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Assessing the small-scale shark fishery of Madagascar through community-based monitoring and knowledge

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ABSTRACT

Over 90% of those employed in commercial capture fisheries work in the small-scale fisheries (SSF) sector and an estimated 97% of small scale fishers are found in least developed countries. However, the capacity for monitoring SSF globally is low and there is a paucity of data, in particular for remote areas within developing nations. The methods presented here demonstrate a low cost participatory approach for gathering data on small-scale fisheries, in particular for those that take place across remote areas. Community-based data collectors were trained to record biological and socioeconomic data on the traditional (non-motorised) shark fishery in the Toliara region of Madagascar over a six year period (2007–2012). An estimated 20 species of shark were recorded, of which 31% (n = 3505) were *Sphyrna lewini* (scalloped hammerhead), a species listed by the IUCN as Endangered (IUCN, 2016). Although the number of sharks landed annually has not decreased during our survey period, there was a significant decrease in the average size of sharks caught. Despite multiple anecdotal reports of shark population declines, interviews and focus groups highlight the possibility that shark landings appear to have been maintained through changes in gear and increases in effort (eg. number of fishers, time spent fishing), which may mask a decline in shark populations. The numbers of sharks taken by the traditional fishery in our study region was estimated to be between 65,000 and 104,000 year^{-1}, whilst estimates using national export and import of dried shark fin from Madagascar, and shark length data in this study, put total landings between 78,000 and 471,851 year^{-1}. Reliable data on the total volume of sharks landed in Madagascar's waters is scarce, in particular from foreign industrial boats both directly targeting shark species and as bycatch in fisheries targeting other species. There is currently no legislation in place to protect sharks from overexploitation in Madagascar and an urgent need to address the lack of shark fishery management across the traditional, artisanal and industrial fisheries.

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1. Introduction

There is a paucity of information on take and bycatch from small-scale, traditional and artisanal fisheries often due to their remoteness, seasonality, and the numerous landing sites and vessels used (Salas et al., 2007). This is despite the fact that over 90% of 120 million employed in commercial capture fisheries work in this sector (Béné et al., 2007; World Bank/FAO/WorldFish Center, 2010). Worldwide, more than one billion people rely on fish as an important source of protein, and it can account for 50% of protein intake in the least developed countries in Africa and Asia (Béné, 2006), where 97% of coastal fishing populations are found (World Bank/FAO/WorldFish Center, 2010). Studies have shown that small-scale fisheries generate a significant proportion of household income. For example, it accounts for 82% of household income in some regions of Madagascar (Barnes-Mauthe et al., 2013), highlighting the importance of sustainable management strategies.

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The recorded global catch of chondrichthyans (sharks, rays and chimaeras) grew rapidly in the latter half of the 20th century, increasing from approximately 270,000 metric tonnes in 1950 to a peak over 900,000 metric tonnes in 2003 (FAO, 2013), largely in response to the increase in the fin market in Asia (Field et al., 2009). However, recent estimates using shark fin market data (Clarke et al., 2006) suggest that FAO figures underestimate the size of the fishery by up to four times; whilst Worm et al. (2013) have estimated that annual shark mortality (including reported landings, dead discards and illegal, unregulated and unreported take) has ranged between 1.41 and 1.44 million metric tonnes from 2000 to 2010 and equates to annual shark mortality of 63–273 million sharks. Sharks are landed both in small-scale and industrial fisheries. Although relative numbers on the volume of sharks landed in specific fisheries are scarce, many countries report significant landings figures from small-scale vessels (Blaber et al., 2009; Cartamil et al., 2011).

Accurate assessments of shark mortality across all fisheries are confounded by the fact that many sharks are finned at sea and discarded or discarded whole, as well as subject to Illegal, Unreported and Unregulated (IUU) fishing (Biery et al., 2011; Worm et al., 2013). These factors have led to a severe underreporting at all scales of fishing activity, from direct take to bycatch (Varkey et al., 2010; Le Manach et al., 2012). This underreporting and lack of official data means that managing shark fisheries presents a significant challenge, whilst threatening the long-term sustainability of these fisheries, and those that rely on them for their livelihoods and food (Shehe and Jiddawi, 2002; Vieira and Tull, 2008; Cartamil et al., 2011).

Sharks and other chondrichthyans are particularly vulnerable to overexploitation through direct take and bycatch due to their relatively slow growth and reproduction rates (Camhi et al., 1998). Coupled with the degradation of marine habitats, this has led to the decline in chondricthyan population numbers worldwide (Baum et al., 2003; Baum and Myers, 2004; Cortés et al., 2006; Ferretti et al., 2008; Hayes et al., 2009). As a result, there has been an increase in the number of shark species listed on the IUCN Red List, with a quarter of species estimated to be threatened with extinction, primarily due to overfishing (Dulvy et al., 2014; IUCN, 2016).

The status of shark fisheries in the Western Indian Ocean is poorly known (Kroese and Sauer, 1998; Le Manach et al., 2012). The rise in shark fishing in Madagascar coincided with the increase in demand for shark fins in Asia (Cooke, 1997), although shark fishing was known as far back as the 1950s (Fourmanoir, 1961; Cooke, 1997). Recorded exports increased rapidly in the late 1980s from 3 t in 1987 to almost 29 t in 1992, with a concurrent rise in local price for shark fin, and the majority of exports going to Hong Kong and Singapore (Cooke, 1997; Cripps et al., 2015). Official imports of shark fins to Hong Kong and Singapore from Madagascar, show growth from 34.5 t in 1986 to a peak of 64.7 t in 1995 (Le Manach et al., 2011, 2012). Despite discrepancies between export and import data (Le Manach et al., 2011, 2012; Cripps et al., 2015), overall trends show export data from the *Ministère des Ressources Halieutiques et de la Pêche* (MRHP) and imports of shark fins both peaking in the early to mid-1990s and declines until the early 2000′s; with increases again from 2004 (Cripps et al., 2015). In addition, there are reports of decreases in shark landings (Laroche and Ramananarivo, 1995; McVean et al., 2006) but shark fins remain a highly valuable marine resource, with the meat retained for local consumption (Cripps et al., 2015).

Previous studies estimate that around 30 chondricthyan species are regularly taken in Madagascar's coastal shark fisheries (Cooke, 1997), that are classified as traditional (local sailing boat which could include a motor) or artisanal (boat with a <50 hp motor) (Repoblikan'i Madagasikara, 1993, 1994). Active shark fisheries have been highlighted along much of Madagascar's coastline, with the SW and NE regions remaining hotspots for fishing and the trade of sharks and their fins (Cooke, 1997; Pascal, 2003; McVean et al., 2006; Doukakis et al., 2007; Robinson and Sauer, 2013). For example, in two villages in SW Madagascar, it was estimated that a total of 123 t of sharks were landed over a 13-month period (McVean et al., 2006).

High numbers of sharks are also landed as direct catch by national and international industrial boats fishing in Madagascar's waters (Randriamiarisoa, 2008; Le Manach et al., 2012; Cripps et al., 2015). Industrial bycatch of sharks has also been reported in the Malagasy longline fleet (Rahombanjanahary, 2012). Madagascar has also signed fishing access agreements with at least 10 fishing partners since 1986 (eg. countries, groups of countries such as the EU, private companies) with an estimated >100 foreign vessels allowed to operate in Madagascar's EEZ (M. Andriamahefazafy unpublished data; Le Manach et al., 2012; Cripps et al., 2015). Furthermore, reported landings demonstrate some foreign vessels are clearly targeting sharks in Madagascar's waters, with Spanish longliner vessels landing 152 MT of sharks compared to 13.98 MT of tuna in 2011 (European Commission, 2013). Le Manach et al. (2012) reconstructed total fisheries landings for Madagascar and estimated that the total catch of sharks is over 8000 t y^{-1} (3800 t y^{-1} domestic catches and 4300 t y^{-1} of catches by foreign vessels).

