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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.

1. 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 (Béné, 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 com-

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plex 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 1990s (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 has 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 15 m 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, 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.

2. 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.

2.1. *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).

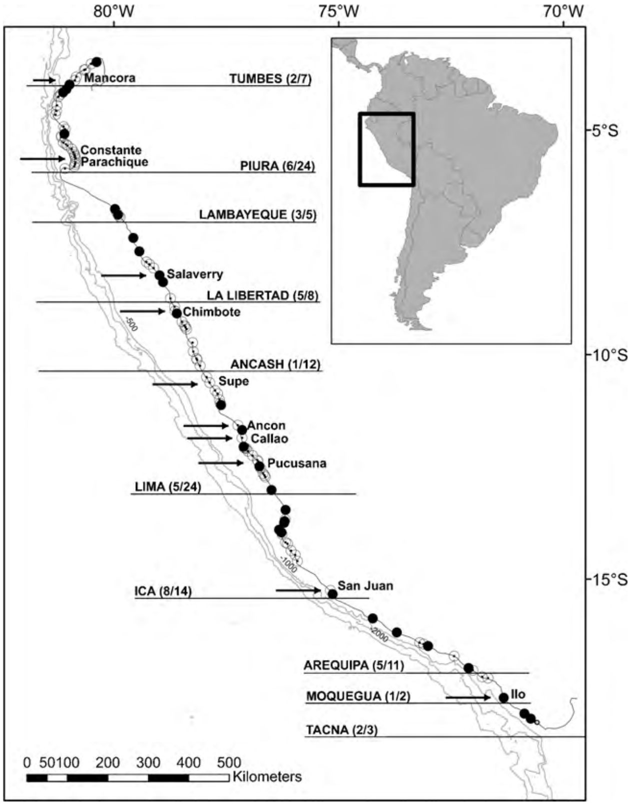

Fig. 1. Distribution of small-scale fisheries (SSF) in Peru. Map shows the location of all fishing harbors. Filled circles denote site used in this study. Horizontal lines demarcate geopolitical regions of Peru (cf. Table 2 and Estrella (2007). The proportion of harbors in each region subject to investigation 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).

2.2. *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.

2.3. *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 sample 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, 1991; 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

Table 1
Fishing ports sampled with on board observers (2002–2007) (Fig. 1). Check marks indicate observed bycatch.

Ports	Number of trips	Number of sets	Number of 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					

[a] Alfaro-Shigueto et al. (2007).
[b] Alfaro-Shigueto et al. (2008).
[c] Mangel et al. (2010).
[d] Awkerman et al. (2006).

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	13 050	+43	2200	2898	+32	308 969	226 743	−27	140	78	−44
Lambayeque	2938	1422	−52	285	222	−22	40 519	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

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.

3. Results

3.1. 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.

3.2. 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 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 elasmobranches 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 remained stable (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).

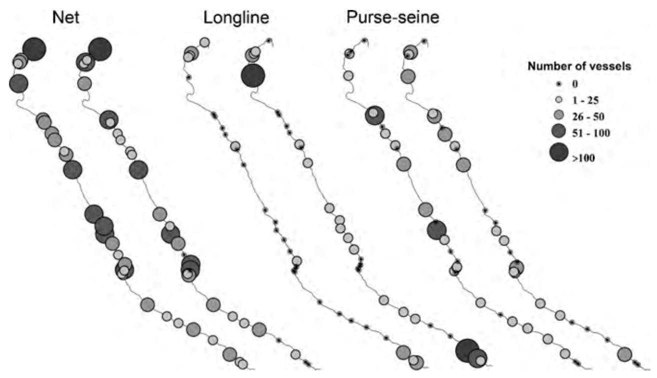

Fig. 2. Coastline maps of Peru showing the change in distribution of net, longline, and purse seine vessels at each sampled port ($n = 30$; cf. Appendix 1) from 1994–1995 (Escudero, 1997; left map of each pair) to 2004 (this study; right map of each pair). Number of vessels is indicated by the scaled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

