Reconstruction of total marine fisheries catches for Madagascar (1950-2008)[1]

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Abstract

Fisheries statistics supplied by countries to the Food and Agriculture Organization (FAO) of the United Nations have been shown in almost all cases to under-report actual fisheries catches. This is due to national reporting systems failing to account for Illegal, Unreported and Unregulated (IUU) catches, including the non-commercial component of small-scale fisheries, which are often substantial in developing countries. Fisheries legislation, management plans and foreign fishing access agreements are often influenced by these incomplete data, resulting in poorly assessed catches and leading to serious over-estimations of resource availability. In this study, Madagascar's total catches by all fisheries sectors were estimated back to 1950 using a catch reconstruction approach. Our results show that while the Malagasy rely heavily on the ocean for their protein needs, much of this extraction of animal protein is missing in the official statistics. Over the 1950-2008 period, the reconstruction adds more than 200% to reported data, dropping from 590% in the 1950s to 40% in the 2000s. This discrepancy has profound management implications as well as consequences for current understanding of Madagascar's fisheries economy and communities' reliance on wild fish for food security.

Introduction

Madagascar is located in the western Indian Ocean, and separated from Africa by the Mozambique Channel (Figure 1). With a land area of approximately 587,000 km², it is the fourth largest island in the World and an African biodiversity hotspot, with around 80% of its terrestrial species being indigenous, and its endemic biodiversity threatened by habitat loss (Brooks *et al.*, 2006; Anon., 2008a). Given its great size, spanning 14 degrees of latitude, Madagascar exhibits a range of geological, oceanic and climatic environments, for example, the east of the country is mountainous with a narrow continental shelf facing the prevailing trade winds and oncoming east equatorial current, while the west side is characterised by large plains in a rain shadow, with the coast fringed by a wide continental shelf (Cooke *et al.*, 2003). The southern region is subject to more arid conditions (Jury, 2003), restricting its agricultural potential. These environmental differences have also shaped marine ecosystems: mangroves are almost exclusively present on the west coast (Giri and Muhlhausen, 2008), whereas coral reefs span the southwest, west and northeast coasts, and include one of the largest coral reef systems in the Indian Ocean, totalling approximately 2,230 km² (Spalding *et al.*, 2001). These geographical differences have also resulted in spatial divergence in the distribution of the island's human population with the eastern part of the island having the highest density, while the west coast is home to the majority of fishers and therefore experiences the highest fishing pressure (Guidicelli, 1984; Bellemans, 1989; Rafalimanana, 1991; Laroche *et al.*, 1997).

[1] Cite as: Le Manach, F., Gough, C., Humber, F., Harper, S. and Zeller, D. (2011) Reconstruction of total marine fisheries catches for Madagascar (1950-2008). pp. 21-37. In: Harper, S. and Zeller, D. (eds.) Fisheries catch reconstructions: Islands, Part II. Fisheries Centre Research Reports 19(4). Fisheries Centre, University of British Columbia [ISSN1198-6727].

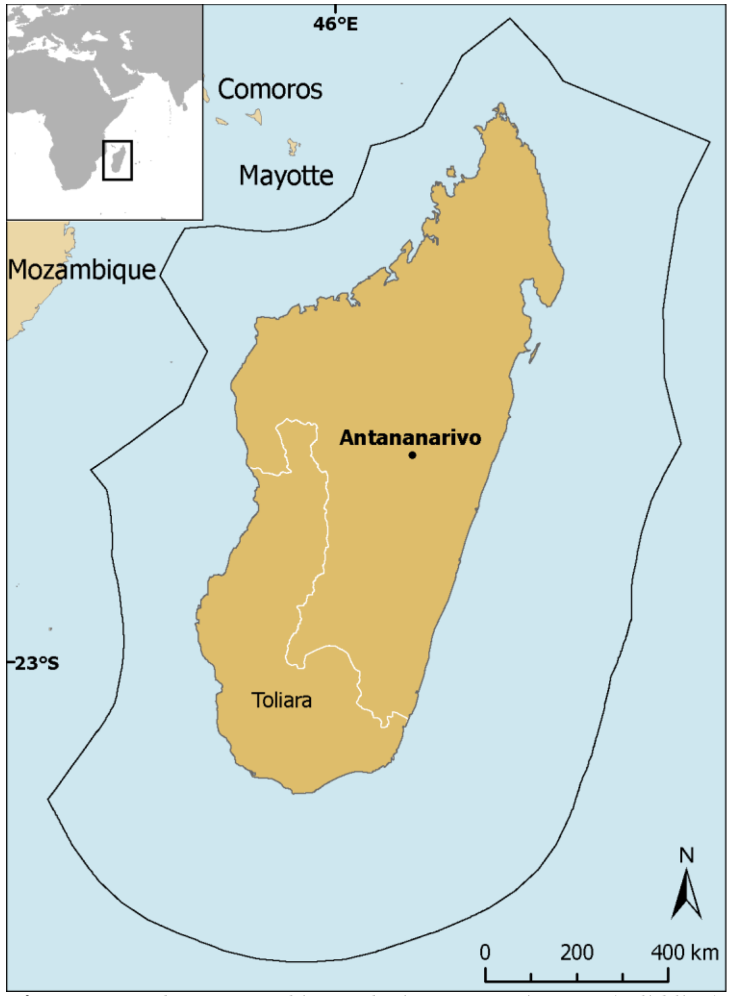

Figure 1: Madagascar and its Exclusive Economic Zone (solid line).

Historically, Madagascar has had several political regimes (Schraeder, 1995). After the Berlin Convention in 1885, which decided the fate of most of the African continent during colonisation, Madagascar was invaded by France in 1896, turning Madagascar into a French colony and finally Overseas Territory in 1946. Although the colonial power invested in national infrastructure such as trains and schools, this period was characterised by protracted political violence, with around 700,000 out of 3 million inhabitants being killed within a few decades (Rousse, 2010). Giving increasing power to national institutions, the French government withdrew step-by-step and in 1960 the First Republic was proclaimed. However, the first Malagasy President was unpopular with the country's people, mainly due to the continuing strong economic and political ties with France. In 1975, the Second Republic aligned itself with the USSR; key sectors of the economy were nationalized and the country experienced a radical socialist and authoritarian political regime. Ten years later, heavy opposition to this regime developed, and in 1992 the Third Republic was proclaimed. Political instability continues to the present day, following a military-backed coup in 2009. Madagascar's current unelected regime faces ongoing economic sanctions and is not recognised by the international community, including the European Union (EU) or the Southern African Development Community (SADC).

Economically, Madagascar is one of the poorest countries in the world. Per capita GDP has declined steadily since Independence, having never exceeded $410, and currently is at less than $300 (year 2000 USD). Approximately 70% of the population currently lives below the poverty threshold, and over half of the country's population is dependent on the exploitation of natural resources for their livelihoods (World Bank, 2010; Horning, 2008). Subsistence fisheries are of prime importance for coastal communities, especially in the south and west of the country where agriculture is virtually impossible due to aridity.