Here we present the first multiyear assessment of the status of the traditional (non-motorised) shark fishery in Madagascar that lands both sharks and guitarfish species (Rhinobatidae), primarily for their fins. This study set up a network of trained community-based data collectors in order to facilitate landings data collection over an inaccessible coastline, whilst building capacity for participatory fisheries monitoring. The results of this study are contextualised with available information on Madagascar-wide shark catch.

2. Methods

2.1. Study area

The study was conducted in 24 villages in two regions on the southwest coast of Madagascar, within the province of Toliara. Data collection took place in twelve villages surrounding the village of Andavadoaka (region 1; Fig. 1; Table 1) (22°04′19.94″S, 43°14′20.00″E), approximately 150 km north of the regional capital of Toliara from 2007 to 2012. Data collection took place in a further twelve villages and islands surrounding the village of Belo-sur-Mer (region 2; Fig. 1; Table 1) (20°55′4.92″S, 44°23′25.65″E), approximately 60 km south of the city of Morondava from 2008 to 2012. The study spanned over 175 km of coastline from Antsepoke in the south (22°15′50.14″S, 43°13′34.80″E) of region 1 to Ampatiky (20° 8′40.15″S, 44°22′10.55″E) in the north of region 2, as well as three offshore islands in region 2 (Nosy Be, Nosy Andravoho and Nosy Andriamitaroke) inhabited by migrant fishers. Region 1 is characterised by two distinct fringing and barrier reef systems separated by a 5 km wide channel in which are situated several patch reefs. Region 2 lies at the northern end of a 55 km long coral reef system, running roughly parallel to the shore at a distance of 10–15 km. This ancient, submerged barrier reef system, with its seven islands and associated shallow reef crests, extends over 600 km to the north.

The human populations in these coastal villages and islands are almost entirely composed of *Vezo* fishers and their families, semi-nomadic fishers who rely exclusively on the marine environment for their livelihoods (Astuti, 1995). The Toliara province has an estimated 186,658 fishermen (Cornell Census, 2001). All fishing is carried out using pirogues (small sailing canoes) or walking with nets, lines or spears, limiting most fishing effort to the nearby reef systems, with fishing at deeper, offshore sites only possible during favourable sea conditions.

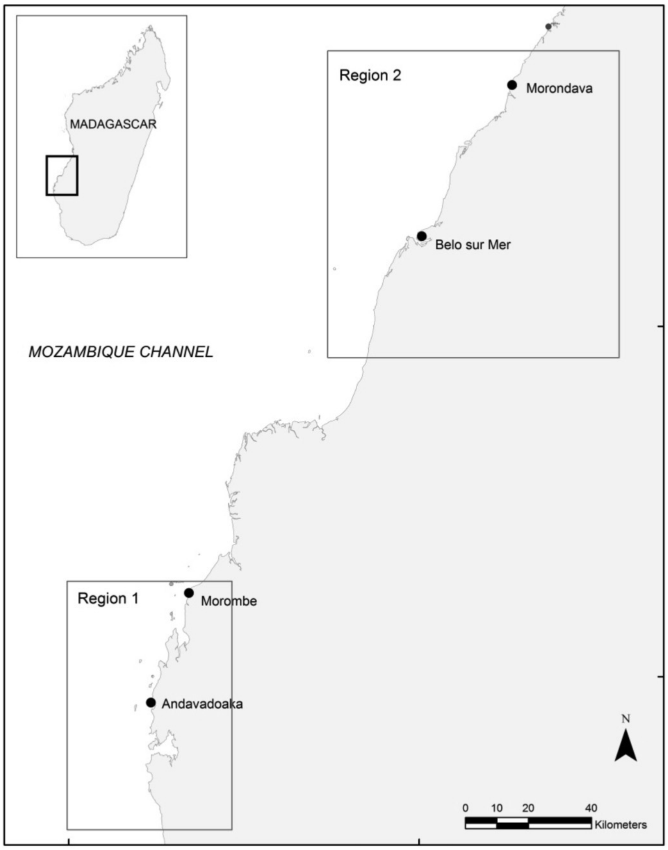

Fig. 1. Map showing the two regions of data collection within this study. Region 1 surrounds the village of Andavadoaka and Region 2 surrounds the village of Belo-sur-Mer. The two largest towns found in each region (Region 1: Morombe; Region 2: Morondava) are also shown.

2.2. *The monitoring programme*

To develop a profile of the shark fishery in the region, a monitoring programme was set up in region 1 in late 2006, and in region 2 in May 2008, that employed local community members as data collectors, known as "*sous-collecteurs*", in each of the 24 villages (Humber et al., 2011). Village presidents, elders or their relatives were, where possible, chosen as data collectors as they were typically in the best position to enable the monitoring programme to be accepted by the village residents, and were also more likely to have the required level of literacy skills. Approximately a quarter of data collectors were women at any one point during the monitoring period.

Data collectors were paid a base monthly salary of 15,000–25,000 (≈US$6–8) Malagasy Ariary (MGA) and an additional 300 MGA (≈US$0.14–0.16) for each landed shark they recorded (intended to be given to the fishers as a gift for allowing their shark to be measured). The average daily wage in the region is <US$2 and this payment acted to supplement their normal income.

2.2.1. *Data collection*

Each community member data collector was trained by the Project Coordinators and Project Assistants to record biological data, fisher demographics and catch-specific information for each shark in the initial training session (~1–2 h) in their village. The Project Coordinator and Assistants were Blue Ventures' employees, trained by the lead author. Training sessions consisted of explanations of how to collect each piece of information, how to enter it into the table in the notebooks provided, and practice with the measuring tape. Notebooks also contained diagrams of measurements. Data collectors were also trained to use a simple digital camera to record catch in order to check the reliability of the data and reduce the possibility of falsified data. For each shark landed, biological data: species, pre-caudal length (PCL) (cm), pre-first dorsal length (cm) and sex were recorded, as were fisheries data: fishing site, method of capture and name of lead fisher.

Table 1
Recorded shark landings for each village in the study. The number of months of monitoring per year is included in brackets. Region 1 = Andavadoaka and Region 2 = Belo-sur-Mer (Fig. 1). DR = Data removed during verification process. Dashes indicate no data collection occurred. Human population data from Oleson et al. unpublished data; Jones, 2012; ACDEM census; Local administrive centre data, unpublished.

Region	Village	Human population 2010	Recorded landings (months of data collection)						Estimated landings
			2007	2008	2009	2010	2011	2012	(2007–12)
1	Ampasilava	507	7 (12)	20 (12)	44 (12)	30 (12)	21 (12)	127 (12)	249
1	Andavadoaka	1419	573 (12)	326 (12)	592 (9)	DR	DR	DR	2478
1	Andranombala	168	125 (12)	98 (12)	99 (12)	35 (3)	DR	DR	589
1	Ankitambagna	97	30 (12)	49 (12)	0 (3)	1 (4)	22 (11)	27 (10)	140
1	Antsepoke	270[a]	16 (12)	13 (12)	13 (12)	3 (10)	47 (12)	70 (12)	166
1	Belavenoke	489	37 (8)	20 (12)	59 (10)	207 (10)	114 (12)	241 (12)	696
1	Bevato	531	40 (12)	170 (12)	65 (12)	110 (12)	101 (12)	149 (12)	635
1	Lamboara	612	79 (12)	72 (12)	301 (12)	1157 (12)	553 (12)	687 (12)	2849
1	Nosy Lava	350[a]	16 (10)	87 (5)	–	–	–	–	205
1	Nosy Mitata	39	–	–	–	–	–	10 (3)	60
2	Ampatiky	480[a]	–	197 (8)	674 (12)	199 (12)	284 (12)	213 (12)	1621
2	Ankevo	649	–	–	DR	DR	265 (11)	434 (12)	1232
2	Antanagnabo	193	–	–	–	–	–	58 (4)	82
2	Antsaranandaka	100[a]	–	39 (3)	–	–	–	–	129
2	Belagnora	170	–	29 (5)	–	–	–	–	36
2	Belalanda	471	–	126 (8)	–	–	–	–	150
2	Belo-sur-Mer	2594	–	120 (8)	2 (7)	–	–	–	156
2	Betania	1342	–	73 (8)	136 (6)	DR	9 (8)	36 (12)	311
2	Manahy	125	–	–	–	–	–	131 (4)	227
2	Nosy Andravoho	0–100[b]	–	–	109 (3)	198 (7)	–	–	434
2	Nosy Andriamitaroke	6–449[b]	–	65 (4)	328 (7)	908 (11)	–	–	1358
2	Nosy Be	15–232[b]	–	61 (1)	DR	DR	DR	53 (2)	1654
Total			923	1565	2422	2848	1416	2254	15457