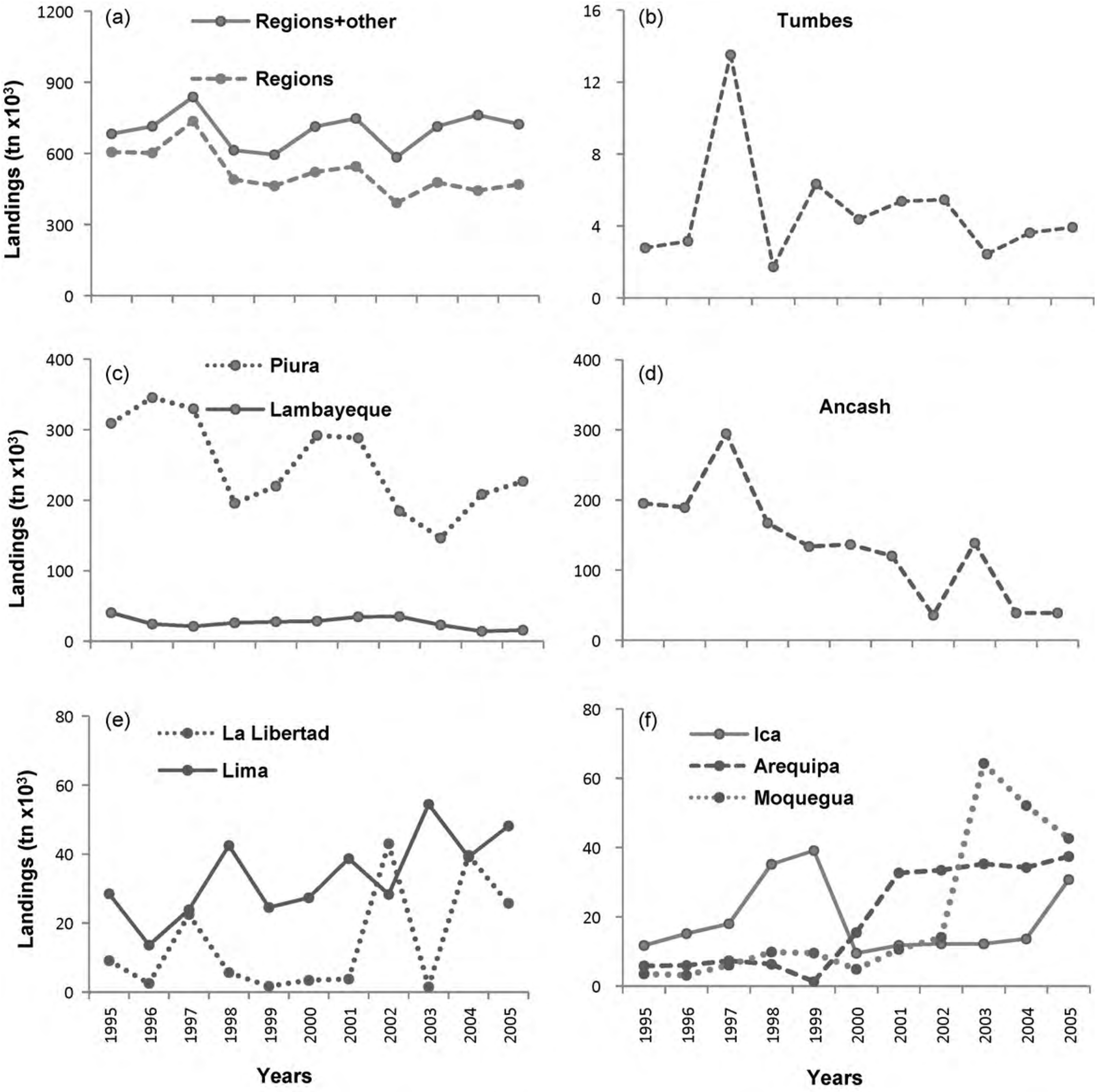

Fig. 3. SSF landings in thousands of tons for human consumption for (a) overall SSF, where 'other' includes landings from unspecified origin and (b–f) by geopolitical region (1995–2005).

3.3. *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 2176 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.

3.3.1. *Longlines*

We sampled longlines fishing for dolphinfish (*Coryphaena hippurus*) (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.

3.3.1.1. General description. All longline trips monitored set their gear at the sea surface and 99% of sets occurred in oceanic waters >200 m in depth (4181.6 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.

Table 3
Description of driftnets and longline fisheries.