In developed countries, scientific fisheries assessments such as stock assessments can provide robust data on which to base fisheries management decisions. However, these approaches are expensive, technically complex and often challenged (Murawski, 2010). Developing countries such as Madagascar rarely have adequate scientific capacity or resources to undertake stock assessments. Consequently, poor or incomplete catch data often serve as the only basis for policy and decision making in such countries. In the absence of effective regulations, catch statistics are thought to approximate fluctuations in fish stocks and are therefore viewed as an acceptable proxy for stock assessments. However, catch statistics generally do not account for Illegal, Unreported and Unregulated (IUU) catches, which are widely recognised as a major barrier towards sustainable fisheries management (Sumaila *et al.*, 2006; Hosch *et al.*, 2011). Such IUU catches often result in serious under-estimates of extracted resources and over-estimate of their sustainability (Jacquet *et al.*, 2010). FAO FishStat (FAO, 2009) provides time-series data on marine fisheries landings starting in 1950. These data are based on statistics provided to FAO by member countries. However, it has been shown for many countries that the statistics submitted to the FAO are often incomplete, particularly with regards to artisanal and subsistence fisheries (Zeller *et al.*, 2007; Jacquet *et al.*, 2010; Wielgus *et al.*, 2010). This is likely the case with Madagascar as well, where the importance of seafood for domestic food security has rarely been recognised by the various governments. Here, we re-estimated total marine catches by Madagascar within its EEZ (or EEZ-equivalent waters) for the period 1950 to 2008, with the aim of providing a more accurate baseline for use in policy decisions. This included a review of all fisheries sectors in the country, which allowed us to highlight missing or under-reported components. The present work is also published in Le Manach *et al.* (2012). Note that Le Manach *et al.* (2012) contains a mislabelled Figure (3b), which was corrected through a subsequent errata, and is correctly presented here as Figure (6).

MATERIALS AND METHODS

Human population data

Human population data were obtained from PopulStat (www.populstat.info) and various other sources (Central Intelligence Agency, 2010; Globalis, 2010) and used to derive the number of fishers for the whole time-series (1950-2008). Linear interpolations were made between years of known data (Figure 2a). A fishers' census conducted by the FAO documented the percentage of artisanal fishers among the population in 1988 for each district (Bellemans, 1989). In the absence of more recent estimates, we assumed that these ratios remained stable between 1988 and 2008. It is likely conservative, as the declining per capita GDP during this period would suggest a growing reliance on small-scale artisanal fishing for livelihood and food security. For the 1950-1988 period, the proportion of artisanal fishers among the total population was assumed to have doubled, increasing from approximately 2% to 4%. Indeed, Bellemans (1989) reported that the number of fishers approximately doubled during the two decades preceding the census (Figure 2b). Billé and Mermet (2002) have also indicated a two-fold increase in the number of fishers between the early 1980s and the early 2000s. Based on this, we estimated a fisher population of 100,000 individuals in 2005 (G. Hosch, pers. comm., Fisheries Planning and Management; Gough and Humber, unpub. data). For this study, the coast was divided in two areas: (1) the southwest, comprising the district of Toliara (Figure 1), where the fishing pressure is known to be the highest (Laroche *et al.*, 1997), and (2) the remaining coastal districts, where fishing pressure is consequently thought to be somewhat lower.

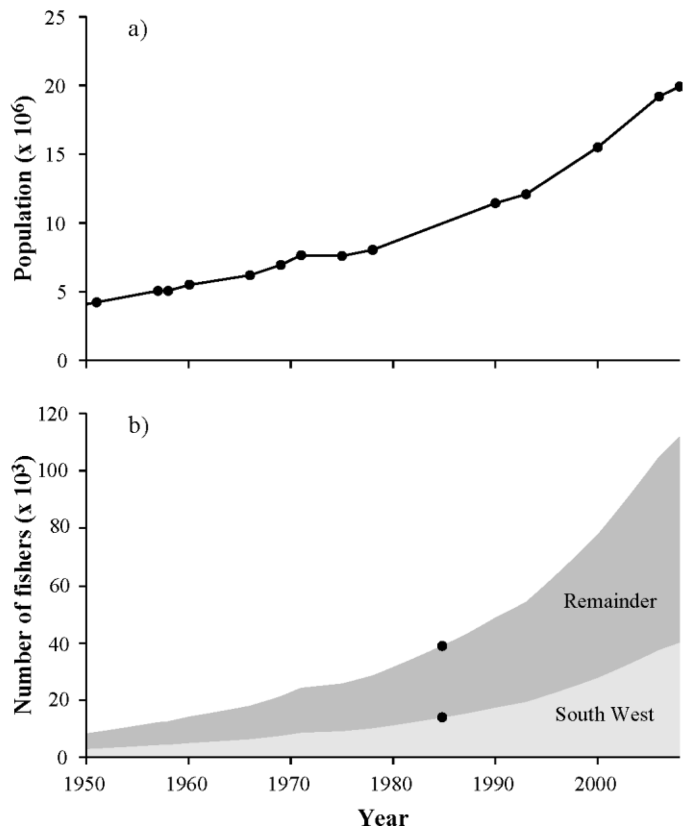

Figure 2: a) Human population of Madagascar with anchor points indicated by solid circles, and b) number of artisanal fishers with the 1987-88 census data foundation (Bellemans, 1989) indicated by dots.

Fisheries sub-sectors

The officially reported landings data which served as the baseline for the study were extracted from the FAO FishStat database (FAO, 2009), and a thorough bibliographic review of fisheries activities in

Madagascar allowed us to determine which sectors were either missing or being under-reported. Data sources included peer-reviewed publications, reports by non-governmental organizations (NGOs), and other grey literature. Expert and local knowledge was collected for each sector in order to formulate the best assumptions possible. For each of these fisheries sectors, catches were then derived for the entire 1950-2008 period, based on anchor points found in the literature and informed knowledge-based assumptions.

Shrimp fishery

The shrimp fishery represents around 4% of Malagasy reported landings for the last decade. However, its market value is significant, reaching almost 70% of the officially recorded marine resource contribution to the GDP, mainly due to important export to Europe, Asia and North America (Soumy, 2006; Anon., 2008b; Kasprzyck, 2008).

The industrial shrimp fishery officially started in 1967, after several years of exploratory trawling (Fourmanoir, 1952a, b; Crosnier, 1965). The number of vessels steadily increased from 11 in 1967 to a maximum of 71 vessels between 1993 and 2003, when the number of licenses started to be controlled. Since then, the number of vessels has decreased, with 47 licensed vessels operating in 2008. Although linked to the economic recession of the 2000s, the increasing price of fuel and the international market being flooded by cheaper Chinese shrimp products, this drop was also due to declines in landed catch and increasing competition with artisanal fishers (Kasprzyck, 2008). Conflict between artisanal and industrial fishers continues to be a serious concern for west coast fishing communities (Cripps, 2009). Despite the intensive exploitation by industrial operators in the past, the decline in the economic viability of the fishery is causing owners to reduce their fleets (Razafindrainibe, 2010; McNeish, 2011). The *Société de Pêche de Morondava* (SoPeMo), a shrimp fishing company based on the west coast, stopped commercial trawling in the region in 2008 (C. Gough, pers. comm.). Unima, the biggest shrimp company in Madagascar is accusing artisanal fishers to have caused the decline in catches (McNeish, 2011).