[a] Estimation by Blue Ventures.
[b] Monthly census data collected between October 2009 and March 2011 by Blue Ventures.

Shark species names were recorded by their local name in Malagasy as they can vary between villages and regions (Cooke, 1997). Due to the highly diverse nomenclature for some shark species we could not draw up a comprehensive species name list with confidence for data collectors to use. In addition, from previous studies we knew the provision of a list of species meant that data collectors would try to categorise landings according to this list, even if the landed species was not found on the list (C. Gough personal observation).

Recorded nets used within the shark fishery were classified into four categories in this study, according to local names: *Jarifa*, a long gill net with the largest mesh between 12 and 25 cm; *Zdzd*, another long gill net that has a large mesh size of 8–10 cm; and *Janoky*, normally a smaller gill net with a smaller mesh size of 4–9 cm that is left overnight in relatively shallow water primarily to target finfish. The final category was simply categorised as *harata* ("net") and encompasses the locally produced nets that will have mesh sizes of 2–5 cm. It is important to note that sharks landed by any of these nets, or other fishing methods such as hook and line or longline, are difficult to clearly classify as targeted or bycatch (retained and sold but not the original target catch). Most fishers will use materials they have to hand, and may change their method of deployment depending on what is available to them (eg. bait for nets).

Community members were visited every 4–8 weeks by the Project Coordinator and/or Project Assistant, to retrieve data and review data collection methods throughout the six year period. Further training with the camera was given if photos were not of high enough quality, as well as any improvements in monitoring (eg. laminated cards showing shark species names to use in photos). The camera's memory cards were wiped after each data collection visit so no accidental replication of photos could occur.

2.2.2. Data verification

Data were entered into an excel spreadsheet by Project Coordinators and Assistants and cross-referenced with the original paper records (by the lead author). Data were removed that did not meet a strict verification process during cross-checks with digital camera records, with only confirmed original records included. Therefore 9307 data records were removed during this process where inconsistencies between the data book and photographs were spotted, including data from two villages in region 1 (Nosy Hao and Nosy Be) removed completely. The majority of inconsistencies were the use of the same shark to create multiple photos and lines of landings data. By removing all duplicates from any month-year where duplications were spotted, we aim to have increased the robustness of these data and ensured that estimates provided are conservative. Interpolation using minimum numbers (see Section: Data interpolation) has also allowed for removed data to be included in estimates and therefore not affect overall calculations for numbers of sharks landed.

In order to manage challenges of falsified data, strict data removal policies were applied in this study where any duplication of individuals as multiple sharks was found, as the real data could not be separated from falsified data. Furthermore methods to improve monitoring, such as including time stamps on photographs, were trialled but were not feasible due to the fact that batteries were regularly removed from the cameras, to preserve battery life in villages with no access to electricity or new batteries.

2.2.3. Number of sample sites

The number of villages recording data at any one time fluctuated depending on the availability of a suitable community member to collect data and changes in shark fishing activity in a particular village or island (due to seasonal fisher migrations and a decree protecting islands in Region 2 from settlement).

2.3. Data interpolation

To account for missing and removed months in data collection, the minimum month's landings for that year were used as proxy (Table 1). For the three islands (Nosy Andravoho, Nosy Andriamitaroke and Nosy Be) it was assumed that there were only 10 months of fishing/year from prior knowledge on fishing seasons on these islands. To account for removed years, we used the minimum annual landings for other years as a proxy. In region 1 data were also interpolated for years when no data collection took place (eg. Nosy Lava), because shark landings were known to occur, even though villages were no longer monitoring landings due to lack of a suitable data collectors. In region 2, data were not extrapolated for years without data collection because data collection was purposefully stopped in these villages when shark landings were negligible.

2.4. Shark fins

In larger villages and towns, shark fin 'middle men' exist who will buy and collect shark fins from fishermen for ~10,000–200,000 MGA/kg (~US$4.5–91.0), according to information on prices collected between 2007 and 2012, to sell to the next person in the value chain, normally a buyer from Asia (Cripps et al., 2015; fin collector pers. comm.). There are two price scales of fin quality: one for guitarfish species and one for all other species (Cripps et al., 2015). Quality ranges from 0 (best) to 4 (worst), and is based primarily on size but also colour, amounts of cartilage fibre, cut and species (Cooke, 1997; Cripps et al., 2015). Two shark fin middle men were also paid 15,000 MGA per month (~USD 6.7) as part of this study, and provided data on the number, size, source, prices and quality of fins they purchased. These data were used as a second measure of shark landings, status of fin size and quality and to assess the total number of sharks exported by Madagascar (see Sections 2.8.1, 3.4 and 3.5). The fins purchased by the middlemen are not necessarily from the same geographical scope as the shark landings in our study, as middlemen will purchase fins from a wider region through the use of fin collectors.

2.5. Socioeconomic interviews

In order to gain an overview of the shark fishery from the villagers' perspectives, *ad hoc* semi-structured interviews (a set of open questions that prompt further discussions) and several structured focus groups were carried out with the data collectors and shark fishermen in villages throughout the regions over the course of the study period. All interviews and focus groups were conducted in Malagasy by the Project Coordinator and/or Assistant(s).

In January to March 2013, participative appraisals were also completed using focus groups with ~10–15 participants in a sample of villages in each region in order to gather ranked reasons for changes in numbers of sharks landed each year. Participatory appraisals are a set of approaches or methods that are designed to enable communities to share, develop and analyse their own knowledge, with the emphasis on the value of local information (Chambers, 1992). Project assistants were trained to carry out focus groups using a consensus workshop methodology by a Blue Ventures' staff member highly experienced in social survey techniques and group facilitation (Blue Ventures is a non-governmental organisation that works with coastal communities to help rebuild tropical fisheries). Semi-structured discussions with the participants were conducted to gather information on the possible reasons behind the changes in shark landings. Similar reasons were then grouped by the facilitator so that there was a simple list. Participants were then asked to rank those they considered the most to least important, and scores tallied.

2.6. Species identification

Although it was not possible to identify individual sharks due to photograph quality and little data existing on shark species lists and identification for Madagascar, a subsample of photographs were sent to three experts to assist validation of certain species identifications and provide further identifications where possible. In order to collate the range of names used for species in Madagascar, workshops were held in June and July 2012 in both regions with ~40 fishers and data collectors to assemble alternatives names for each shark name featured in the data, and to map different names for local names given to species.

2.7. Length-length calculations

PCL was converted to total length (TL) in order to calculate frequency size distribution and to compare catch to minimum TL at maturity for scalloped hammerheads *Sphyrna lewini* and sliteye sharks *Loxodon macrorhinus*. PCL was converted to TL using length–length conversion data obtained from FishBase (2016) (Supplementary Table A.1.). PCL was not converted to TL for guitarfish species, but a minimum and maximum PCL for two potential species, *Rhynchobatus djiddensis* and *Rhinobatus annulatus* were calculated from known length–length equations, in order to compare catch to maturity for guitarfish species (Supplementary Table A.1.).

