☐ no estoy seguro
- ________________ ☐ muy seguro ☐ parcialmente seguro ☐ no estoy seguro
- ________________ ☐ muy seguro ☐ parcialmente seguro ☐ no estoy seguro

22. ¿Durante qué meses del año ha capturado más tortugas con este arte?
E F M A M J J A S O N D

23. ¿Cuántas tortugas cree que capturó en el último año, con este arte?
Marque una: ☐ 0 ☐ 1-3 ☐ 4-10 ☐ 11-20 ☐ 21-50 ☐ >50

24. ¿Captura ocasionalmente delfín/lobo/ballena cuando utiliza este arte? ☐ Sí ☐ No
Si la respuesta es Sí:

25. ¿Qué especies de **delfín/lobo/ballena** captura cuando utiliza este arte (***use ilustraciones***) y qué tan seguro está de la identificación de estas especies? Liste las especies de mayor a menor frecuencia.
- ________________ ☐ muy seguro ☐ parcialmente seguro ☐ no estoy seguro
- ________________ ☐ muy seguro ☐ parcialmente seguro ☐ no estoy seguro
- ________________ ☐ muy seguro ☐ parcialmente seguro ☐ no estoy seguro
- ________________ ☐ muy seguro ☐ parcialmente seguro ☐ no estoy seguro

26. ¿Durante qué meses del año ha capturado más delfín/lobo/ballena con este arte?
E F M A M J J A S O N D

27. ¿Cuántos delfín/lobo/ballena cree que capturó en el último año, con este arte?
Marque una: ☐ 0 ☐ 1-3 ☐ 4-10 ☐ 11-20 ☐ 21-50 ☐ >50

28. ¿Captura aves cuando utiliza este arte? ☐ Sí ☐ No
Si la respuesta es Sí:

29. ¿Qué especies de **aves** captura cuando utiliza este arte **(*use ilustraciones*)** y qué tan seguro está de la identificación de estas especies? Liste las especies de mayor a menor frecuencia de captura.
- ________________ ☐ muy seguro ☐ parcialmente seguro ☐ no estoy seguro
- ________________ ☐ muy seguro ☐ parcialmente seguro ☐ no estoy seguro
- ________________ ☐ muy seguro ☐ parcialmente seguro ☐ no estoy seguro
- ________________ ☐ muy seguro ☐ parcialmente seguro ☐ no estoy seguro
- ________________ ☐ muy seguro ☐ parcialmente seguro ☐ no estoy seguro

30. ¿Durante qué meses del año ha capturado más aves con este arte?
E F M A M J J A S O N D

31. ¿Cuántas aves cree que capturó en el último año, con este arte?
Marque una: ☐ 0 ☐ 1-3 ☐ 4-10 ☐ 11-20 ☐ 21-50 ☐ >50

PREGUNTAS HISTÓRICAS

32. ¿Las personas en su comunidad han capturado como objetivo tortugas marinas alguna vez? ☐ Sí ☐ No

33. *Si la respuesta es Si* ¿Continúan haciéndolo? ☐ Sí ☐ No

34. ¿Las personas en su comunidad han colectado huevos de tortugas marinas alguna vez? ☐ Sí ☐ No

35. *Si la respuesta es Si* ¿Continúan haciéndolo? ☐ Sí ☐ No

36. Comparado a cuando usted comenzó a pescar, ¿la abundancia de tortugas marinas es ahora…?
☐ Mayor ☐ Menor ☐ Igual ☐ No sé

37. Comparado a cuando usted comenzó a pescar, ¿la captura de tortugas en el arte de pesca es ahora…?
☐ Mayor ☐ Menor ☐ Igual ☐ No sé

38. ¿Las personas en su comunidad han capturado como objetivo delfines alguna vez? ☐ Sí ☐ No

39. *Si la respuesta es Si* ¿Continúan haciéndolo? ☐ Sí ☐ No

40. Comparado a cuando usted comenzó a pescar, ¿la abundancia de delfines es ahora…?
☐ Mayor ☐ Menor ☐ Igual ☐ No sé

41. Comparado a cuando usted comenzó a pescar, ¿la captura de delfines en el aparejo de pesca es ahora…?
☐ Mayor ☐ Menor ☐ Igual ☐ No sé

42. ¿Las personas en su comunidad han capturado como objetivo aves marinas alguna vez? ☐ Sí ☐ No

43. *Si la respuesta es Si* ¿Continúan haciéndolo? ☐ Sí ☐ No

44. Comparado a cuando usted comenzó a pescar, ¿la abundancia de aves marinas es ahora…?
☐ Mayor ☐ Menor ☐ Igual ☐ No sé

45. Comparado a cuando usted comenzó a pescar, ¿la captura de aves en el aparejo de pesca es ahora…?
☐ Mayor ☐ Menor ☐ Igual ☐ No sé

PREGUNTAS DE UTILIZACIÓN Y PROTECCIÓN

46. ¿Qué hace (o haría) usted si captura tortugas marinas?
☐ Comer ☐ Vender ☐ Usar de carnada ☐ Botar (muertas) ☐ Liberar (vivas) ☐ Otro uso

47. ¿Qué hace (o haría) usted si captura delfín/lobo/ballena?
☐ Comer ☐ Vender ☐ Usar de carnada ☐ Botar (muertas) ☐ Liberar (vivas) ☐ Otro uso

48. ¿Qué hace (o haría) usted si captura con aves marinas?
☐ Comer ☐ Vender ☐ Usar de carnada ☐ Botar (muertas) ☐ Liberar (vivas) ☐ Otro uso

49. ¿Sabe usted si las tortugas están legalmente protegidas? ☐ Sí ☐ No ☐ No sé
50. *Si la respuesta es Sí*, ¿estas leyes se cumplen? ☐ Sí ☐ No
51. ¿Cuál es la penalidad como consecuencia por no cumplir la ley?__________________ ☐ No sé

52. ¿Sabe usted si los delfines están legalmente protegidos? ☐ Sí ☐ No ☐ No sé
53. *Si la respuesta es Sí*, ¿estas leyes se cumplen? ☐ Sí ☐ No
54. ¿Cuál es la penalidad como consecuencia por no cumplir la ley? __________________ ☐ No sé

55. ¿Sabe usted si las aves marinas están legalmente protegidas? ☐ Sí ☐ No ☐ No sé
56. *Si la respuesta es Sí*, ¿estas leyes se cumplen? ☐ Sí ☐ No
57. ¿Cuál es la penalidad como consecuencia por no cumplir la ley? __________________ ☐ No sé

58. ¿Hay otros pescadores en la comunidad que capturen tortugas marinas? ☐ Sí ☐ No
59. ¿Qué hacen con ellas?____

60. ¿Hay otros pescadores en la comunidad que capturen delfines? ☐ Sí ☐ No
61. ¿Qué hacen con ellos?____

62. ¿Hay otros pescadores en la comunidad que capturen aves marinas? ☐ Sí ☐ No
63. ¿Qué hacen con ellos?____

SÓLO PARA LOS ENCUESTADORES

64. ¿Qué tan abierto y honesto parecía el pescador contestando las preguntas de pesca incidental?
☐ Muy abierto/honesto ☐ Parcialmente abierto/honesto ☐ Nada honesto

65. ¿Qué tan interesado y comprometido se veía el pescador con la entrevista?
☐ Muy interesado ☐ Parcialmente interesado ☐ Aburrido/Nada interesado