Artisanal fishers have targeted shrimp since the 1970s. Before then, shrimp was considered incidental bycatch and was used as a complementary food, consumed as an overcooked paste. Since then, artisanal fishers have been attracted by this high-value resource and sell a large portion of their catches to local markets and processors. Due to its rapid expansion, we assumed a yearly growth rate for the artisanal shrimp fishery of 4.5% from 1970 to 2005 (Kasprzyck, 2008; C. Chaboud, pers. comm., Institut de Recherche pour le Développement). The 2005 landings of 3,500 tonnes were used as a basis to carry backward this 4.5% yearly growth rate to 1970.

Bycatch from shrimp fisheries is largely associated with industrial trawl vessels, and is known to be particularly high for tropical shrimp fisheries. Typically, discarded bycatch is not accounted for in reported landings, and we assumed this also applied to Madagascar. One of the earliest estimates for bycatch in the Malagasy shrimp fishery was an amount between 18,000-20,000 tonnes per year in the 1980s (Roullot, 1989). Kelleher (2005) proposed a 1:4.1 bycatch ratio and a discard rate of 72%, which gives tonnage values for the late 1980s similar to Roullot (1989), suggesting that the bycatch was almost entirely discarded. However, it is worth noting that a part of this bycatch is traded to local fishers who fill up their pirogues in exchange for some tobacco or a small amount of money and the local fishers land it and sell it for consumption in the local markets (A. Harris, pers. comm., Blue Ventures Conservation). Here, we applied a discard rate of 72% from 1990 to 2000, and a 90% discard rate for the 1967-1990 period (Table 1), based on Roullot (1989). Lower bycatch ratios and discard rates have been suggested for the last few years (late 2000s). Randriarilala *et al.* (2008) reported a bycatch ratio of 1:2.5 for 2003-2005, which suggests an annual amount of between 8,500 tonnes and 12,700 tonnes per year. This decrease, even stronger since 2005, seems to have been influenced by two developments in Malagasy regulations (Razafindrainibe, 2010). The first development was the introduction of legislation in the 1990s (decree 1999/2000) requiring industrial vessels to retain at least 50% of bycatch to supply fish to local markets. However, the effectiveness of this regulation has been questioned by Randriarilala *et al.* (2008), who assessed a discard rate of 62% for the period 2003-2005. The second development was the introduction of Turtle Excluder Devices (TEDs) and Bycatch Reduction Devices (BRDs) in the Malagasy shrimp fishery in 2003 (Anon, 2003; Razafindrainibe, 2010). Since 2005, all vessels are mandated to be equipped with such BRDs (decree 2003-1101), which considerably reduce the amount of bycatch (Kasprzyck, 2008; Table 1). This reduction is estimated to be approximately 32%, depending on the year, fishing conditions and area (Fennessy and Isaksen, 2007). Therefore, we considered a bycatch ratio of 1:1.7 from 2005 onward, while discard rates were set at 62% since 2001 (Table 1). However, only approximately 30% of licensed boats carry enforcement personnel from the national fisheries surveillance authority, and it is not clear whether crews use TEDs and BRDs when not under surveillance. Indeed, without surveillance, crews have little incentive to follow legislation, since the economic conditions under which crews work create a major incentive to maximise bycatch for private sale at sea. Shrimpers work seven days a week and are paid per tonne of shrimp landed, with base salaries as little as $25 per month.

The bycatch is dominated by fin fish (e.g., *Otolithes argenteus*, *Johnius dussumieri*, *Trichiurus lepturus* and *Pomadasys maculatus*), and to a lesser extent, invertebrates such as sea urchins and jellyfish, which can represent an important component of total bycatch. Chen and Chow (2001) estimated a discard survival rate of 8% for fin fish, 35% for cephalopods and 60% for crustaceans in a tropical shrimp fishery in Asia. We assumed here that all the discarded bycatch had a similar mortality, and thus applied mortality rates of 8%, 35% and 60% to the respective bycatch amounts of fin fish, cephalopods and other crustaceans.
The commercial shrimp fleet also comprises two other sectors of much lower capacity:

- A small fleet of mini-trawlers with engine power less than 50 horse power. This fleet was intended to introduce more efficient gears to the artisanal fisheries. However, they were taken up by industrial fisheries societies to allow them to fish in certain areas otherwise not accessible by their large boats (Kasprzyck, 2008; *Direction des Pêches* in Morondava, pers. comm.). Landings reported to FAO increased from 45 tonnes to 700 tonnes per year from 1975 to 2008 (peak at 750 t in 2003), and were considered reliable and were included without modification in the 'industrial grouping' described above.
- A deep-sea shrimp fishery was initiated in 1992 and ended in 2005 due to technical issues, mainly due to the nature of the sea floor. No information was available concerning associated bycatch. Catches fluctuated between 100 and 150 t·year^{-1} and were also included without modification in the 'industrial grouping'.

Table 1: Summary of data, assumptions and sources used to reconstruct total catches by shrimp fishing fleets in Madagascar.

Time period	Shrimp catches (t·year^{-1})	Associated bycatch and discards		Sources	Comment
		Bycatch ratio	Discards (%)		
1967-2008	300 - 13,300[a]	-	-	Domalain *et al.* (2000); Goedefroit *et al.* (2002); Razafindrakoto (2008), Rokotodratsimba *et al.* (2008) ; FAO (2009)	-
1967-1989		1:4.1	90	Roullot (1989)	
1990-2000		1:4.1	72	Kelleher (2005)	
2001-2004		1:2.5[b]	62	Randriarilala *et al.* (2008)	Decree 1999/2000
2005-2008		1:1.7[b]	62		BRD introduction

[a] Values reported to FAO were kept for the years 1966, 1994, 2000-2003, as they were deemed more representative than those reconstructed. [b] Based on a 32% reduction of bycatch due to BRDs (Fennessy and Isaksen, 2007)

Shark fishery

Although consumption of sharks is common, Madagascar only reports landings of less than 10 tonnes per year for the 2001-2008 period, according to FAO. However, the FAO trade database documents shark exports of up to 85 tonnes per year since 1992, and an independent report suggests that shark meat and fins have been exported since the early 20th century (Petit, 1930). In fact, artisanal fishers target sharks for the export market of fins, but carcasses are rarely discarded, and the meat is either consumed locally or to a lesser extent, sold to Comoros. A number of endangered benthic species, such as the critically endangered sawfish (*Pristis pectinata*), were once commonly caught by artisanal fishers along the mangrove-fringed coast of western Madagascar, but are now considered extremely rare throughout the region (A. Harris, pers. comm., Blue Ventures Conservation).

Sharks are also caught as bycatch in other Malagasy commercial fisheries, such as the shrimp fishery, in which sharks have been reported as representing 1% of the bycatch (C. Chaboud, pers. comm., Institut de Recherche pour le Développement; Table 2). Due to the high price of shark fins, we assumed that all sharks are finned, and that all of the carcasses are retained for local consumption or exported to Comoros (C. Chaboud, pers. comm., Institut de Recherche pour le Développement; A. Harris, pers. comm., Blue Ventures Conservation).

