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

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Summary

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 *c*. 5900 turtles captured annually (3200 loggerhead turtles *Caretta caretta*, 2400 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, > 9500 vessels, > 37 000 fishers), and our observed effort constituted *c*. 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 impacts of 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 SSF by combining methods that account for fishing effort and bycatch, such as using onboard and shore-based observers. We highlight sea turtle bycatch in SSF in the southeast Pacific as a major conservation concern but also suggest possible paths for mitigation.

Key-words: BPUE, bycatch, Peru, small-scale fisheries, turtles

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

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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. increased fishing line weights to speed sink rates (Brothers, Cooper & Løokkeborg 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 SSF 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; Alfaro-Shigueto *et al*. 2008; 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 because of 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 because of their role in food security, but also as a source of employment (Alfaro-Shigueto *et al*. 2010). 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; Alfaro-Shigueto *et al*. 2010). The main fishing gears used include purse seines, gillnets, handlines, diving and longlines (Estrella Arellano & Swartzman 2010), with longlines exhibiting the steepest increases (Alfaro-Shigueto *et al*. 2010). 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 (3°S) to Pisco (13°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 analysis indicates that leatherback turtles off Peru originate 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), 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 $< 0{\cdot}8$ 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, 2008). Here, we generate robust estimates of the species composition and magnitude of turtle captures in four SSF at three sites spanning the Peruvian coast. We aim to provide an insight into of 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 (Alfaro-Shigueto *et al.* 2010). 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 (Alfaro-Shigueto *et al.* 2010). 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 (Alfaro-Shigueto *et al.* 2008). 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, KY, USA). For injured and comatose turtles, handling and resuscitation techniques were followed as described by the Southeast Fisheries Science Center, USA (http://www.sefsc.noaa.gov/species/turtles/observers.htm). For each capture event, observers recorded whether the turtle was (i) entangled, (ii) hooked or (iii) 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.

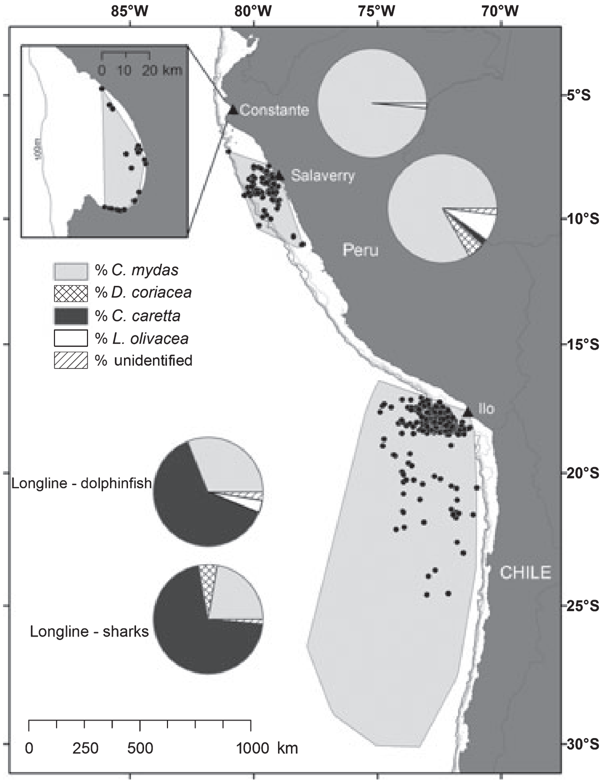

Fig. 1. Fisheries sampled (N to S): Constante (bottom set nets), Salaverry (driftnets) and Ilo (longlines). Fishing areas are indicated by polygons and represent each of the grounds used by each fishery based on set locations (represented by dots). Species composition of turtle bycatch for each fishery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

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).

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 per trip	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	

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 data base. 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 Appendix S1, Supporting Information for further information).