66. ¿Qué tan seguro parecía el pescador respondiendo las preguntas numéricas?
☐ Muy seguro ☐ Razonablemente seguro ☐ Inseguro

67. **Otros comentarios**: ____

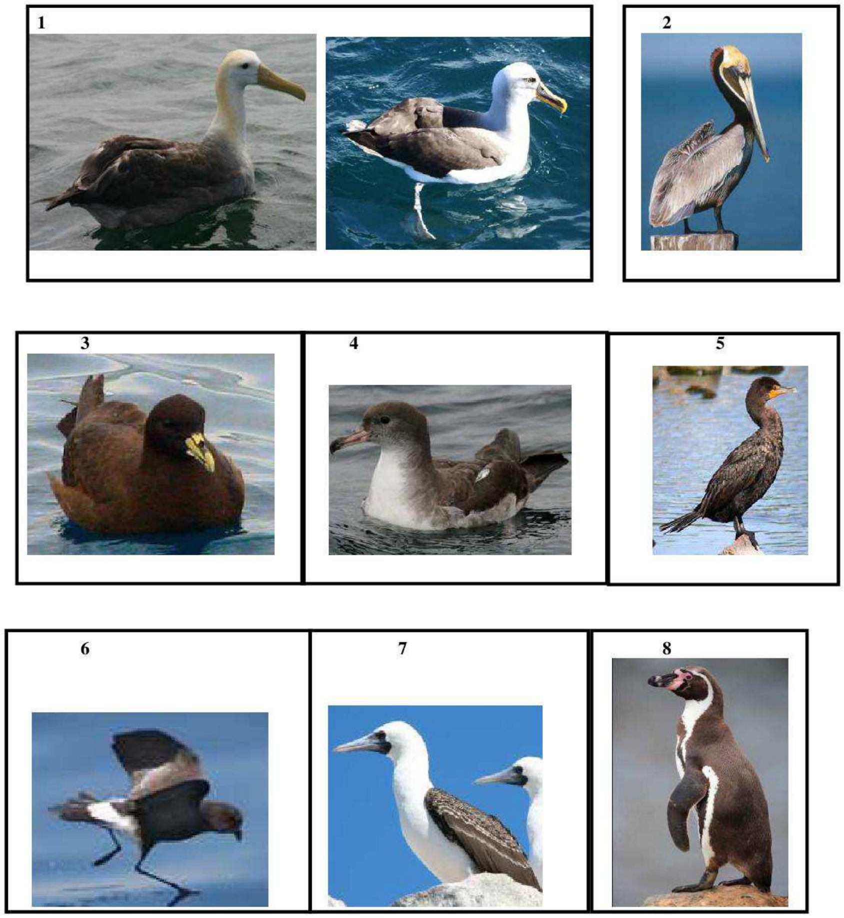
____

____

____

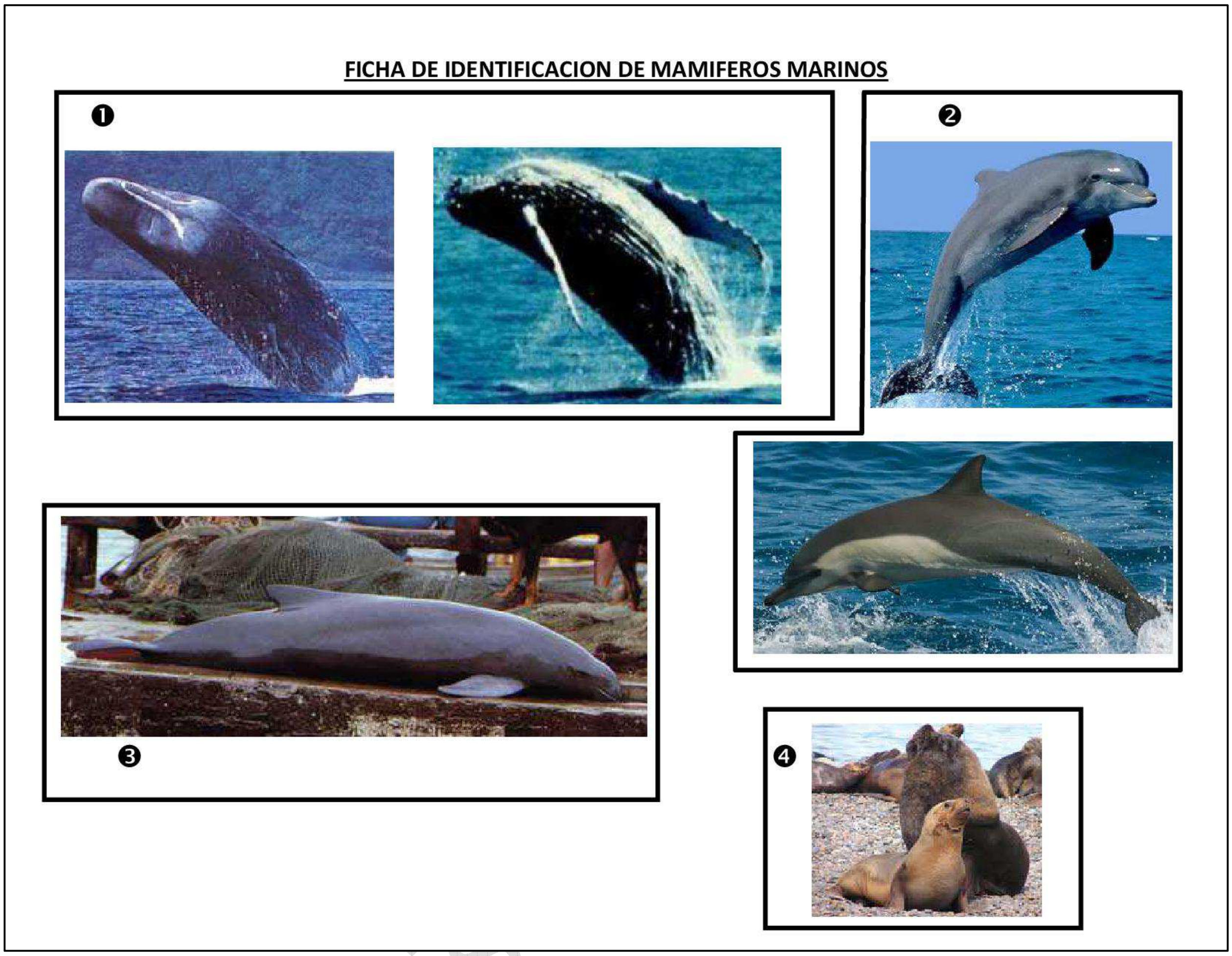
____

FICHA DE IDENTIFICACION DE AVES MARINAS



List of ID guide photos by number including common name in English, Spanish and family/genus/species:

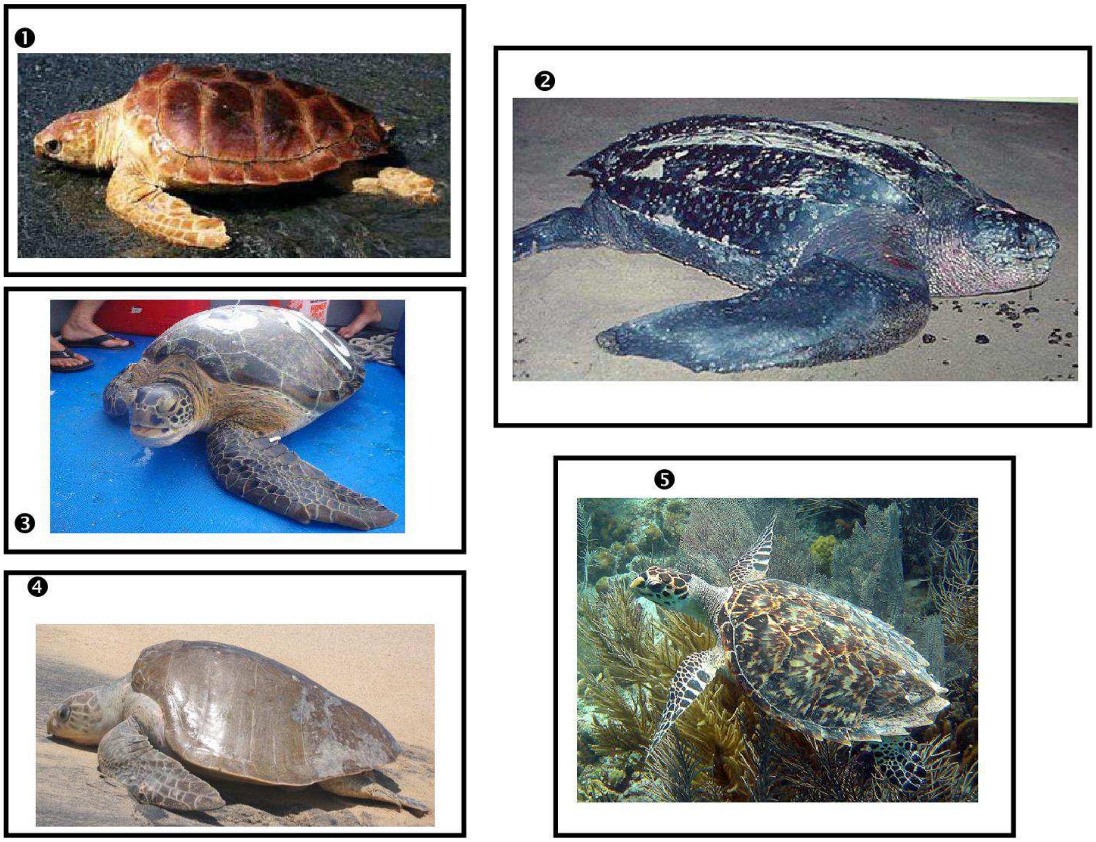
1: Albatross	Albatros, Pajarote, Pajarona	Diomedeidae
2: Pelican	Pelicano, Cocho	*Pelecanus*
3: Petrels	Petrel, cágalo	Procellariidae
4: Shearwaters	Pardelas	Procellariidae
5: Cormorants	Cormoranes	*Phalacrocorax*
6: Storm petrels	Golondrina de tempestad	Hydrobatidae
7: Boobies	Piqueros	*Sula*
8: Penguins	Pinguinos	*Spheniscus*



List of ID guide photos by number including common name in English, Spanish and family/genus/species:

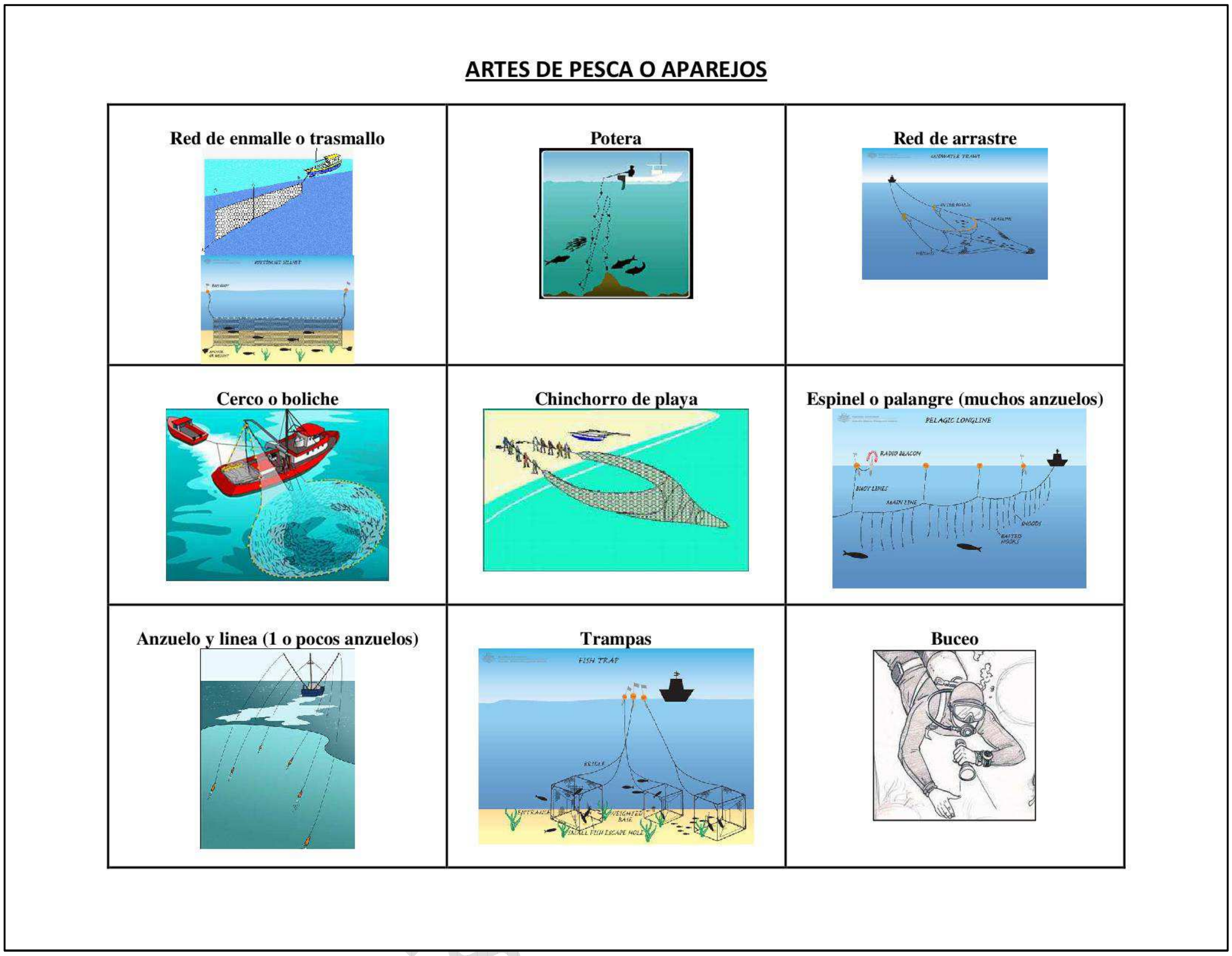
1: Large cetaceans	Ballenas, cachalotes	Balaenopteridae, Physeteridae
2: Dolphins	Delfines, bufeos	Delphinidae
3: Porpoises	marsopas, toninos	*Phocoena spinipinnis*
4: Sea lions	lobos marinos	*Otaria flavescens*, *Arctocephalus* spp.