Finally, shark liver oil has also been traditionally used for cooking and to waterproof wooden boats (Cooke, 1997). The quantity of oil used for this purpose is substantial in the Maldives, as Anon. (2001) reports a use of between 54 and 58 kg of oil per year, for each boat. However, as it was impossible to assess the number of sharks required to treat the whole Malagasy artisanal fleet, this component was not considered in this study. Shark liver oil is also a valuable commodity on international markets, with Madagascar's sharks targeted by illegal, unreported and unregulated (IUU) boats for this purpose as well as for the fins. A number of known IUU vessels, which previously targeted Patagonian toothfish in the southern Ocean (see Palomares and Pauly, this volume), are reported to have recently converted to shark fishing in southern and western Madagascar by substituting bottom trawl nets with bottom-set gillnet gear to target nurse sharks for liver oil (mainly *Nebrius ferrugineus* and the vulnerable *Pseudoginglymostoma brevicaudatum*) (SADC, 2008; Anon. 2010a and b).

Table 2: Summary of data, parameters, assumptions and sources used for the reconstruction of shark fisheries catches in Madagascar.

Sector	Timeperiod	dry fin[a] (t)	Sources	Catch (t)	Comment
Targeted	1950-1979	-	Petit (1930)	160 - 570[b]	Exports at least since 1930s. Backward extension of 1980 per fisher catch rate
	1980-1985	-		600 - 3050	Backward extension of 1986-1988 trend in derived catch
	1986-1995	34.5 - 64.7	Cooke *et al.* (2001)	3,430 - 6,440	
	1996-2008	-		5,400 - 3,760[c]	Decrease of 3%·year^{-1}
Shrimp bycatch	1967-2008	-		Up to 385 t (1998)[d]	

[a] Hong Kong and Singapore imports; [b] 1950 value of 60 t derived through keeping the 1980 catch per fisher fixed.
[c] Values for this period were based on interpolations from the 1994 fin trade data, and an assumed 3% per year decrease in catches (McVean, 2006; Cooke *et al.*, 2001; Y. Sadovy, pers. comm. University of Hong Kong). [d] Values were based on reconstructed industrial shrimp catches and an assumed 1% of total shrimp bycatch composed of sharks (C. Chaboud, pers. comm., Institut de Recherche pour le Développement)

Cooke (1997) and Cooke *et al.* (unpub. data) review the shark fishery in Madagascar, focusing on exports of fins to the Hong Kong and Singapore markets. Given the high market price of fins, we assumed that all captured sharks were finned, and therefore, trade in fins was the best proxy available to assess the minimum quantity of sharks caught each year. Three approaches were used to reconstruct total shark catches by Malagasy fishers (Table 2). Data on the trade of shark fins were used to conservatively estimate the likely minimum catches of sharks that occurred in Madagascar's waters during the period 1970-1994: dried fins imported between 1986 and 1995 by Honk-Kong and Singapore from Madagascar were converted to whole body, wet weight using a conversion factor of 98.5% (Cortes and Neer, 2006; Jacquet *et al.*, 2008; Y. Sadovy, pers comm. University of Hong Kong). We assumed that the market started to greatly expand in 1980, and therefore linearly extended the 1986-1988 trend backwards to 1980. For the 1950-1979 period, we assumed that the 1980 per fisher catch rate remained constant back to 1950, and expanded it to total catches using fisher population data. For the 1996-2008 period, we conservatively assumed that the 1994 per fisher catch rate decreased by 3%·year^{-1}, based on literature and local knowledge (McVean *et al.*, 2006; Y. Sadovy, pers. comm., University of Hong Kong). Currently, catches are reported to decrease, and fishers catch fewer and smaller sharks, most of the time farther from shore than before (Cooke, 1997 and 2003; McVean, 2006; Cooke *et al.*, unpub. data). The high market demand for shark fin as a lucrative yet diminishing fisheries resource is a key factor driving Madagascar's nomadic

Vezo fishers further afield during their annual migration, with shark fishers exploiting remoter regions of the west coast of Madagascar, further offshore and in larger numbers, than ever before (Cripps, 2010). As an example of this escalation in fishing effort, the recent introduction of new intensive fishing techniques in the offshore Barren Isles archipelago and around Morondava, involves teams of artisanal fishers deploying weighted 'barrage' nets several kilometres in length, targeting sharks and guitarfish (Cripps 2010). Based on this information, we applied a 3% per year decrease in catches since 1994 (Table 2).

Non-shrimp invertebrate fisheries

The remaining landings data reported to FAO have been aggregated into a miscellaneous invertebrate grouping, which includes cephalopods and other molluscs, crabs and lobsters, shells and sea cucumbers. These species are heavily targeted by men, women and children for both subsistence and commercial purposes (Rasolofonirina and Conand, 1998; Frontier Madagascar, 2003; Anderson *et al.,* 2008; Barnes and Rawlinson, 2009; Cripps, 2009; Gough *et al.* 2009; Tucker *et al.*, 2010). The under-reporting of invertebrate fisheries is visible in the statistics reported to the FAO, since reported landings are very similar to exported fisheries products (r^2=0.75; not shown). Also, there are no reported invertebrate catches before 1962. However, coastal populations rely heavily on reef gleaning for invertebrates for their daily protein needs, although a significant amount is sold (Cripps, 2009; Gough *et al.* 2009). Indeed, invertebrate landings account for a major component of fisheries-derived income for artisanal fishers in many parts of Madagascar. Beside holothurian fisheries, octopus is the dominant commercial fishery in much of the southwest and northeast of the country, and lobster plays a crucial role in coastal livelihoods from the rocky shores of the southeast. A thriving trade in marine curios, predominantly molluscs, is also present in most coastal towns. In all these cases, catches are sold to collectors by local fishers for international export. Therefore, we assumed that invertebrate extraction by the local population was happening prior to 1962 and that this sector is missing from the official data.

In order to re-estimate the total extraction of invertebrates, product weight as it appears in the trade data was converted to (whole body) wet weight, using FAO conversion factors (Anon., 2000). A highly conservative export rate of 80% (for sea cucumber, cephalopods, crabs and lobsters) or 20% (for the other products) was then applied for the entire time period for which exports were thought to have occurred (1970s-2008) in order to calculate the domestic subsistence component. Finally, the average subsistence catch rates for the first three years of exports were applied to the number of inhabitants prior to the first year of export, in order to estimate the domestic subsistence component of invertebrate catches back to 1950.

Table 3: Summary of parameters used for the estimation of small-scale catches

Coastal Area[a]	Time period	Number of fishers	CPUE	Fishing days[b]	Catches (t)	Comment	Source
South-West	1950	2,900	6.7	-	5,155	-	
	1988	16,000	5.8	-	24,110	-	
	1991	18,100	5.0*	-	23,574	-	Laroche (1997)
	1950-1988	-	-	260	-	Stable CPUE	
	2008	40,100	2.1	-	21,853	-	
	1988-2008	-	-	260	-	-5% CPUE·year^{-1}	
The remainder	1950	5,300	6.1	-	8,300	-	
	1988	28,500	5.7	-	42,347	-	
	1950-1988	-		260	-	Stable CPUE	
	2002	55,300	4.3*	-	62,178	-	Doukakis (2007)
	2008	71,600	3.8	-	71,344	-	
	1988-2008	-	-	260	-	-2% CPUE·year^{-1}	

*Anchor points; [a] See Figure 2 for area definitions; [b]Assumed average number of fishing days in Madagascar (McVean, 2006; Gough and Humber, unpub. data; G. Hosch, pers. comm. Fisheries Planning and Management).