2.8. National estimates of shark landings

Official export figures from Madagascar show annual dried shark fin exports ranged between 31.9 and 43.3 t between 2007 and 2011, whilst annual imports from Madagascar to Hong Kong ranged between 13.9 and 29.8 t within the same period (Cripps et al., 2015).

Two methods were then used to estimate national shark landings, as well as to contextualise landings and regional estimates, using data collected in this study.

2.8.1. Dried shark fin data

The number of dried shark fins recorded in this study was converted into the number of sharks by dividing by four (on average four fins are taken per shark). The total weight of these dried sharks fins was compared to the total weight of dried shark fins exported and imported to estimate the relative number of sharks.

2.8.2. Length-weight data

First, the total wet weight of sharks represented by national export and import figures of dried fin weights from Madagascar was calculated using a conversion factor that the average yield of dried fins from shark wet weight is 1.44% (Anderson and Ahmed, 1993). Although dried fin weights from shark wet weight can vary, few studies have been published, and this is likely to be a conservative figure (Clarke et al., 2004).

Second, to estimate numbers of sharks represented by total wet weight, we used two methods to generate a range. (1) Total wet weight for import and export data were divided by 12.25 kg (the average weight recorded for sharks sampled in northern Madagascar (Robinson and Sauer, 2013). (2) In the second method, length data from our study was used to calculate the average wet weight of identified sharks in our study. The average wet weight of *Sphyrna lewini* and guitarfish species were calculated using the following formula: weight (g) = a × length (cm)^b. Calculations were made using length–weight conversion data obtained from the website Fishbase.org. Values for *a* (0.0048) and *b* (3.07) were the geometric means given for *S. lewini* by FishBase. All guitarfish species were considered to be the giant guitarfish (*R. djidensis*) and values for *a* (0.00384) and *b* (3.06) were the only entry given by FishBase.org. This assumption was made as all species of guitarfish are given the same local name in Malagasy, and therefore selecting the largest species ensured that a minimum number of sharks were estimated from the wet weight. The wet weight of 79 *L. macrorhinus* were taken in village of Andavadoaka in 2009–2010 was 1.63 kg ± 0.55.

The aim of using these two methods to generate a range was to account for the presence of many small animals within the identified shark species within this study, and therefore any potential underestimations of shark numbers in national estimates.

2.9. Statistical analyses

All statistical tests were carried out using the MASS package for R v.2.12.0 (R Development Core Team, 2010). To investigate the relationship between year and PCL of each shark species, and PCL and gear, we used generalized linear models (GLMs), with log transformation of PCL, and with Gamma errors and log link functions. We assessed the suitability of the models using residual diagnostic plots and goodness-of-fit metrics via the dispersion parameter.

3. Results

3.1. Number of sharks

Table 1 shows a list of villages included in this study, their human population size, the number of sharks recorded each year, and the number of months for which shark catch was recorded, between 1 January 2007 and 31 December 2012 (data collection in Region 2 did not start until May 2008).

A total of 11,428 landed sharks (including guitarfish species) were recorded in this study, with a range of 923–2848 sharks recorded.year^{-1} (Table 1). After accounting for missing months of data we estimated total catch for these sites to be 15,457 (a range of 939–3833 sharks recorded.year^{-1}), with an estimated 3017 landed in 2012. No effort was made to estimate shark landings in 2007 for region 2. These figures are likely to be the minimum shark landings for each village as all data collectors were not able to record every landed shark. Data collectors estimated that on average they were recording 60% of shark landings (n = 12, range = 16–100%, sd = 25.0). We could not adjust the landings data in relation to the percentage of landings recorded for each village as not all villages provided estimates of recording intensity.

3.2. Species

Species names were recorded in the local dialect of Malagasy due to the difficulty in shark identification. Local names for shark species can vary by village and 56 different names were recorded in this study, from which approximately 20 species of shark were identified (Table 2; Supplementary Table A.2, Supplementary Table A.3). Although it was not possible to positively identify all landed sharks, the most numerous recorded names in Malagasy correspond to two species (scalloped hammerhead *Sphyrna lewini* and sliteye *Loxodon macrorhinus*) and one family of rays, Rhinobatidae (Guitarfish species), and accounted for >75% (n = 8637) of landings recorded (Fig. 2; Supplementary Table A.1). Within all remaining landings ("Others", Fig. 2) (n = 2791; 24.4%), no single local name recorded by data collectors accounted for >2% (region 1) or >10% (region 2). All identified species and families are found on the IUCN Red List, with *S. lewini* listed as Endangered, *L. macrorhinus* Least Concern and all guitarfish species listed as Vulnerable (IUCN, 2016) (Table 2).

Scalloped hammerheads featured prominently in both regions shark fisheries (region 1 = 20.1%, n = 1341; region 2 = 45.4%, n = 2164), with sliteyes being the dominant landing in region 1 (56.0%, n = 3729) although only accounting for 4.2% (n = 201) in region 2 (Fig. 2). Changes in species landings by year show increases

Table 2
List of local names given to sharks during community-based monitoring of shark fishery 2007–2012. Species identification of local names was through previous reports and papers, and from photographs presented to three experts. Asterisks indicate the confidence in species identification as *** confident or ** probable. The appearance of two latin names indicates either the ID of two separate photos under the same local name or a + sign for two conflicting identifications. IUCN Red List category provided in square brackets: DD = Data Deficient; LC = Least Concern; NT = Near Threatened; VU = Vulnerable; EN = Endangered; NA = Not Assessed (IUCN, 2016).

		Identification(s)	
Local name given	Total number recorded	Latin name	Common name
Andranomamy	9	*Hemipristis elongata**** [VU]	Snaggletooth shark
Balemy	3		
Balidake	264	*Centrophorus moluccensis**** [DD]; Mustelus sp.**	Smallfin gulper shark; Smoothhound sp.
Balita	1		
Bemaso	12	No consensus	
Besofy	9		
Bevombotse	10		
Blue	2		
Bobokoro	1		
Bole	1		
Boriloha	24		
Dofikoro	124	*Carcharhinus sorrah**** [NT]	Spot-tail shark
Fatike	396	*C. moluccensis****; Squalus sp.***; Mustelus sp.**	Smallfin gulper shark; Spurdog sp.; Smooth-hound sp.
Fesoke	257	*C. sorrah****; *Carcharhinus limbatus*** [NT]	Spot-tail shark; Blacktip shark
Fesotse	38	*Carcharhinus amblyrhynchos**** [NT]; Carcharhinus sp.**	Grey reef shark; Requiem sp.
Fireke	1		
Firekembole	1		
Fotivonto	134	*Carcharhinus brevipinna*** [NT] or C. *limbatus***	Spinner shark or Blacktip shark
Foty	27		
Foty rambo	18		
Garamaso	23		
Gogo	16		
Hiahia	18		
Jalinta	4	*Stegostoma fasciatum**** [VU]	Zebra shark
Jangita	19	*S. fasciatum****	Zebra shark
Kary	48	*Galeocerdo cuvier**** [NT]	Tiger shark
Kasioke	3912	*Loxodon macrorhinus**** [LC]	Sliteye shark
Katsatsake	47		
Keliterake	27		
Lava Loha	2		
Lavaoro	452	*C. sorrah****; *C. limbatus****	Spot-tail shark; Blacktip shark
Lejeleja	3		
Maintindambosy	74	*Carcharhinus leucas*** [NT]; *C. sorrah***	Bull shark; Spot-tail shark
Maintipaty	158	*C. sorrah***	Spot-tail shark
Mangaraoro	18	*L. macrorhinus****	Sliteye shark
Manofaty	1		
Maragnitsoro	280	*C. sorrah****; *L. macrorhinus****; *H. elongata****	Spot-tail shark; Sliteye shark; Snaggletooth shark;
Meso	19		
Ogne	1		
Palaloha	760	*Sphyrna lewini**** [EN]	Scalloped hammerhead
Ragnaragna	14		
Ranomaso	5		
Santira	13		
Soroboa^{+}	1200	Rhinobatus sp.***; *Rhynchobatus djiddensis*** [VU]; *Rhynchobatus laevis*** [VU]	Guitarfish sp.; Giant Guitarfish; Smooth nose wedgefish
Soroboavato	2	Rhinobatus sp.***	Guitarfish species
Tandaly	28		
Tomango	49	*Triaenodon obesus**** [NT]	Whitetip reef shark
Tsaka	1		
Tsatsake	57		
Vaevae	6	Pristiophoridae*** [LC to DD]; *Pristiophorus nancyae*** [NA]	Sawsharks; African dwarf sawshark
Valovombotse	11		
Vantare	3		
Vao	19		
Vatar	4		
Viko	2745	*S. lewini****	Scalloped hammerhead
Voro	1		