FICHA DE IDENTIFICACION DE TORTUGAS MARINAS



List of ID guide photos by number including common name in English, Spanish and family/genus/species:

1: Loggerhead turtle	Cabezona, amarilla, caguama	*Caretta caretta*
2: Leatherback turtle	Laud, siete quillas, Galápagos	*Dermochelys coriacea*
3: Green turtle	Verde, negra	*Chelonia mydas*
4: Olive ridley turtle	Pico de loro, lora	*Lepidochelys olivacea*
5: Hawksbill turtle	Carey	*Eretmochelys imbricata*



Translation for fishing gear ID guide graphics:

Red de enmalle o trasmallo: Gillnet or trammelnet

Potera: jigger

Red de arrastre: trawler

Cerco o boliche: purse seiner

Chinchorro de playa: beach seiner

Espinel o palangre: longline

Anzuelo y linea: Handline

Trampas: Trap cages

Buceo: Diving

Chapter V: Trading information for conservation: a novel use of radio broadcasting to reduce sea turtle bycatch

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In press at Oryx

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Abstract

Bycatch in small-scale fisheries poses a major threat to seabirds, marine mammals and sea turtles. This is also true for small-scale fisheries in Peru because of the magnitude of these fisheries and the important marine biodiversity found in Peruvian waters. Here we describe how we implemented a novel approach to mitigate bycatch impacts on sea turtles in Peru. We used high-frequency (HF) two-way radio communication to exchange information with fishers. We sought data that would afford insights into fishing patterns and levels of turtle bycatch so that we could identify high-density bycatch areas in real time, and warn other fishers of the fact. In return, we provided oceanographic and atmospheric information useful for the fishers themselves. Radio communication also served as a platform to promote the use of safe handling and release techniques for incidentally caught animals. During the program, over 24 months, we communicated with over 200 vessels and with between 200 and 3000 fishers using primarily longlines, gillnets, jiggers, purse seiners and trawlers. Our findings suggest that HF radio communication is a useful tool (low cost, widely used by fishers, with extensive spatial coverage), building links with fishers and potentially reducing fishery impacts to sea turtles, but also has served to obtain important information on data deficient fisheries and the relevant bycatch data associated with small-scale fishing practices.

Introduction

Fisheries management is challenging (Beddington et al., 2007) in part due to the miscommunication between regulators and fishermen regarding regulatory processes and requirements (Jentoft, 2000; van Densen & McCay, 2007). This can result in limited trust among stakeholders, potentially leading to failure to manage the resource effectively (Kaplan & McCay, 2004). This is particularly true in small-scale fisheries, which are typically poorly managed (Salas et al., 2007; Jacquet & Pauly, 2008). Nonetheless, when communication is used appropriately, it can strengthen fisheries management practices (Hartley & Robertson, 2008; Gutierrez et al., 2011). This has been the case for communication tools used within fisheries to reduce impacts on protected species such as seabirds and turtles (Gilman et al., 2006). The use of modern communications tools to enhance conservation programs has been found to be productive in other arenas (e.g. warning on the presence of wildlife hunters in African countries), especially in remote geographic areas (Banks & Burge, 2004; Kavanagh, 2008).

In Peru, small-scale fisheries play an important role in provision of food and are a source of employment for more than 200,000 people (McGoodwin, 2001). Bycatch in these fisheries, however, has been shown to have an impact on threatened seabirds (Awkerman et al., 2006), sea turtles (Chapter 3) and marine mammals (Mangel et al., 2010). Addressing conservation of these protected species in small-scale fisheries is difficult, partly due to the remoteness of many coastal communities (Chuenpagdee et al., 2006), hampering management and enforcement. Also, the limited educational level of many stakeholders involved in these fisheries (Berkes et al., 2001) can contribute to the poor understanding of the conservation status of threatened fauna (Van Bressem et al., 2006).

In the case of sea turtles, a taxon highly impacted by fisheries around the world (Lewison & Crowder, 2007; Peckham et al., 2007; Casale, 2011), a variety of existing solutions to reduce bycatch are in place or being tested in many fisheries around the world. These approaches include: technological innovation (turtle excluder devices TEDS, circle hooks, lights) (Watson et al., 2005; Cox et al., 2007; Wang et al., 2010), educational programs for fishers (Marcovaldi & Marcovaldi, 1999), the use of incentives (Ferraro & Gjertsen, 2009), legally non-binding measures (e.g. Inter-American Convention for the Protection and Conservation of Sea Turtles); and fisheries closures (NMFS, 2000). For small-scale fisheries, however, solutions are not widely executed and usually implemented voluntarily since most of these fisheries are poorly regulated, with limited enforcement and lack of economic incentives (Salas et al., 2007; Jacquet & Pauly, 2008).

Communication tools have been used as an alternative way to prevent bycatch events of sea turtles and other marine protected fauna in industrial fisheries (Gilman et al., 2006; Howell et al., 2008). Fleet communication programs within the US North Atlantic longline swordfish, North Pacific and Alaska trawlers and Alaska demersal longline fisheries have been shown to reduce bycatch and prevent the established bycatch threshold from being exceeded (Gilman et al., 2006). In the US Hawaiian longline fleet managers provide fishermen with updated maps of sea surface temperature as a tool to help them decide on where to fish while avoiding loggerheard turtle bycatch (Howell et al, 2008).

Five species of marine turtles have been recorded in the waters of Peru, primarily as foraging animals (Chapter 3). Tagging, genetics and satellite tracking have demonstrated linkages with distant rookeries. Genetics of leatherback turtles *Dermochelys coriacea* off Peru suggest they are from rookeries both in the eastern (i.e. Mexico and Costa Rica) and in the western Pacific (i.e. Papua New Guinea, Indonesia and Solomon Islands) (Dutton et al., 2010). Satellite tracking studies (Eckert & Sarti, 1997; Shillinger et al., 2008) have linked Peru and the Mexican and Costa Rican rookeries. A proportion of the green turtles *Chelonia mydas* visiting Peru originate from the Galapagos (Hays-Brown & Brown, 1982; Seminoff et al., 2008) and Mexico (Velez-Zuazo & Kelez, 2010). Loggerhead turtles *Caretta caretta* are linked to populations breeding in Australia and New Caledonia (Alfaro-Shigueto et al., 2004; Boyle et al., 2009). Olive ridley *Lepidochelys olivacea* tagging and genetics suggest they originate from Costa Rica, Colombia and Mexico (Zeballos & Arias-Schereiber, 2001; Velez-Zuazo & Kelez, 2010). There is a paucity of information for the hawksbill turtle *Eretmochelys imbricata* but there may be links with Ecuador (Gaos et al., 2010). All these species are vulnerable to fisheries impacts (see Chapter 1 and 3), and it has been suggested that the effect of fisheries bycatch on some of these stocks has been detrimental (Spotila et al., 2000; Limpus & Limpus, 2003; Seminoff et al., 2008).

Peruvian small-scale fishing vessels often conduct trips offshore for more than three weeks (Chapter 1); as a result, fishers remain on land for short time periods, preventing their participation in conservation programs (i.e. attending workshops or outreach talks conducted at their ports). To address this, we implemented a high frequency (HF) radio communication program which communicates with fishers at sea to provide guidelines on the use of safe release methods to help incidentally captured turtles, as well as information useful to them in exchange for voluntary reports of turtle bycatch locations. The aim was to use the provided locations to identify potential areas of high bycatch. These areas were then reported back to fishers operating in the same areas in an attempt to reduce the impacts of their fisheries on these threatened sea turtle populations.