Small-scale fisheries: subsistence and artisanal catches

Between 1950 and 2008, landings of tuna-like species, narrow-barred Spanish mackerel (*Scomberomorus commersoni*) and miscellaneous marine fish represented the bulk of the data reported to FAO, accounting on average for 82% of total seafood landings in Madagascar. They are exclusively caught by artisanal fishers, as there are no industrial fisheries targeting these species.Unfortunately, estuarine catches were reported by Madagascar as inland catches until 1989, after which they were accounted for in the marine landings (Stamatopoulos and Rafalimanana, 1991). The same authors also report these estuarine catches to be 30,000 tonnes per year in the late 1980s. Finally, the official records of fish caught in the 1950s would signify a highly unrealistic local consumption of approximately 0.7 kg·person^{-1}·year^{-1} (based on a coastal population representing 90% of the total human population). Considering the change in reporting protocol and this unrealistic consumption rate, we replaced the data supplied to FAO (tuna-like species, mackerel and miscellaneous marine fish) and re-estimated small-scale catches based on CPUE and fishing effort data from independent studies (Laroche and Ramananarivo, 1995; Laroche *et al.*, 1997; Doukakis *et al.*, 2007), in combination with the number of fishers for the two regions as defined in Figure 2. Based on local knowledge and reports, which suggest decreases in CPUE over time (Bellemans, 1989; Laroche *et al.*, 1997; Frontier Madagascar, 2003; Langley, 2006; Doukakis *et al.*, 2007; Gough *et al.*, 2009), we applied different CPUE estimates for areas and time periods as shown in Table 3.

Other fisheries

A commercial joint venture fisheries operation between Japan and Madagascar was established in the 1970s under the name of *Compagnie Malgache Nippone de Pêcherie* (COMANIP) for the exploitation of Madagascar's skipjack tunas, *Katsuwonus pelamis* (Marsac and Stequert, 1984; Gilbert and Rabenomanana, 1996). Independent catch data were not available; therefore we considered the data reported to FAO as reliable and included them in the final result without modification. Thus, we assumed no underreporting of skipjack tuna catches during this period. This is likely conservative, given the known occurrence of substantial and widespread underreporting of tuna catches.

An exploratory deep-sea fishery in the Malagasy EEZ started in 2001. There is only one value provided by the FAO of 4157 tonnes for the year 2002. This sector is described by Soumi (2004) to have increased without any further indication; therefore, we assumed a growth rate of 5% per year between 2002 and 2008.

In the last two decades, fishing tourism has rapidly expanded in Madagascar (Jain, 1995). Most of the catch, dominated by large pelagic species such as marlin and tuna, is not catch-and-release, and is therefore killed and retained. However, none of the 60 people contacted in this study (employees or managers of sport-fishing charter companies) were willing to share information with us. As a result we were unable to quantify extractions made by this sector. In terms of overall tonnage, this sector is likely to be small, but may have effects on the population structure of these species, especially the billfishes.

Foreign fishing in Madagascar's waters

Since 1986, a fishing agreement has been in place with the European Commission, allowing EU purse-seine vessels to catch tuna in Malagasy waters (Gilbert and Rabenomanana, 1996). Catches of 10,000 tonnes have been declared each year since 1986. However, given that licence fees are based on this tonnage, it is highly likely that catches are largely under-reported, and may actually be around 18,000-20,000 tonnes per year (Anon., 2002). It is also interesting to note that a substantial Asian long-line fleet has been fishing in Malagasy waters most of the time illegally without access agreements, with entirely un-reported catches of tuna. Anon. (1995) reported legal catches of 6,000-8,000 tonnes. However, some estimates are up to 50,000 t·year^{-1} (Fowler, 2005). Indeed, Malagasy authorities do not possess the resources to patrol their own EEZ and therefore cannot address the problem of illegal fishing for such high-value species (Jain, 1995; Cooke, 1997; A. Harris, pers. comm. Blue Ventures Conservation; G. Hosch, pers. comm., Fisheries Planning and Management). Given that no formal access agreements exist between Madagascar and these countries, these catches are illegal under international law. For this long-line fleet, 7.5% of the bycatch is composed of sharks (Cooke, 1997; Fowler, 2005), of which only fins are retained. Finally, a longline fleet, whose catches are uncertain (Fowler, 2005), is operating from La Réunion (René *et al.*, 1998) and is targeting tuna and other large pelagic species (e.g., swordfish, marlin). For our purposes, we assumed this longline fleet started fishing in Malagasy waters around 1990 and catches increased linearly to 5,000 t·year^{-1} in 2008. Cases of this sort of unreported fishing are sometimes covered by media journals (Anon., 2010b) but have remained largely unaddressed by Malagasy authorities or Regional Fisheries Management Organizations (Cullis-Suzuki and Pauly, 2010). These catches, important in an ecosystem sense, are estimated here and listed in Appendix Table A1, but are not included in our reconstruction of Malagasy fisheries catches, since they are made by foreign countries.

RESULTS

Reconstructed catches by sector, taxa and year are presented in Appendixes Tables (A1, A2).

Shrimp fishery

Total shrimp catches, which were very low prior to 1967, increased until the late 1990s-early 2000s, with peak catches of 12,850 t·year^{-1} in 2003 (Figure 3a). Industrial landings stabilised in the 1990s at around 8,500 t·year^{-1}, with a peak of 9,850 t·year^{-1} in 1998. They have declined substantially since 2002, with only 5,200 t caught in 2008. Similarly, small-scale catches increased from approximately 300 t·year^{-1} during the 1950s, to 750 t·year^{-1} in 1970 and to 3,500 t·year^{-1} in 2005. Thereafter, they underwent a gradual decline to around 2,700 t·year^{-1} in 2008 (Figure 3a).

Bycatch also followed a similar trend, and reached a maximum of 38,800 t·year^{-1} in 1998, of which 25,500 t were discarded (72%). Since then, bycatch has decreased to around 8,000 t·year^{-1} in 2008, of which 4,400 tonnes were discarded (62%; Figure 3a).

Over the 1950-2008 time-period, the artisanal component represents 27% and the industrial sector 73% of total shrimp catches.