Table 2 (*Continued*)

Local name given	Total number recorded	Identification(s)	
		Latin name	Common name
Shark species identified from photos with no associated Malagasy name		[+]*Carcharias taurus* [VU] or *Odotaspis noronhai* [DD] or *O. ferox* [VU]**; *Hexanchus nakamurai* [DD]***; *Isurus oxyrinchus**** [VU]; *Prionace glauca**** [NT]; *Pseudoginglymostoma brevicaudatum**** [VU]; *Squatina africana**** [DD]	Sand or Bigeye or Smalltooth sand tiger; Bigeye sixgill shark; Shortfin Mako; Blue shark; Shorttail nurse shark; African angelshark
Rays (not guitarfish family)	32		
No species name recorded	25		
Total	11428		

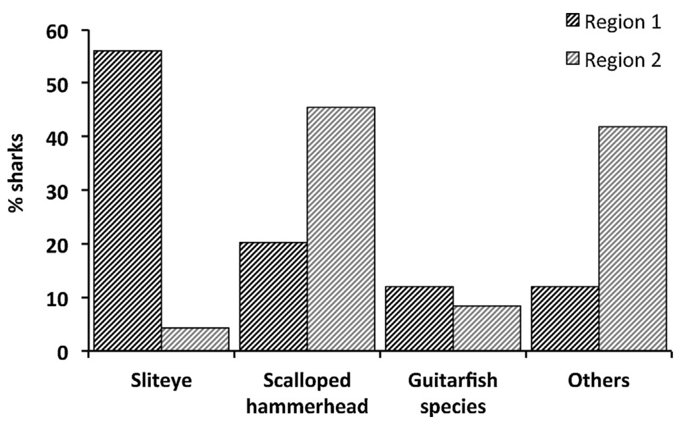

Fig. 2. The main shark species by percentage numbers by region. All remaining landed sharks are categorised as "Others". No local name within this category accounted for >2% (region 1) or >10% (region 2) of recorded landings.

in guitarfish species landings in region 1, and scalloped hammerheads and sliteyes in region 2 over the study period (Supplementary Fig. A.2). Scalloped hammerheads increased in landings in 2012 in region 1, along with a pronounced peak in sliteye landings in 2010.

3.2.1. Size-frequency and average wet weight

The mean and range of recorded size of scalloped hammerheads, sliteyes and guitarfish species were 63.6 cm (20–270 cm), 65.3 cm (18–93 cm) and 89.5 cm (14–300 cm), respectively. Size distribution using TL (scalloped hammerhead, sliteye) and PCL (guitarfish species) was strongly skewed towards smaller individuals for scalloped hammerhead and guitarfish species, whilst skewed towards larger individuals for sliteyes (Fig. 3). The dominant size class was 51–60 cm for both male and female scalloped hammerheads and it is estimated that at least 95.3% (n = 1998) of females and 10.6% (n = 1211) of males were juveniles in this study (Fig. 3; Supplementary Table A.1.). However, the majority of both female (77.6%, n = 1710) and male (94.7%, n = 1563) sliteyes recorded were mature. Using available conversion data for guitarfish species, our landings would be the equivalent of 89.0% (n = 1067) juvenile *R. djiddensis*, and 78.0% (n = 936) below the maximum PCL for *R. annulatus*.

The overall average weight was estimated as 6.4 kg per shark for identified species within this study.

3.2.2. Size over time

There was a significant effect of year on average PCL size for scalloped hammerheads sharks ($F_{1,3441}$ = 1369.2, $p < 0.001$), and PCL decreased between 2007 and 2012 from 89.3 cm to 45.1 cm (Fig. 4a).Year also had a significant effect on average PCL size for sliteyes ($F_{1,3869}$ = 12.076, $p < 0.001$) (Fig. 4b), guitarfish ($F_{1,1197}$ = 337.83, $p < 0.001$) (Fig. 4c) and the grouped remaining shark landings ("others") ($F_{1,2706}$ = 209.59, $p < 0.001$) (Fig. 4d). Average PCL of "others" decreased from 99.0 cm in 2007–69.4 cm in 2012. Decreases in size of sharks landed were also reported in interviews with data collectors (Supplementary Table A.4).

3.3. Regional estimates

The most recent data from 2012 provides a robust yet conservative estimate of the number of shark landings within two communes in the Toliara province, and an estimate of 0.21–0.33 sharks/fisher/year. If a similar catch rate is assumed for the remaining Toliara province fishers we estimate that 39,000 to 62,000 sharks are landed per annum in this region. If we also take into account that data collectors estimated that on average they recorded 60% of shark landings in their village, we estimate that total take in the traditional fishery in the Toliara province could range from 65,000 to 104,000 sharks per annum.

3.4. Fin numbers and quality

A total of 56,651 (total dry weight of fins was 6,425.6 kg; average fin weight 0.113 kg) fins were recorded by fin collectors over the six year study period, and represents a minimum of 14,163 sharks. For all years apart from 2011, fourth quality fins accounted for >70% of fins bought by middlemen, apart from 2011 where a 5th quality was introduced by the collector for even lower quality <10 cm fins (worth 2–3000 MGA/kg; ~0.89–1.3 USD/kg) and accounted for 44% of fin data. Whilst some dried shark fin data may be from sharks landed from our study region, the two sets of data cannot be directly compared, due to differences in the collection area of middlemen.

3.5. National estimates of shark landings

Between 2007 and 2011, the number of dried fins recorded in this study represents an average minimum of 2562 sharks landed per annum. The weight of dried fins recorded in this study by fin collectors accounted for approximately 3.07% of annual national export records and 4.88% of Hong Kong import records of dried fins for the five year period 2007–2011. Scaled up, this could represent an annual range of 52,519 to 83,373 sharks landed; varying with the range of export and import data reported each year.

However, if we assume that dried fin weight is 1.44% of total body weight (Anderson and Ahmed, 1993), then the dried shark fin data in this study and numbers of sharks estimated, would give 32 kg per animal. Given our data, and that previously recorded in northern Madagascar, show a range of 6.4–12.25 kg per animal, it suggests that there are many more than 14,000 animals represented in the dry fins weights recorded in this study. If it is assumed more conservatively that the average weight per shark is 12.25 kg, then the number of sharks represented by the total dried shark fin weight (6425.6 kg) is 36,426 and represents an annual range of 124,000–197,700 sharks landed.