To make comparisons among fishing gears in terms of BPUE, we worked with basic units of turtle catch per set; however, to facilitate comparison with other studies, catch per km of net and catch per 10^3 hooks for longlines were also calculated. Descriptive statistics are presented as mean $\pm$ 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 per set) and for loggerhead turtles in the dolphinfish longline fleet (39%; 1·42 turtles per set). 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 *c.* 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 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 $\pm$ 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 $\pm$ 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 Papua New Guinea (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 $\pm$ 9·3 cm (42–75·5). Minimum carapace length of females nesting in the Pacific rockeries 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 $\pm$ 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 (Alfaro-Shigueto

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 bycatch per unit of effort (BPUE) per set 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									
		Live		Dead		Mode (%)									
	Species (*n*)	Retain	Release	Retain	Discard	H	E	H/E	Set+	BPUE per set	Mean Catch	Released	Live Retain	Dead	Mortality
Bottom set net	*Chelonia 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
	Lepidochelys 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
	Caretta caretta (1)	–	–	100	–	–	100	–	0·003	1	15 (10–22)	0	0	15 (5–15)	15
	Dermochelys 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

et al. 2010) 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 per set). 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 (Alfaro-Shigueto *et al.* 2010), 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 neighbouring Ecuador and Chile to address the impacts of longlines and gillnets at wider geographic scales.

For longline fisheries, we recorded 635 turtles captured with an effort of *c.* 900 000 hooks. The annual effort for small-scale longline fisheries in Peru is estimated at 80 million hooks (Alfaro-Shigueto *et al.* 2010). For net fisheries, we observed 838·3 km of nets set in which 172 turtles were caught. This compares with *c.* 100 000 km of nets deployed per annum nationwide (Alfaro-Shigueto *et al.* 2010). 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 allow 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)

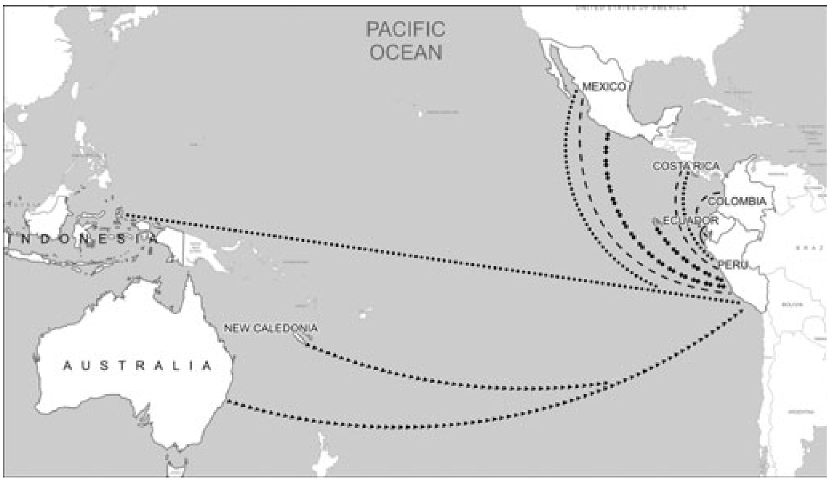

Fig. 2. Schematic view of linkages of turtles breeding stocks to Peruvian foraging grounds. Leatherback turtles (•): western and eastern Pacific rockeries (Eckert & Sarti 1997; Shillinger *et al.* 2008; Dutton *et al.* 2010). Olive ridleys (– –): Colombia, Mexico and Costa Rica (Zeballos & Arias-Schreiber 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 rockery for the species.

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 are 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 south-eastern 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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Supporting Information

Additional Supporting Information may be found in the online version of this article.

Appendix S1. Supplemental methods. Equation to estimate Bycatch per unit of effort (BPUE) and mean estimated catch of turtles.

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

Table S2. BPUE per set values given per month by fishery and by species, number of sets (No. sets) and number of sets with bycatch (set+).

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