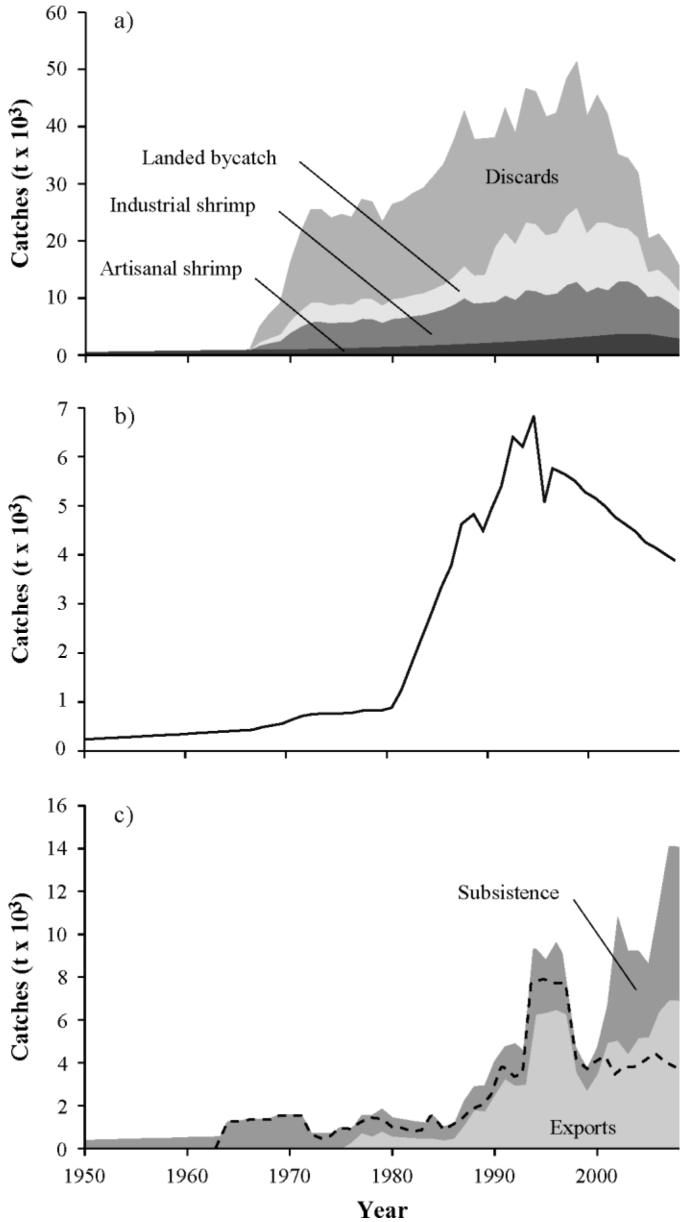

Figure 3: a) Shrimp catches by the industrial and artisanal sectors, and the associated bycatch (landed and discarded); b) total shark catches by small-scale fishers and c) catches for non-shrimp invertebrates, separated by exports or commercial (light grey), and subsistence (dark grey) catches (dotted line represents the data supplied to FAO).

Shark fishery

The reconstructed data for sharks conservatively suggests low catches until 1980, averaging 350 t·year^{-1}, followed by a rapid and substantial increase, from approximately 500 tonnes in 1980 to a peak of almost 7,000 t·year^{-1} in 1992 (Figure 3b). Since then shark catches have decreased to 3,800 t·year^{-1} in 2008 (Figure 3b).

Non-shrimp invertebrate fishery

Total invertebrate catches increased from 1,500 t·year⁻¹ in 1950 to 4,000 t·year⁻¹ in 1975 and were deemed to be exclusively for subsistence purposes during that time (Figure 3c). Since 1975, total catches have comprised both a subsistence and a commercial (export) component and, although fluctuating over time, have steadily increased to approximately 16,000 t·year⁻¹ by 2008 (Figure 3c). Over the 1950-2008 time-period, invertebrate catches have totalled 193,800 tonnes, of which the subsistence component represents 45% and commercial exports 55%.

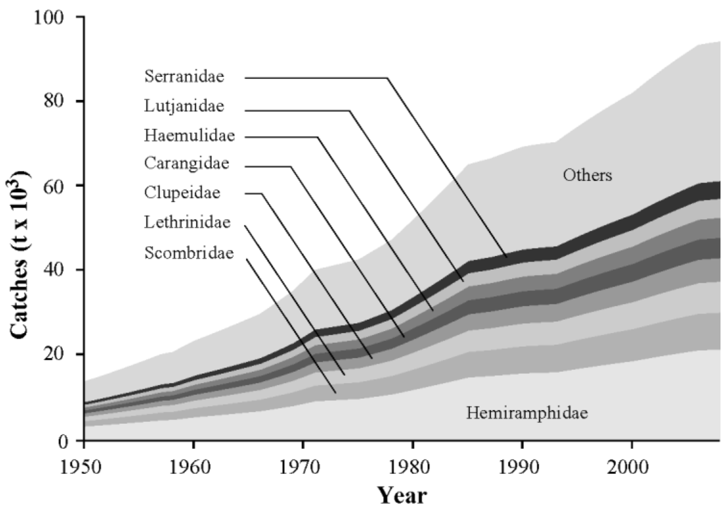

Figure 4: Total reconstructed catches of the small-scale finfish fishery, showing the taxonomic breakdown (based on Laroche *et al.*, 1997). Approximately half of these catches are for subsistence, and the other half for sale on the local market (C. Gough and F. Humber, pers. obs.).

Small-scale finfish fisheries: subsistence and artisanal catches

Reconstructed subsistence and artisanal catches of finfish by small-scale fishers have increased steadily over the 1950-2008 time-period (Figure 4). Total subsistence and artisanal catches in 1950 were around 13,500 t·year⁻¹ and have increased to around 93,000 t·year⁻¹ by 2008 (Figure 4).

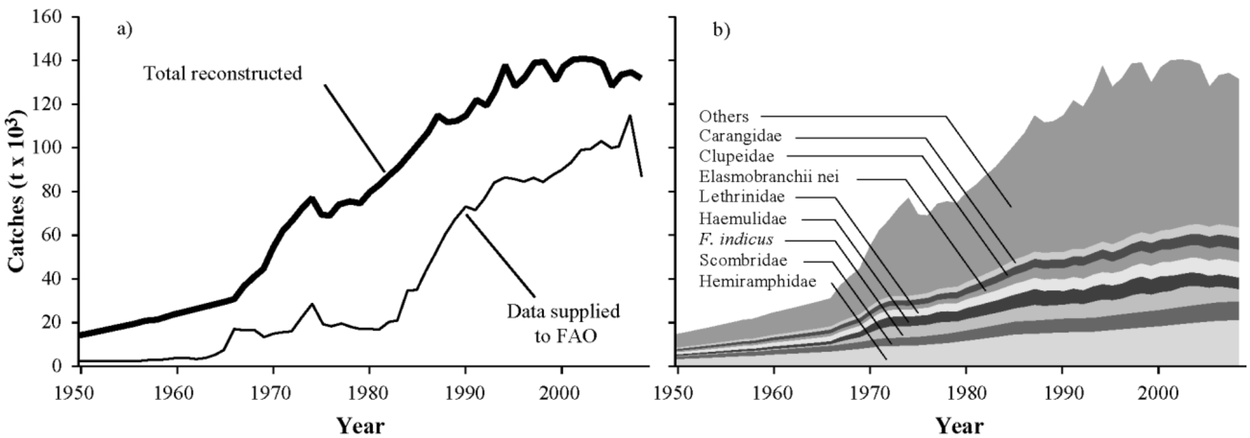

Figure 5: a) Total reconstructed catches versus reported landings as supplied to FAO by Madagascar; and b) Taxonomic composition of the overall reconstructed catches. *Fenneropenaeus indicus* is a shrimp species; all the other groups (except the mixed-group 'others') are from the small-scale, finfish fishery.