As national estimates from dried shark fin data collected within this study seemed unrealistic, national export and import data

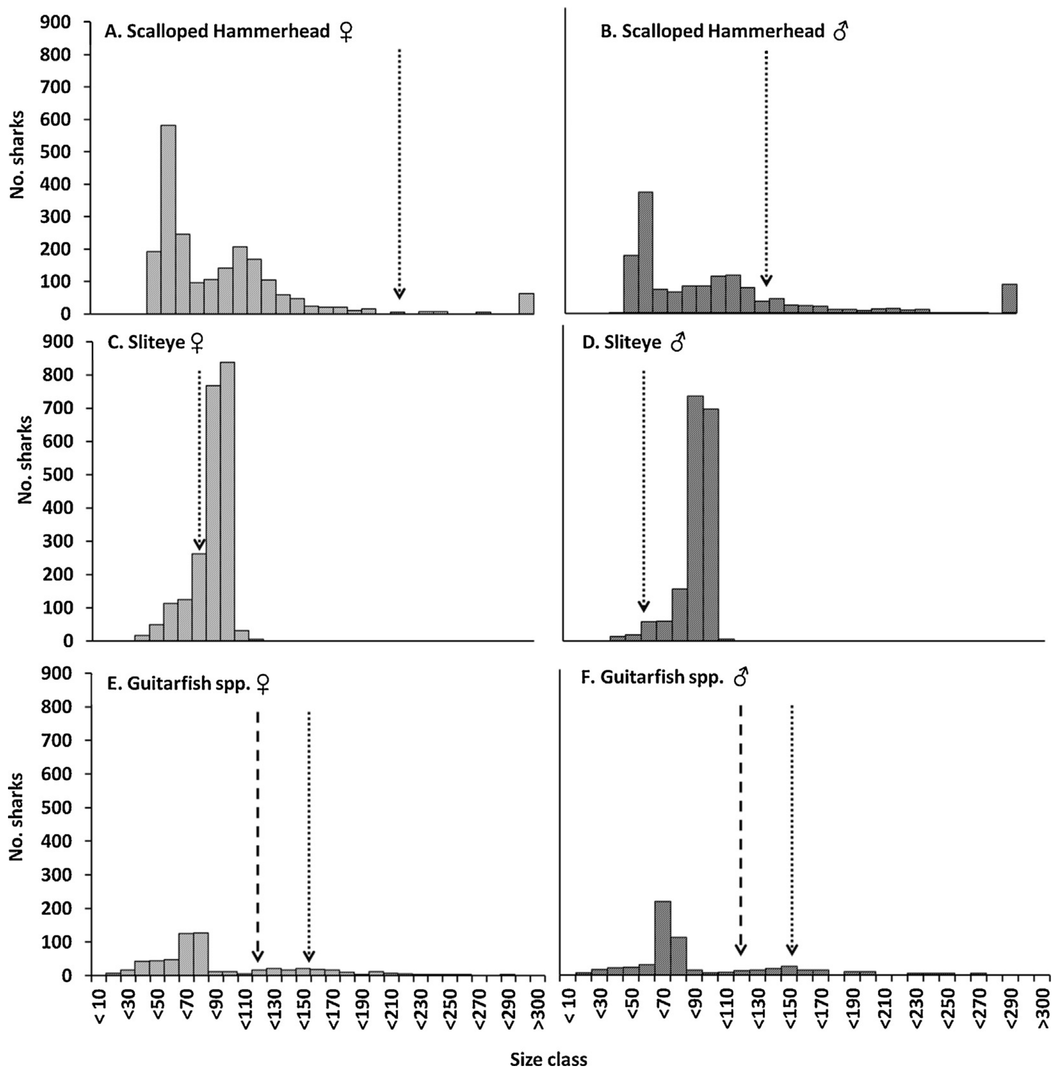

Fig. 3. Size-frequency of scalloped hammerheads (*S. lewini*), sliteye (*L. macrorhinus*) and guitarfish species (Rhinobatidae), recorded 2007–2012 in SW Madagascar. Size class is Total length (TL, cm) for panels a-d and pre-caudal length (PCL, cm) for e-f. Dotted lines on a to d represent minimum TL at maturity. Dotted lines in e-f indicate minimum PCL at maturity for *R. djiddensis* and dashed lines indicate maximum PCL for *R. annulatus.* Minimum PCL at maturity and maximum PCL were calculated from known length–length equations for *R. djiddensis* from Fishbase.org (Supplementary Table A.1).

were also used to estimate national landings of sharks. Converting national export and import data on dried fin weight to wet weight of sharks gave an annual range of 963–3008 metric tonnes. Using the range for average shark weight as 6.4–12.25 kg, annual shark landings are estimated at 78,616–471,851 during 2007–2011.

3.6. Trends in landings numbers

To assess catch trend over time, the estimated number of sharks landed by villages with long-term monitoring (minimum 8 months in each survey year in region 1; minimum 4 years, with variable number of months monitoring, in region 2) were plotted (Fig. 5). Landings in region 1 increased from 2007 to 2012 with a peak in 2010 (n = 1521). This peak was driven by high catch in one village (Lamboara) of 1157 sharks. In region 2 there was a small increase from 2008 to 2012 with a peak in landings in 2009 (n = 1112). Landings by village show greater variation by year (Supplementary Fig. A.1 .). Interviews with data collectors and shark fishers revealed that 53% of villages (n = 9) questioned believed that there had been a decrease in the numbers of sharks available over the last five to twenty years (Supplementary Table A.4).

3.7. Fishing methods

Nets (gill nets) were used to land over 80% (n = 9464) of sharks, followed by hook and line (11.7%; n = 1338) and longline (4.3%; n = 495) across both regions (Supplementary Table A.5). Changes in fishing gears are apparent year by year, most notably an increase in use of smaller meshed nets (*janoky* and "net") (Supplementary Table A.5). There was a significant difference between the average size of shark landed between four types of net, hook and line, and longline ($F_{1,11123} = 936.21$, $p < 0.001$), with nets (mesh 2–5 cm) landing sharks with an average size of 50.0 cm (n = 2541, range = 13-224, sd = 17.1) and *Jarifa* nets (mesh 12–25 cm) with an average shark size of 110.9 cm (n = 1221, range = 27-300, sd = 52.3) (Supplementary Fig. A.3 , Supplementary Supplementary Table A.6). However, similar species of shark were primarily landed across each gear (scalloped hammerhead, sliteye and guitarfish species) (Supplementary Table A.6).

4. Discussion

This paper describes a replicable method to assess the status and changes within small-scale fisheries, working with community