Methodology

Equipment and tools

We broadcasted from a fixed station based at Lima (12° 30' S, 77° 24' W) using a Vertex 1700 HF radio (Price range: USD 1600 - 1800). Power output was 100 to 125 watts. Receiving frequency was 30 kHz – 30 MHz, and transmission frequency was 1.6 – 30 MHz. We used a multiband antenna that offered flexibility in switching between bands and frequencies during communications.

In addition to the radio, we used the internet to access daily updated oceanographic data (sea surface temperature SST, wind directions, chlorophyll, tides and alarm events e.g. tsunamis, rough sea conditions, using web sites that offer these services without charge (e.g. www.buoyweather.com). Local web sites were also used, such as the Peruvian Coastguard Dirección de Capitanías y Puertos (DICAPI) (www.dicapi.mil.pe) and the Instituto del Mar del Perú (IMARPE) (www.imarpe.gob.pe).

Communications

Broadcasts were made from 9 am to 3 pm, local time, from January 2009 to December 2010. The number of broadcast days per month varied. From January to March 2009 we broadcasted 20 days per month, from April to July 2009, 13 days per month; from August 2009 to May 2010, 7 days per month, and from June to December 2010, 8 days per month. Broadcasts were initiated by us on an open 'work frequency' used daily by fishermen throughout Peru, and whenever fishers were interested in more information, they would respond and initiate a conversation. Further in this conversation they would usually request to go into a personal frequency to provide marine fauna information and fishing areas used.

Fisheries information

Communications were two-way and in real time, preferable with fishing vessel captains. During each radio conversation we requested the boat name and ID, tonnage capacity, port of origin, date of departure and estimated date of arrival in home port, number of crew, fishing gear used, position on the boat of the person contacted (e.g. crew, captain), target species, fishing area used and any further information of fishing effort (type and number of hooks, number of fishing net panels) and their contacts (phone number, common radio frequency used, email). We registered information of turtle bycatch location, numbers captured, final fate (released live, discarded dead or retained for consumption), condition of capture (i.e. entangled, hooked) and species, if identified. Radio broadcasters were biologists and veterinarians, trained in handling, resuscitation and release techniques, thus whenever turtle bycatch was reported, we provided instructions on marine turtle safe handling and release, based upon United States National Marine Fisheries Service onboard observers protocols (NMFS-SEFSC, 2008). Our contact details were also shared with fishers, including name, phone number, address and email.

Results

Broadcasting coverage

We obtained a total of 535 communications of which 74% were with vessels who had previously communicated with us (2.3 ± 2.5, range: 1 - 22 contacts, n = 535) (Fig 1). The program reached 234 small-scale fishing vessels from 18 fishing ports, from Manta, Ecuador to Iquique, Chile, giving a broadcast range spanning over 3,000 km of coastline (Fig 3). The number of communications per port of origin was, by an order of magnitude, led by Ilo, Paita, Pucusana, Ancon, Callao and Chimbote ports with others constituting much smaller proportions of contacts (Fig 2).

Contacts

Over 239 days of communications only 16.3% (39 days) had no contacts with fishing vessels. The overall rate of radio contacts was 2.4 vessels daily (SD ± 1.7, range: 0 - 7, n = 239 days). A total communication time of 208h was obtained. Average talk time per contact was 23.8 min (SD ± 11.9, range: 3 - 117 min, n = 522). Considering that at least one fisher per vessel (n=234) heard the conversation, we estimate that at least 234 fishermen were reached. However if one also includes the number of crew onboard per communication (6.3, SD ± 2.3, range: 3 - 22, n = 437 trips) for all contacts (n=535), we estimate that as many as 3370 fishermen may have been reached by this program.

Fisheries description

In most cases we contacted the fishing captain (89.9%, n = 535), followed by crew member (8.8%) and the cook on board (1.3%). Most of the contacts were with longline vessels (80.4%), followed by gillnet boats (15.0%), jiggers targeting squid (3.4%), purse seiners (1.1%) and one trawler (0.2%).

Reported fishing areas showed that longliners operated extensively from Ecuador to Chile, and as far as 600 nm offshore. Jigger boats stayed close to the coast, operating primarily from northern ports. Gillnet vessels operated mostly within and on the edge of the continental shelf, and were less common towards the southern coast. The limited number of locations reported by the purse seiners precluded further insights into possible pattern of distribution of this fleet (Fig 3).

Reported target species included dolphinfish *Coryphaena hippurus* (57.9%), elasmobranchs, mostly blue *Prionace glauca* and mako sharks *Isurus oxyrinchus* (25.0%), swordfish *Xiphius gladias* (7.0%), Humboldt squid *Dosidicus gigas* (4.7%), bonito *Sarda chiliensis chiliensis* (2.2%), Patagonian toothfish *Dissostichus eleginoides* (1.5%), anchoveta *Engraulis ringens* (0.9%) and schooling fishes (i.e. chub mackerel *Scomber japonicus*, Chilean jack mackerel *Trachurus murphyi*) (0.5%).

The average reported capacity given in gross tonnage GRT was 13.0 tn (SD ± 8.9, range: 4 - 70, n = 227 vessels). Vessels of 6 - 15 GRT were the most common (80.7%, n = 227 vessels), with a minority of vessels from 30 - 70 GRT (6.4%).

Because most communications were with longline boats, we obtained more detailed information for this fishing method. The type of hook used varied within the 'J' shape hooks from number 1 to 14 (the higher the number, the smaller the size of the hook). A higher percentage of vessels used number 3 (19.5%, n = 430 trips), number 5 (29.8%) and number 2 (15.8%). The mean number of hooks reported by longline vessels was 1680.6 (SD ± 521.7, range: 700 - 4000, n = 410 trips).

Turtle bycatch

From a total of 535 communications, 44.3% fishers reported incidental turtle captures, totaling 1395 animals. The majority of the bycatch was of hard-shelled turtles: green turtles (74.3%), loggerhead turtles (17.5%) and olive ridley turtles (5.7%). Leatherback turtles composed 2.5% of reported bycatch.

Of the reported turtle bycatch, 52.5% were entangled and 47.5% were hooked. In most cases (97.3%), these turtles were released alive; however, 1.9% turtles were discarded dead and 0.7% were retained when dead and consumed as food onboard.

Reported bycatch was higher during the summer while the lowest number of events was reported in spring for all species (Table 1). Although green turtle interactions were reported from most of the range, they appeared to be particularly common in central areas (Fig 4). This species appeared to have a more northerly distribution in winter/spring (Table 1). A generally northerly distribution was evident for interactions with olive ridley turtles, which also were more prominent in winter/spring (Table 1, Fig 4). Conversely, reports of loggerhead interactions had a more southerly distribution (Table 1, Fig 4).

Although leatherback interactions were least numerous, they spanned the whole latitudinal range of the study. All locations for loggerhead turtles were off the continental shelf in contrast with the other turtle species (Fig 4).