Overall reconstruction

Over the whole 1950-2008 time-period, total catches taken by Malagasy fishers in Madagascar's EEZ are estimated at 4.7 million tonnes. Thisreconstructed total is twice as high as the data supplied to the FAO by the government of Madagascar (Figure 5). Significantly, the re-estimation added over 550% for the earlier time-period (1950s), but adjusted the reported data by only 39% for the 2000-2008 period (Figure 5a). The taxonomic composition of reconstructed total catches shows a constant attern over time (Figure 5b).

Foreign fishing in Madagascar's waters

Tuna catches taken by foreign vessels are thought to have increased substantially since the mid-1980s. Current catches are somewhat uncertain due to obvious unreported and illegal catches. A minimum estimate is over 70,000 t·year^{-1} (Figure 6). Catches are likely dominated by Asian longline fleets operating illegally, with catches having increased to 50,000 t·year^{-1} by 2008. The EU purse-seine fleet, although operating legally through access agreement, is known to substantially under-report by at least 100%, with official catches reported as around 10,000 t·year^{-1}, while estimated actual catches are around 18,000 t·year^{-1} (Figure 6). Note that the publication by Le Manach *et al.* (2012) contains a mislabelled version of Figure (6). The present version is labelled correctly.

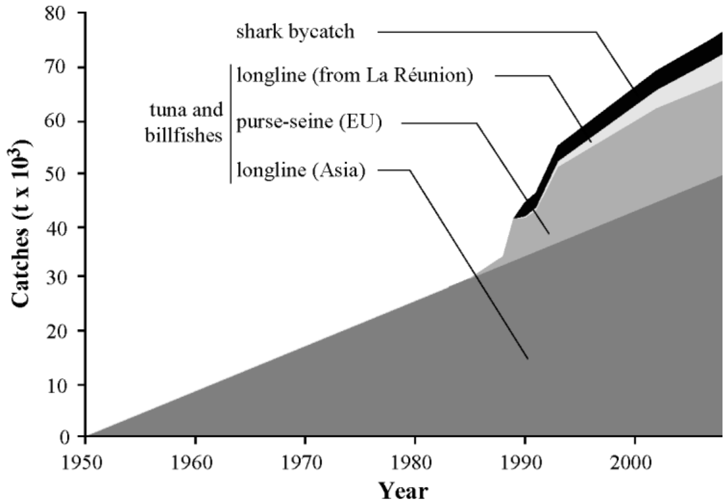

Figure 6: Estimated time-series of tuna catches in Madagascar's EEZ.

DISCUSSION

Overall, reported data show a steady increase in landings, due to the expansion of industrial fleets in the early 1980s. According to our analysis, Malagasy fisheries had been underreported by over 500% in the early time period, and seem to be underreported at present by at least 40%. The reporting is therefore improving, but current values, likely under-estimates, are still very substantial.

Our reconstructed catch time-series shows a levelling off of catches over the last two decades (Figure 5). It is worth noting that this levelling off of total catches is partly related to the improvement of bycatch handling by the shrimp industry causing decreased bycatch/discards since the 1990s. However, it is also certainly due to decreases in catches seen in various invertebrates (including shrimp) and shark fisheries, which suggest that overfishing is likely to be taking place.

The official data also fail to account for a large part of the subsistence fishery, which represents 75% of the total reconstructed catch over the whole period, and 83% for the period 1950-1980. Such marginalization of small-scale fisheries is common (Pauly, 1997), although inclusion in official statistics is crucial. As a consequence of this marginalization, total Malagasy catches may be approaching or even exceeding sustainable yields for coastal stocks, estimated at 180,000 t·year^{-1} (Anon., 2008b), with it remaining undetected.

Another issue that has been dealt with in this report is the poor taxonomic information included in official statistics supplied to FAO. The major group in these official statistics represents over 80% of total catches, and is only described as 'marine fish nowhere else included'. Although we made a taxonomic breakdown of total catches, information related to species composition remains extremely poor. This fact justifies the importance of the implementation by FAO of taxonomic census every three to five years in order to create more reliable species composition times-series.

Although not included in the total reconstruction, we also reviewed foreign fisheries in Madagascar's EEZ. Current catches of tuna, billfishes and sharks are likely to be over 70,000 t·year^{-1}, most of which are made illegally. This situation raises serious legal questions, and also points to the issue of inappropriate low fishing access fees paid by developed countries (Kaczynski and Fluharty, 2002; Hanish and Tsamenyi,

2009) and poor to non-existing monitoring and enforcement of such agreements (e.g., Jain, 1995). Indeed, the monitoring and enforcement system for the entirety of Madagascar is only composed of 3 monitoring vessels, 8 speedboats, 18 inspectors and 22 observers (R. Fanazava, *pers. comm.*, Centre de Surveillance des Pêches). This lack of monitoring and enforcement capability has led to increasing illegal pirate fishing in the waters of Madagascar, as evidenced here, which likely contributes significantly to unsustainable fishing practices in the Western Indian Ocean.

For the large-scale commercial shrimp industry, no real discrepancies exist between landings reported to FAO and our re-estimated landings. However, the overall CPUE is decreasing, possibly because catches have been significantly higher (by up to 5,000 $t \cdot year^{-1}$) than the estimated maximum sustainable yield of 8,700 $tonnes \cdot year^{-1}$ (Kasprzyck, 2008). It is worth noting that no values were reported to the FAO before 1964, when the first exploratory trawls were conducted. Prior to this date, local people were nevertheless fishing and consuming shrimp, and our study has filled this gap by assigning a subsistence component to this sector, although this was negligible compared to total catches. Also, the significant bycatch produced by shrimp trawlers is missing from official data, and this issue needed to be addressed since this bycatch is often made unavailable to the local population, when not collected by artisanal fishers. Our study highlights the importance of such bycatch for Madagascar since the beginning of this fishery.

The reconstructed time-series of shark catches gives a very different picture to the official data. The former considers that an artisanal fishery has existed since at least 1950, while the latter show little indication that a shark fishery exists despite this being fairly well documented in the independent literature (see Petit, 1930; Cooke, 1997). These values are based on the fin trade using strong assumptions and are considered highly conservative given that Hong Kong and Singapore do not account for 100% of the fin market. However, they are likely to be closer to actual catches than the previous assumption in which a lack of data has been incorrectly interpreted as no catch.

Concerning the small-scale finfish fishery, our reconstruction provides very similar estimates to those provided to the FAO for the 1989-2008 period. For 1950-1989, our results however differ greatly, as they fill the gap made by estuarine catches accounted for in reported inland catches before 1989. This misreporting of estuarine catches is documented but has never been incorporated into official statistics. Importantly, there are increasing concerns about the rate of growth in small-scale catches slowing, eventually leading to declining catches by the small-scale, artisanal and subsistence fisheries. This finfish fishery supplies the bulk of local seafood consumption demand, as most of the catches are sold and consumed locally, and declines in catches could have significant impacts on the food security of coastal communities.