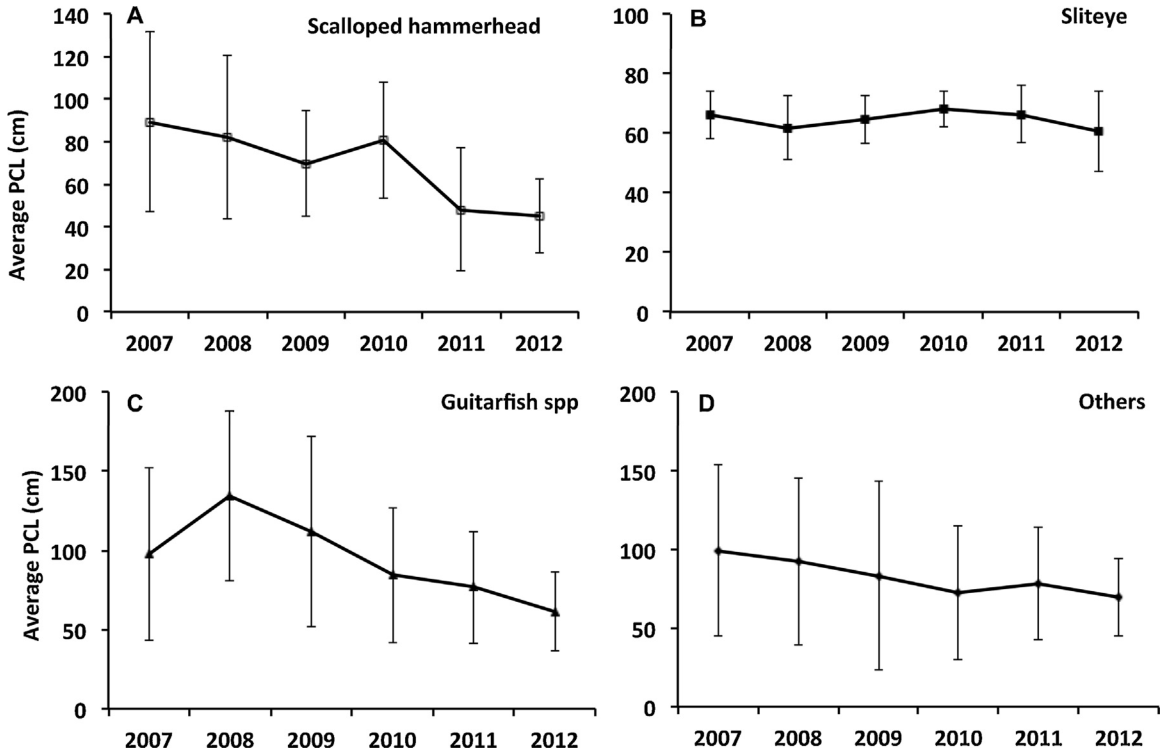

Fig. 4. Average shark size (PCL) by the species (a) scalloped hammerhead (b) sliteye or the family (c) guitarfish species over both regions (2007–2012). Error bars are standard deviations. Others (d) contains all sharks recorded that were not classified as one of the three species/family.

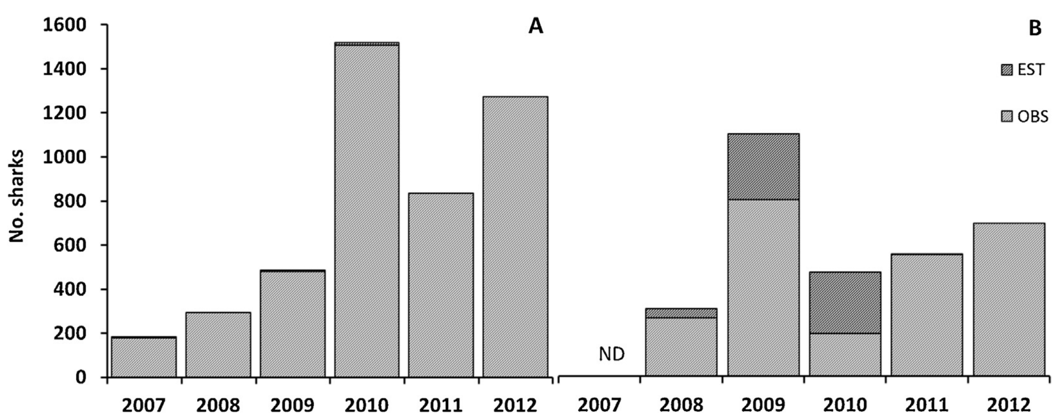

Fig. 5. Total observed (OBS) and estimated (EST) landings recorded in (a) Region 1 villages (Ampasilava, Antsepoke, Belavenoke, Bevato and Lamboara) with at least 8 months monitoring for each year 2007–2012 and (b) Region 2 villages (Ampatiky, Ankevo and Betania) that recorded data for a minimum of four years. ND = No data for Region 2 in 2007 as monitoring did not start until May 2008.

members to directly measure shark landings. Small-scale fisheries are regularly cited as data deficient (Ehrhardt and Deleveaux, 2007; Jacquet et al., 2010), despite their importance for income and protein; also an issue cited in such shark fisheries (Alfaro Shigueto et al., 2010; Le Manach et al., 2012).

The results of this study show that in terms of definitive numbers, the traditional shark fishery in southwest Madagascar has not declined between 2007 and 2012. However, the number of sharks recorded in this study across 22 villages (~1900/year) is lower than the number of sharks (1164) recorded by McVean et al. (2006) from two villages over a 13 month period in 2001–2002 in the SW; and could be due to differences in fishing activity in villages selected and decreases in the shark fishery from 2001 to 2007. *Sphyrna* species (hammerheads) also dominated the traditional shark fishery in McVean et al. (2006), representing 29% of sharks landed; and also 24% of catch in the artisanal shark fishery in northern Madagascar (Robinson and Sauer, 2013). Guitarfish species are only identified as being part of the fishery in these two studies, but do not seem to be caught in any significant numbers. Sliteye sharks are not listed in McVean et al. (2006), although are noted in other reports (Cooke, 1997; Randriamiarisoa, 2008; Robinson and Sauer, 2013).

Although numbers of sharks landed did not seemingly decline during this study, declines in shark population numbers were reported during social surveys within this study. Declines in the traditional shark fishery in Madagascar were reported by the late 1990s (Cooke, 1997), with fishers reporting they had to go further afield to catch sharks (Smale, 1998). Regular reports from community elders cite that in their youth large sharks were present in lagoonal areas in SW Madagascar and are no longer present.

Significantly smaller sharks were also landed over the study period but it is not possible to determine whether this is due to overfishing of larger individuals or changes in gear, although this study shows apparent shifts from larger meshed to smaller meshed nets. Increases in fishing effort or shifts in gear use could also mask declines in the numbers taken in shark fishery. Changes in gear use in Madagascar have been described previously, where gear preference had shifted from gill nets to less selective long-lines, with smaller sharks being targeted (McVean et al., 2006). Randriamiarisoa (2008) also noted a decrease in the size of sharks landed in the traditional fishery, and that with fishers reporting decreasing catches, production was maintained through greater effort; and Robinson and Sauer (2013) reported decreases in abundance and size of sharks in the northern artisanal fishery. Artisanal shark fisheries in other countries have shown similar responses to declines in shark landings; in the Maldives, markets developed for smaller sharks (Anderson and Waheed, 1999), and in Indonesia catch and fishing effort for elasmobranchs has increased whilst catch per unit effort and average size of sharks has decreased (Keong, 1996; White and Cavanagh, 2007).

The size of sharks recorded here, with the majority of hammerheads estimated to be immature, is also of concern. The median size range in this study (51–60 cm) is already less than the 1 m standard length reported in McVean et al. (2006). Large numbers of juvenile and sexually immature sharks have been shown to occur within both artisanal and industrial fisheries (Doherty et al., 2014; Bizzarro et al., 2009; Dapp et al., 2013), as declines in upper tropic level species has increased reliance on smaller, coastal elasmobranchs (Sala et al., 2004; Bizzarro et al., 2009). A high proportion of gravid females, neonates and small juveniles could also suggest that shark nursery areas are under heavy fishing pressure (Castillo-Géniz et al., 1998; Cartamil et al., 2011; Bustamante and Bennett, 2013).

Conservative regional estimates, to account for the fact that villages more dependent on shark fishing were targeted, would be 39–65,000 sharks landed.year^{-1} in the traditional fishery in the Toliara province. However, it is likely that the estimate of 65–104,000 sharks landed.year^{-1} is more realistic due to the large proportion of data that were not captured by data collectors.

National landings estimates based on dried shark fin weights collected within this study are likely to be underestimated, as the weight of sharks represented by the weight of shark fins, and number of estimated sharks, does not correlate. This could be due to the fact that the number of shark fins was not recorded accurately by fin collectors, given the large number of small fins known to be collected (F. Humber, pers. obvs). Additionally, the estimate of four fins per shark could be conservative as up to 6 fins per shark can be taken (Biery and Pauly, 2012). Therefore, we would assume that the national landings estimates are closer to 78–471,851 sharks.year^{-1}, with wide annual ranges due to large annual fluctuations in exports and imports reported, and the different assumptions of wet weights used for calculations. Limited data exists on the ratio of dry fin weights to wet weight of shark, although the figure used here of 1.44% is likely to be conservative (Clarke et al., 2004). Conversion factors for wet weight of sharks fin to wet weight of whole sharks have also been shown to vary considerably across species and location (Biery and Pauly, 2012), and we could assume the same is likely for dry shark fin to wet weight of whole sharks.