Follow-up contacts and other bycatch

In fifty-seven communications, other bycatch was reported, including Procellariform seabirds (54.4%), cetaceans (36.8%) (dusky dolphins *Lagenorhynchus obscurus,* common dolphins *Delphinus* spp., bottlenose dolphins *Tursiops truncatus,* humpback whales *Megaptera novaeangliae*), and sea lions *Otaria flavescens* (5.3%); and manta rays *Manta birostris* and *Mobula sp.* (3.5%). During 10 communications, fishers reported metal identification tags found on seabirds and turtles.

We received follow-up contacts from forty-seven vessels, via cellular phone calls reporting bycatch events. We also received visits in Lima, by four fishers interested in personally meeting program staff and obtaining educational materials on sea turtles and the target species. Additionally, an email account was created, and we received seven emails from fishermen providing pictures from their cell phone cameras.

Radio used as a safety tool

On four occasions we assisted vessels that were damaged or adrift. We worked as a bridge between these vessels and the Peruvian Coast Guard, local fishing association or their families, since direct contact from the vessels was not possible. Further assistance in coordinating their rescue was also provided.

Discussion

Very quickly, the benefits of this low cost program have become apparent as an alternative route to engage fishers in marine conservation offering a means to mitigate the impact on fisheries on sea turtles. We decided to provide a salary to the staff running this program (ca. 200 USD/month for part time personnel). However, costs can be reduced if the program is runned by trained volunteers, especially when limited funding is available. The radio program covered a vast area (from Ecuador to Chile), and the real time communications with fishers offered a unique opportunity to exchange information that benefited their fisheries (i.e. temperature, wind directions, tides); but also was able to identify areas of potential high turtle bycatch, later reported back to fishers as a warning to fish with caution.

The number of small-scale vessels in Peru has been estimated at circa 9000 fishing vessels (Chapter 3), thus our program reached 2.6% of this total for the country. However, the number of fishers reached through this study was possibly as many as 3000, highlighting the opportunity offered by this program to engage large numbers of active fishers in conservation programs. Also the personal contacts provided by the fishers (i.e. email, phone number), provided channels for further communication to be explored, especially for those with emails or social network accounts.

Similar efforts using communication to prevent loggerhead turtles bycatch in high-use areas has also been undertaken in the Hawaii-based longline fleet (Howell et al., 2008). Through the 'turtle watch' program, Howell et al. (2008) consolidated information on reported bycatch, sea surface temperature and satellite telemetry data, to create and distribute maps on areas of high-use of loggerheads in the North Pacific. Correspondingly, communications within the US north Atlantic longline and north Atlantic and Alaska trawl fleets, have been used to reduce fleet-wide bycatch of sea turtles, seabirds and certain crustaceans and fish species (Gilman et al., 2006).

The vast majority of contacts were with the small-scale longline fleet. Given the continued growth of this fishery in the country (Chapter 1; Estrella & Swartzman, 2010), this program has future opportunities to work and extend together with this fishery that operates widely in the southeast Pacific region. The general characteristics of the fleet obtained from the radio program (i.e. size of vessel, capacity in tonnage), were similar to those obtained from government records (Estrella & Swartzman, 2010) and onboard observers program (Chapter 1). Fishing areas used by each of the net and longline fleets - within and off the continental shelf respectively - were also consistent with those identified through onboard observer programs (Chapter 3). The species specific spatial patterns of bycatch locations reported were also in broad concordance with those obtained by onboard observer programs (Chapter 3). Additionally, seasonality of bycatch peaking in the summer season (December-March) concurs with other studies for the same region (Hays-Brown & Brown, 1982; Donoso & Dutton, 2010; Chapter 3). These overlaps in the fisheries operations and fishing areas used by small-scale fisheries, as well as in species seasonality and spatial distribution, confirm the accuracy of programmes such as these.

The final fates of captured turtles reported via radio indicated that the vast majority were released alive, with a minority being discarded dead or retained when dead for eating onboard. Similar patterns were documented by onboard observer programs for longline fisheries with observers onboard (Chapter 3). No fisher, however, reported via radio to have retained a live turtle for consumption onboard, which may be due to the uncertainly by fishers as to how such information would be used.

The radio program offered direct benefits to the fisheries (i.e. advice on oceanographic features, alarm events, hazardous presence of manta rays for small vessels). The use as a safety tool, in cases where vessels were adrift, was a serendipitous service provided by this program. Considering that safety at sea is a particular weakness in small-scale fisheries (FAO, 2008), the radio can be seen as a backup or alternative plan for vessels that have no other safety devices for at-sea emergencies (e.g. distress radio beacons). The radio program, which is still in operation daily, is now also transferring to fishermen information on market prices for their catch, allowing them to better time their return to port or choose a port with a better price.

One of the major advantages of the use of this radio program included the direct, personal contact established with the main stakeholders involved in turtle conservation at sea, promoting an opportunity to establish a relationship of trust with individual fishermen located in remote areas. Our communications were mostly with the captain of the vessel (ca. 90%), noting that the captain is the major authority in the vessel (Bureau of Labor Statistics, 2010) and the one responsible for overseeing the fishing operation and the most likely to make decisions related to bycatch (i.e. release, keep for use or sale). Contacting these individuals is considered optimal for the promotion of safe release methods for the sea turtles obtained as bycatch.

Small-scale fisheries in the southeastern Pacific are among the largest in terms of the number of fishing vessels (CPPS, 2003; Stewart et al., 2010). We used a widely available technology, which if linked with other similar stations in the region, could act as a mass media tool. Its relatively low cost when compared with other forms of educational campaigns and mitigation measures, highlights this approach as an alternative for situations where fisheries are highly dispersed, making traditional outreach methods cost prohibitive. Our trade of information principle could be expanded into different fleets and could be used to conduct rapid assessments of local fisheries, implement networking within fleets and generally encourage the active participation of fishers in marine conservation.

Acknowledgements

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Table 1. Number of turtle bycatch reported by port. Presented by Quarterly: Autumn (Q1: 22th April - 21th June), Winter (Q2: 22nd July – 21st September), Spring (Q3: 22nd October-21st December) and Summer (Q4: 22nd December – 21st March).

Ports	***Chelonia mydas***				***Caretta caretta***				***Lepidochelys olivacea***				***Dermochelys coriacea***			
N→S	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Manta				3								1				
Paita	20	44	25	73					5	30	2	11	1	1		2
Bayovar																
San Jose																
Salaverry	7			13				1				2				
Chimbote	59	13		67	1			3	1			2		1		3
Huacho	4															
Chancay	3			16												
Ancon	6	17	13	262		5		30		5		10				7
Callao	17		2	70	1			6	1				2		2	1
Pucusana	57	2	8	186	19			26	2			5	3	1	2	6
Pisco			1	4												
San Juan	8			5	24							2				
Planchada	1															
Ilo	12			3	29	10		74					1			1
Morro	1				3											
Vila																
Iquique					12								1			
TOTAL	195	76	49	702	89	15	0	140	9	35	2	33	8	3	4	20

Figure 1. Number of communications per vessel (N=535). From 2 to over 11 (11- 22) contacts per vessel.