Throughout this report, historical events and changes in reporting protocols illustrate the importance of linking historical information and fisheries data to current management plans, especially in maritime developing countries such as Madagascar, where fisheries are of fundamental importance for the food security of the people. The consequences of diminishing fisheries are likely to be particularly severe in an island nation in which over 50% of children under five years of age suffer delayed development due to a chronically inadequate diet, and where chronic food insecurity affects over 65% of the population (Back-Michaud *et al.*, 2009; Anon., 2010c).

Acknowledgments

We acknowledge the support of the *Sea Around Us* Project, a scientific collaboration between the University of British Columbia and the Pew Environment Group. We also thank Alasdair Harris, Gilles Hosch, Phaedra Doukakis, Rojo Rambonimanana, Christian Chaboud and the Wildlife Conservation Society for information and knowledge sharing.

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Appendix Table A1: Annual catches by domestic and foreign fisheries in Madagascar's EEZ, 1950-2008.

Year	Domestic fisheries (t)		Foreign fisheries (t)		
	Data reported to FAO	Re-estimated catches	Purse-seine (EU)	Longline (Asia)	Longline (France)
1950	2400	14295	0	0	0
1951	2500	15170	0	847	0
1952	2500	16070	0	1695	0
1953	2600	16995	0	2542	0
1954	2600	17946	0	3390	0
1955	2600	18923	0	4237	0
1956	2600	19925	0	5085	0
1957	3000	20942	0	5932	0
1958	3000	21447	0	6780	0
1959	3500	22811	0	7627	0
1960	4000	24205	0	8475	0
1961	4000	25243	0	9322	0
1962	3500	26304	0	10169	0
1963	4000	27387	0	11017	0
1964	5501	28491	0	11864	0
1965	7801	29617	0	12712	0
1966	17500	30883	0	13559	0
1967	16600	36787	0	14407	0
1968	16900	40937	0	15254	0
1969	13400	44617	0	16102	0
1970	15100	54319	0	16949	0
1971	15800	62029	0	17797	0
1972	16200	66801	0	18644	0
1973	22401	72408	0	19492	0
1974	28701	77014	0	20339	0
1975	19501	69410	0	21186	0
1976	18451	68934	0	22034	0
1977	19760	74354	0	22881	0
1978	18160	75462	0	23729	0
1979	17260	74619	0	24576	0
1980	17373	79804	0	25424	0
1981	16875	83133	0	26271	0
1982	20455	87439	0	27119	0
1983	21195	91293	0	27966	0
1984	35038	96501	0	28814	0
1985	35112	101705	0	29661	0
1986	44353	107033	520	30508	0
1987	52488	114869	1040	31356	0
1988	61141	111675	1550	32203	0
1989	67731	112374	8125	33051	0
1990	73515	115101	7400	33898	263
1991	71438	121887	8000	34746	526
1992	77021	118912	11250	35593	789
1993	84317	126392	14500	36441	1053
1994	86618	137783	14889	37288	1316
1995	85840	128033	15278	38136	1579
1996	84644	132157	15667	38983	1842
1997	86547	138809	16056	39831	2105
1998	84405	139285	16444	40678	2368
1999	87638	129942	16833	41525	2632
2000	90167	137120	17222	42373	2895
2001	93615	140240	17611	43220	3158
2002	99326	140689	18000	44068	3421
2003	99671	140276	18000	44915	3684
2004	103416	138493	18000	45763	3947
2005	99986	128148	18000	46610	4211
2006	100943	133449	18000	47458	4474
2007	115148	134454	18000	48305	4737
2008	87834	131771	18000	50000	5000

Appendix Table A2: Six most important taxa caught by domestic fisheries in Madagascar's EEZ, 1950-2008.

Year	Hemiramphidae	Scombridae	*Fenneropenaeus indicus*	Haemulidae	Lethrinidae	Elasmobranchii	Others
1950	3043	1246	274	677	1049	605	7402
1951	3232	1323	291	719	1114	642	7850
1952	3426	1403	308	762	1181	681	8310
1953	3626	1484	325	806	1249	721	8784
1954	3831	1568	343	852	1320	761	9270
1955	4042	1655	361	899	1393	803	9770
1956	4259	1744	380	947	1468	846	10282
1957	4481	1835	389	996	1544	890	10806
1958	4587	1878	414	1020	1581	912	11054
1959	4882	1999	440	1086	1682	970	11752
1960	5184	2123	459	1153	1787	1030	12469
1961	5409	2215	479	1203	1864	1075	12998
1962	5639	2309	499	1254	1943	1121	13539
1963	5874	2405	519	1306	2024	1167	14091
1964	6113	2503	540	1359	2107	1215	14654
1965	6357	2603	561	1414	2191	1263	15228
1966	6606	2705	689	1469	2277	1313	15824
1967	7002	2867	1436	1964	2413	1395	19711
1968	7407	3033	1856	2284	2553	1477	22328
1969	7823	3203	2183	2554	2696	1561	24598
1970	8367	3426	3522	3388	2884	1675	31057
1971	8926	3655	4489	4022	3076	1790	36071
1972	9065	3711	5271	4460	3124	1821	39348
1973	9203	3768	5309	4491	3172	1849	44618
1974	9341	3824	5068	4369	3219	1875	49318
1975	9478	3880	5242	4450	3266	1902	41190
1976	9818	4020	5107	4475	3383	1970	40162
1977	10164	4161	5603	4857	3503	2041	44025
1978	10515	4305	5466	4885	3624	2110	44556
1979	11050	4524	4823	4647	3808	2214	43554
1980	11595	4747	5296	5074	3996	2324	46771
1981	12152	4975	5340	5249	4188	2621	48608
1982	12721	5208	5503	5502	4384	3003	51119
1983	13300	5445	5581	5708	4584	3381	53294
1984	13891	5687	5846	6043	4787	3758	56489
1985	14494	5934	6078	6380	4995	4141	59683
1986	14653	5999	6539	6823	5050	4394	63574
1987	14803	6061	7216	7366	5102	4860	69461
1988	15022	6151	6427	6905	5177	5013	66980
1989	15232	6236	6438	6952	5249	4834	67432
1990	15432	6318	6415	6283	5318	5156	70178
1991	15530	6358	6973	6713	5352	5411	75549
1992	15608	6391	6419	6363	5379	5969	72781
1993	15681	6420	7477	6991	5404	5824	78596
1994	16095	6590	7884	7042	5547	6258	88369
1995	16494	6753	7003	6764	5684	5257	80078
1996	16878	6910	7211	6890	5817	5829	82622
1997	17248	7062	8200	7421	5944	5809	87125
1998	17605	7208	8561	7744	6067	5788	86312
1999	17948	7348	7537	7047	6185	5756	78121
2000	18278	7483	8195	7405	6299	5736	83725
2001	18743	7674	7990	7011	6459	5735	86627
2002	19193	7858	8942	6172	6614	5728	86182
2003	19620	8033	9098	6203	6762	5727	84834
2004	20031	8201	8363	6144	6903	5725	83124
2005	20427	8363	7189	5415	7040	5715	73998
2006	20807	8519	7233	5558	7170	5714	78449
2007	20902	8558	6554	5463	7203	5665	80109
2008	20991	8594	5717	5323	7234	5615	78298