	Gillnet		Longline	
	Driftnet	Bottom set	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 mahi mahi, bonito	Sharks, rays flounder, lobster	Mahi mahi	Blue and shortfin mako
Vertebrate bycatch				
Turtles	√	√	√	Low
Seabirds	√	√	√	Low
Mammals	√	√	0	Low
Trips observed	53	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 (m)	–	–	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 (1.8 mm)	Steel cable plastic coated (2.2 mm)
Weighted swivels	–	–	39.7–42.2 g of steel or nickel	
Total hooks observed	–	–	878 947	749 724
Hooks/set	–	–	955 ± 444 (350–2000)	
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 × 42 g/each	6 units × 2 kg/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 h, *n* = 905)	3:58 ± 6.0 h (0:30 min–22:24 h, *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 ($US)	2000–2400 (based on materials cost for pane and an average number of panes of 20$US)		2500–3000 (based on material costs to equip a vessel with 1500 hooks)	
Gross gain/trip ($US)	1056.8 ± 1224.2 (17.2–5544, *n* = 46)	82 ± 257.4 (0–1017.4, *n* = 17)	3437.3 ± 3236 (839–11 250, *n* = 25)	6294.4 ± 6278 (607–24 091, *n* = 17)
Net gain/trip ($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% profit 1286 ± 2176 (−2716 to 6536, *n* = 28)	100% profit 2163 ± 3472.6 (35.7 to 11 393, *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 (500–12 698, *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

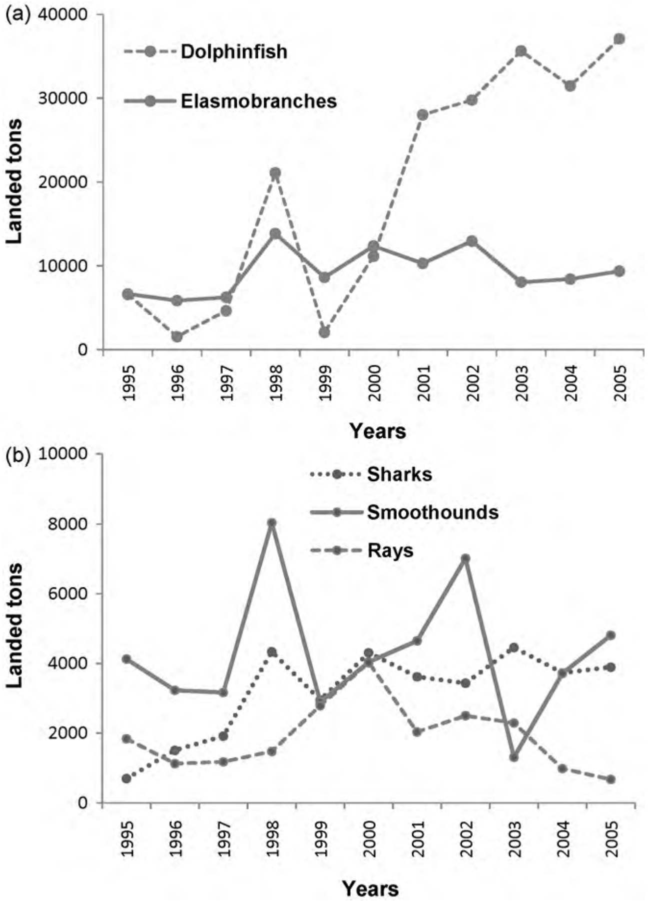

Fig. 4. Landings in tons of target groups for longlines and gillnets (1995–2005) (a) dolphinfish and total elasmobranches and (b) sharks, smooth hounds and rays.

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 4–5 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.

3.3.1.2. Profitability. Based on the 2007 market prices of materials, the cost to fully equip a longline vessel with 1500 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.

3.3.1.3. 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

3.3.2. 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 (<200 m 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.

3.3.2.1. 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 (9–27 m). Profits were distributed based upon the number of net panes 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 panes 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 ridley 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.

3.3.2.2. 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 panes used per trip was 20.2 ± 4.3 (10–36). The cost for materials for the entire gear was approximately $2000. Trip costs averaged $592.6, with 52% of trips being profitable and with a mean profit of $1056.8 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).

3.4. 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 1.9 km 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.

4. 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, fourfold 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.

4.1. 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.

4.2. 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 (Megalofonou et al., 2005).

4.3. 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, 2008) 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

5 nm 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).

4.4. 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; Alfaro-Shigueto et al., 2008) 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 (Campell and Cornwell, 2008).

4.5. 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 that 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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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.fishres.2010.06.004.

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