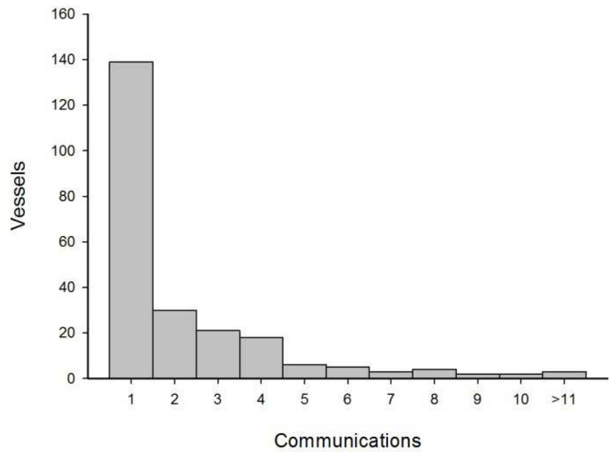


Figure 2. Percentage (%) of communications per port. Ports listed from north (Manta) to south (Iquique) (N=535 communications).

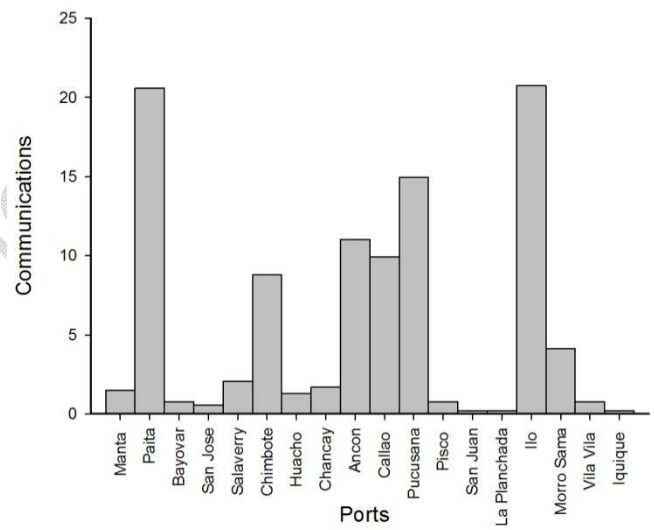


Figure 3. Fishing areas used by gear type: Gillnet (■), Jigging (○), Longline (□) and Purse-seine (●). Manta (-0.95 S, -80.7 W) in Ecuador and southernmost location for longline are not shown. EC: Ecuador, PE: Peru and CH: Chile. Ports denoted by ▲. Location of Radio station at Lima is marked by an arrow next to Callao port.

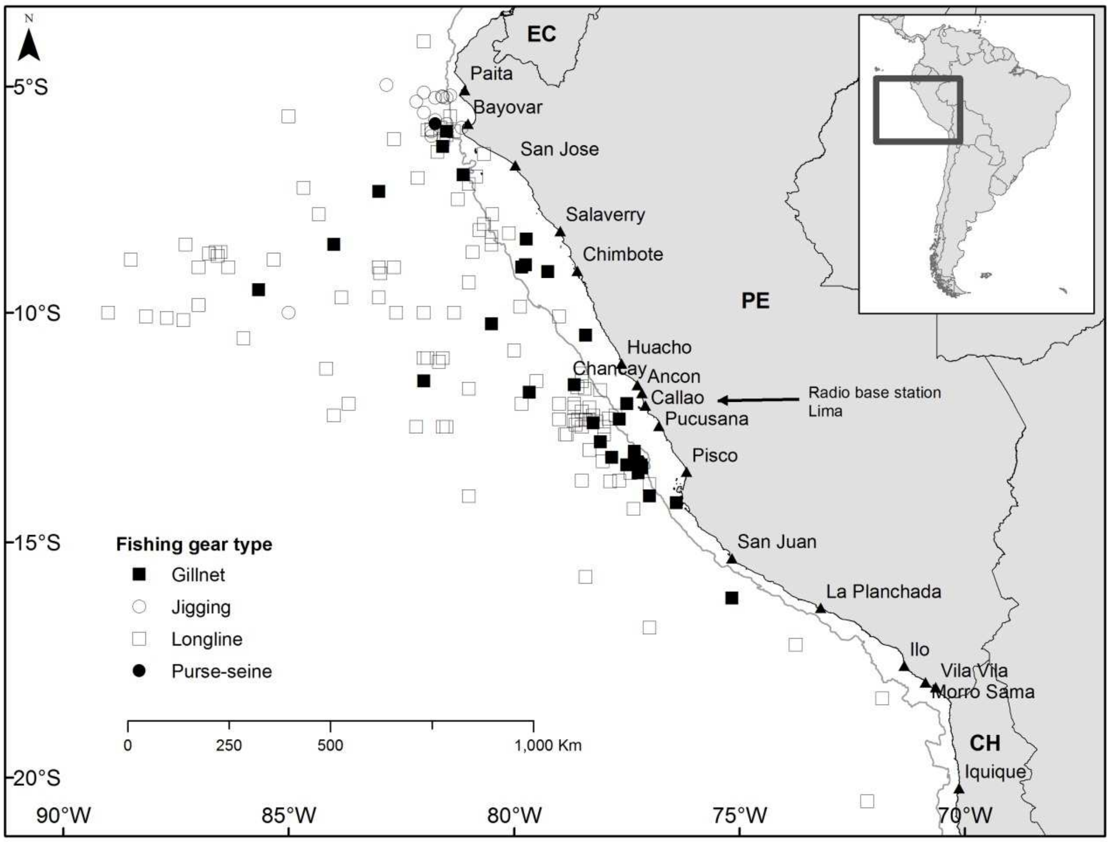
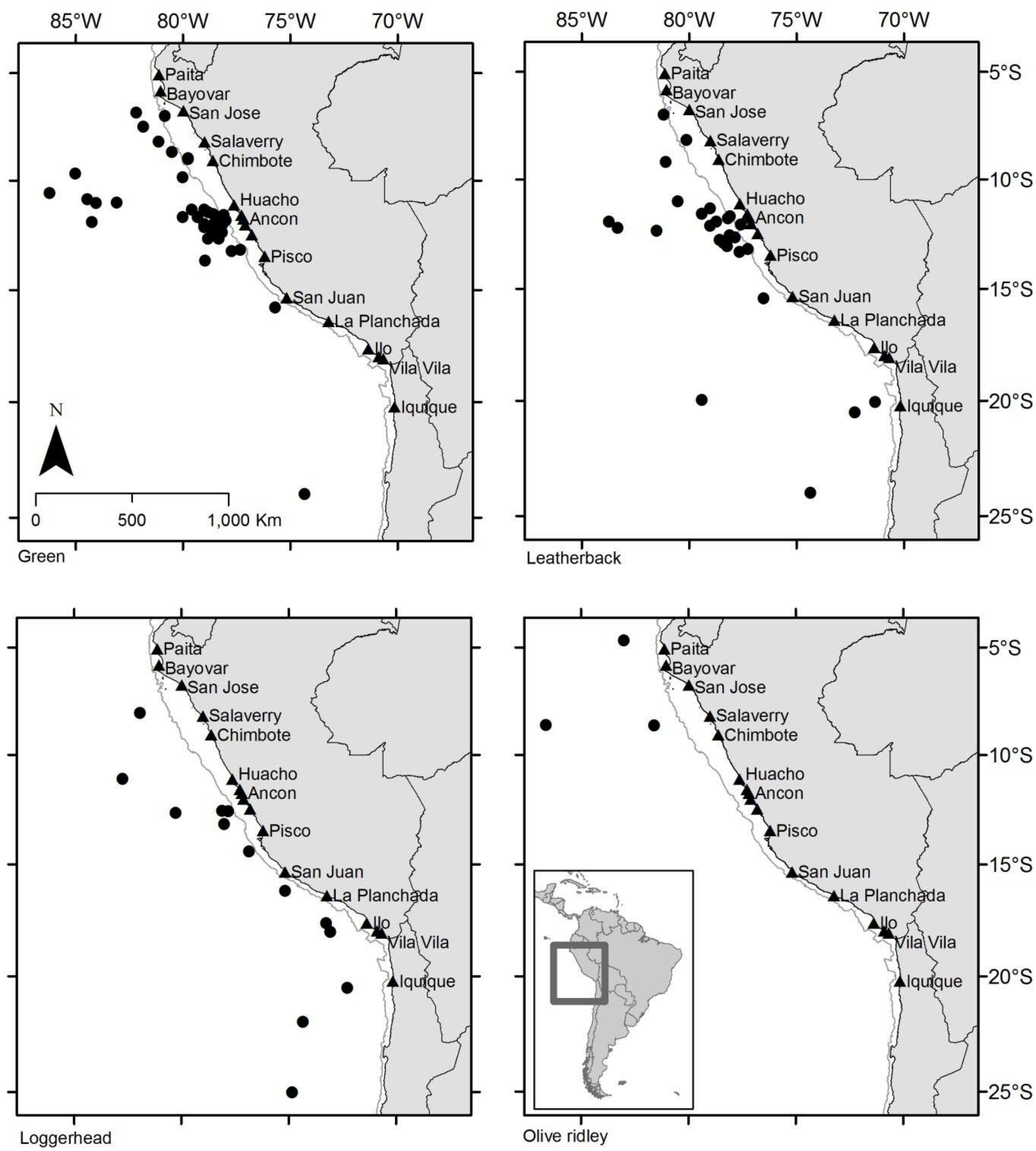