The estimated number of sharks taken within the Toliara province alone by the traditional fishers in this study could equal current estimates of the number of sharks represented in Madagascar's official export figures. Although southwest Madagascar has the largest fishing population in Madagascar, sharks are also landed in large numbers in the traditional and artisanal fisheries in other regions of Madagascar (Robinson and Sauer, 2013; Doukakis et al., 2007; Randriamiarisoa, 2008); as well as by national and international industrial boats (Le Manach et al., 2012). Official export figures are considered unreliable and incomplete and there are regular inconsistencies between regional and national data (Randriamiarisoa, 2008; Robinson and Sauer, 2013). It is likely that only a small volume of sharks landed in industrial fisheries are recorded in Madagascar's national exports, as the majority of them will not return to port (G. Cripps pers.comm.). Furthermore, although it is estimated that >90% of Madagascar's shark fin exports were to Hong Kong, discrepancies between Madagascar's export figures show that it is likely that other countries are significant importers (Cripps et al., 2015). These missing data are not captured within estimates in this study. Underreporting within fisheries is a global problem (Zeller et al., 2011a, 2011b; Pauly and Froese, 2012), and in particular within both small-scale fisheries (Jacquet et al., 2010; Wielgus et al., 2010; Le Manach et al., 2012) and shark fisheries (Worm et al., 2013).

The importance of shark fisheries to the present day economy of local fishing communities in Madagascar remains unclear. Barnes-Mauthe et al. (2013) found that fishers in southwest Madagascar (study region 1) only occasionally or opportunistically targeted sharks and therefore ranked 15th out of 17 species groups for total market value. Less than five years prior to this study Ravelosoa (2005) found that 70% of fishers from the southwest's regional capital, Toliara, said shark fishing was their primary activity. This also highlights one of the difficulties in defining what may be considered target or bycatch within small-scale fisheries in Madagascar. The majority of fishers are opportunistic and will simply go fishing with the materials they have to hand and will catch what is available, with no catch discarded. Fishing gears can also be deployed in different areas or in different ways (eg. baited) to try and target different species. Unfortunately, it was not possible to assess changes in fishing effort (eg. catch per unit effort, CPUE) through the landings data in this study as days when no sharks were landed by fishers were not recorded. Calculating a reliable CPUE within this fishery, and through the use of community data collectors whose effort in recording data would also fluctuate daily, was further complicated by the complexity of opportunistic shark fishing, trying to sample fishers that did not catch sharks, fishing gears left in-water overnight and the variable number of fishers per boat.

Community-based monitoring or participatory research has been successfully used not only to assess remote, small-scale fisheries (Uychiaoco et al., 2005; Benbow et al., 2014; Prescott et al., 2016) but also illegal fisheries and endangered marine populations (Humber et al., 2011, 2015; Pilcher and Chaloupka, 2013). Community-based monitoring can also play an important role in engaging stakeholders, building community capacity, and buy in for local management regimes or conservation initiatives (Andrianandrasana et al., 2005; Evely et al., 2011; Garnier et al., 2012). Empowerment of local communities can be increased directly, or as an unexpected outcome, through community-based monitoring (Constantino et al., 2012); and participatory monitoring systems have been shown to lead to quicker and more effective conservation management decision making by communities (Danielsen et al., 2007, 2010). In northern Mozambique, community-based monitoring and management of marine turtles and other natural resources triggered the creation of a community-led marine sanctuary (Garnier et al., 2012). Participatory monitoring, control and surveillance has been highlighted as a key activity in the development of successful local natural resource management in Madagascar (Wildlife Conservation Society, 2016).

However community-based methods, despite being cost effective (Humber et al., 2011; Holck, 2008), can have their limitations and setbacks. Designing suitable methods for this monitoring did not allow for fishing effort to be captured (eg. through the recording of days fishing with zero shark landings) and it is recommended that further studies investigate options for capturing this information to some degree. Providing financial incentives to participate in monitoring can also present challenges (Kinch, 2006). In this study the small monetary incentives lead to falsified data in some cases, but were spotted through the use of digital cameras. It is likely that long-term behaviour change is required for such schemes to run without incentives (De Young 1993; Syme et al., 2000).

Cameras also provided the means to help identify some shark species landed, although the quality of photos did not always allow for this; and the diverse local nomenclature for shark species meant that it was impossible to draw up a comprehensive list before or during this study. Many photos of sharks were also identified as members of deep-water shark families by experts, for which established taxonomies and IDs are not yet available (David Ebert pers. comm.).

The need for urgent management measures for sharks, in particular for data poor artisanal fisheries, has been increasingly recognised (FAO, 1999; John and Varghese, 2009; Hoq, 2011). In recent years there has been surge of countries taking the lead to implement new management initiatives for sharks (Vince, 2009; Pew Charitable Trusts, 2014), with country-wide and large-scale shark sanctuaries now in place in many countries including the Cook Islands, French Polynesia, Honduras, Maldives, Palau, with commercial fishing also banned in the Bahamas and British Virgin Islands (CMS Sharks MoU, 2014). However, as of late 2014, Madagascar's first shark sanctuary was put in place in Antongil Bay, NE Madagascar, as part of a network of community-managed areas granting local rights for fishery areas (Wildlife Conservation Society, 2015).

Madagascar has neither domestic legislation nor a national plan of action for sharks in place at present (Humber et al., 2015). Recommendations for shark fisheries management in Madagascar have highlighted the need for a National Plan of Action (NPOA) (Cripps et al., 2015; Humber et al., 2015). As a precursor, a shark assessment report could be completed that would identify priority data, research or policy gaps, that would ensure the objectives of any NPOA reflected the specific needs of Madagascar. A criticism of some NPOAs has been that they are not grounded in the individual needs of a country (I. Campbell pers. comm.). Community-based monitoring could play an important role as a tool for collecting data, as well as monitoring, control and surveillance as part of a NPOA (Humber et al., 2015), and has recently been used to collect data and protect marine turtle nests at a priority site in Madagascar (Humber et al., 2016).

It will be important for any shark fisheries management to take into account that >50% of sharks (in tonnes) taken from Madagascar's water could be from foreign fishing vessels either as bycatch or as direct take (Le Manach et al., 2012). Efforts by Madagascar to improve fishing access agreements should not only take into account unfair payments, but also the fact that vital marine resources, such as sharks, are being overexploited without record or accountability. Recommendations for foreign vessels could include 100% observer coverage, a requirement that fins remain naturally attached, more detailed export and import requirements to allow trade to be more closely tracked and increase transparency, and recognition that sharks are valued (targeted) bycatch which should be reflected in fishing agreements with stricter limits and enforcement (Cripps et al., 2015).

The proliferation of community-led marine resource management (often supported by an NGO) in Madagascar (Rocliffe et al., 2014), and the recent shark sanctuary put in place in NE Madagascar, could provide a template for the growth of nearshore shark fisheries management in Madagascar through the established network of >65 locally managed marine areas (LMMAs) covering >11,000 km^2 (MIHARI, 2016). Harnessing the growth of LMMAs in Madagascar, to create a network of protected areas in Madagascar, is likely to be more cost efficient and effective than a network of government-led marine protected areas, that may have limited buy-in nor the capacity for monitoring, control and surveillance. Participatory approaches such as community-based monitoring have been key tools in their development, whilst systems for ongoing community-led surveillance and enforcement will be key to their long-term success.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.fishres.2016.08.012.

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