Figure 4. Turtle captures with available location data are represented by dark circles. Each graphic represents a turtle species, from left to right: a. Green (*Chelonia mydas*, n=45), b. leatherback (*Dermochelys coriacea,* n=27), c. loggerhead (*Caretta caretta,* n=14) and olive ridley (*Lepidochelys olivacea*, n=3). Ports denoted by black triangle. Manta, Chancay, Callao, Pucusana and Morro Sama are not shown.



General Discussion

Small-scale fisheries (SSF) support the livelihoods of ca. 200 million people (McGoodwin, 2001) and supply food to more than 1 billion people worldwide (Béne, 2006), although there are limited efforts in understanding their distribution, magnitude in number of vessels or fishermen, and even less regarding their impacts on marine wildlife (Mora, 2008). This is particularly true when considering the impact of SSF on marine turtle populations. Recent interest in this subject was raised due to an article by Peckham et al. (2007), where numbers of turtles incidentally captured by SSF in Baja California was comparable to those caught by industrial fisheries.

Since this article, several more papers presenting empirical data on the impact of SSF on marine turtles have been published (Lee Lum, 2007; Casale, 2011). However, these valuable efforts tend to overlook the associated information related to these fisheries, including the magnitude of the problem, fisheries information associated with the bycatch (i.e. distribution of fishing effort, fishing gears) and the livelihoods of those associated with these fisheries, who are usually highly dependent upon fishing resources. This is mostly due to the fact that work with SSF faces numerous logistical challenges (e.g. activities are widely dispersed, usually located in remote areas, operated by marginalized communities) (Salas et al. 2007), and these fisheries operate under minimal management conditions (e.g. open access fisheries regimes, non-mandatory onboard observers; Salas et al., 2007; Moore et al., 2010). These conditions make further assessments of turtle bycatch in SSF exceedingly difficult.

This thesis presents the first assessment of the interactions between marine turtles and SSF in Peru, and highlights the feasibility of assessing bycatch in these fisheries; and shows how these long-overlooked fisheries can pose a significant threat to marine turtles - representing an equal or in some cases a higher risk to marine turtles than that posed by industrial fisheries (Lewison and Crowder, 2007; Peckham et al., 2007; Casale, 2011).

The description presented in the first chapter of the operation of the most common fishing gears used by SSF in Peru, such as gillnets and longlines, indicated that they can have different impacts, but also highlighted the continuous growth of the fisheries itself as the human population in coastal environments grows. It makes clear the impacts of SSF on marine turtle populations and also the complexity of associated characteristics of Peruvian SSF (e.g. highly mobile, rapid evolution of fishing gears). Chapter two provides a close-up view of how different fishing gears affect a given demographic segment of the loggerhead turtle. In this particular fishery, given the characteristics of the bycatch (e.g. most turtles are released alive, almost no retention of turtles was reported to be used for food), we highlighted, for the first time, opportunities for regional conservation work with countries sharing the same resource (i.e. foraging stocks in Peru and Chile originating in Australian and New Caledonian nesting rookeries) (Alfaro-Shigueto et al. 2004; Boyle et al. 2009; Mangel et al. 2011). The third chapter proposes the combination of methods to assess turtle bycatch, delineates the turtle populations where Peruvian SSF has an impact but also provides the first estimation of turtle bycatch for the country. I note that the use of turtles for food is not uncommon in many coastal communities in Peru (marine bushmeat) and discuss the relationship noted by Brashares et al. (2004) between bushmeat trade and fisheries in Africa, and how in Peru, a fisheries dependent country due to its geography, creates additional pressures to exploit marine bushmeat. The fourth chapter revisits gillnet fisheries but for a wider geographical region. Using survey questionnaires we assessed turtle bycatch by net fisheries from Ecuador to Chile, and validate this data with other data obtained by more traditional empirical methods. From this regional assessment, we once again gather valuable information on SSF for multiple countries (i.e. number of fishing vessel per port, fishing gear composition, demographics of fishermen by country), and show that these fisheries are vast in Ecuador although given the turtle populations affected, SSF in Peru and Chile also deserve continued attention. The fifth chapter proposes the use of a High Frequency radio program conducted in real-time with fishermen at sea as an alternative means to prevent turtle bycatch. This program showed efficiency in coverage of fishing ports from Ecuador to Chile, acceptance by fishermen and is a tool that can be used to promote sustainable SSF in the region.

Future work building upon these studies is necessary and should include work the following topics: finer scale information is necessary for Ecuadorian SSF and could be gathered and compared using the methodologies described here for Peru (i.e. shore-based and onboard observers, surveys, HF radio programs to prevent bycatch); the use of turtle as food remains a widespread practice and should not be disregarded given continued human population growth and depletion of fisheries, and may necessitate dramatic changes and improvements in management in the near future. More work is also recommended with leatherback and hawksbill turtles (the two critically endangered species in the region) as their rarity makes it particularly challenging to understand their distribution and overlap with fisheries. A regional, coordinated effort exists for hawksbill turtles (Gaos et al, 2010) and a similar effort should be developed for the leatherback. On a positive note, we have found that identifying key fishermen leaders in communities with high bycatch, who can serve as liaisons for conservation initiatives, is an effective means to identify or adapt other conservation plans and a means to involve small-scale fishermen in finding and implementing solutions. Small-scale fisheries can benefit from bycatch reduction in a number of ways (e.g. reduced net damage, time savings, eco-labeling) and there is a clear need to find the opportunities and overlaps where fishermen can be linked with potential bycatch solutions. Given the size and importance of small-scale fisheries globally there is a clear need to promote the long-term sustainability of these fisheries, both for the communities they serve and the marine fauna with which they interact.

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