Reconstructing Domestic Marine Fisheries in Mayotte from 1950–2010*

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Abstract

National fisheries statistics often underestimate total catches due to a lack of available catch data from unmonitored sectors. Here, we used a catch reconstruction approach to improve the Food and Agriculture Organization of the United Nations (FAO) time-series of the domestic catches made by Mayotte (France) since 1950. Thus, we also removed FAO data corresponding to industrial tuna vessels that were deemed as non-domestic fisheries. The total reconstructed catches from 1950–2010 were just nearly 84,000 tonnes, which is 1.4 times the official domestic catches reported to FAO. The main reason for this discrepancy was the limited official data prior to 1989, corresponding to unreported catches from shore-based activities and small-scale boat fisheries. This reconstructed catch time-series provides a more comprehensive view of Mayotte's historical catches, which may serve to influence future policy and management decisions regarding the sustainability of fisheries.

Introduction

Mayotte is composed of several islands, Grande Terre making up most of Mayotte's 375 km² land mass (Figure 1). It is surrounded by a barrier reef with a productive (Biais *et al.* 1987) yet increasingly threatened lagoon,[1] which contributes the bulk of the 1,100 km² inshore fishing area in Mayotte's 63,000 km² Exclusive Economic Zone (EEZ; www.seaaroundus.org). Mayotte is the most southeastern of the four islands that make up the Comoros Archipelago (Figure 1). Unlike the three other islands (i.e., the Union of the Comoros), Mayotte voted to keep its ties to France in a 1976 referendum and was recognized as one of its Overseas Territories (Dumas 2009). In 2011, Mayotte officially became the 101st French Department and France's 5th Overseas Department (Dumas 2009; Guézel *et al.* 2009a; Hopquin 2011).[2]

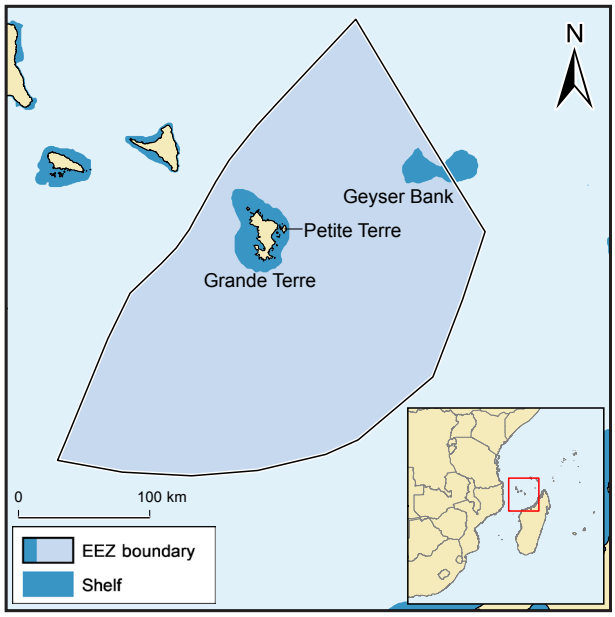

Figure 1. Map of Mayotte and its EEZ showing the two main islands of Grande Terre and Petite Terre, as well as the extent of the continental shelf (in darker blue). The Union of the Comoros is visible in the top left corner.

Since 1950, Mayotte's population has grown rapidly and is now following Mauritius as the second most densely populated island in the southwest Indian Ocean (500 inhabitants per km²; IEDOM 2011). The population has increased considerably since the 1980s, from 47,000 in 1978 to 186,000 in 2007 (INSÉE 2007), due to both a high birth rate and immigration. Mayotte's relatively high GDP for the region (INSÉE 2011) is in large part responsible for this immigration: many Comorans have immigrated to Mayotte in search of improved economic and social security, as well as the possibility of acquiring French citizenship (IEDOM 2011). In recent years, the number of Comorans living in Mayotte has more than doubled, from 26,000 in 1997 to almost 53,000 in 2002 (IEDOM 2006). A significant portion of these immigrants is illegal and occupy jobs in the agricultural and fishing sectors (Anon. 2004; Guézel *et al.* 2009a).

* Cite as: Doherty B, Herfaut J, Le Manach F, Harper S and Zeller D (2015) Reconstructing domestic marine fisheries in Mayotte from 1950–2010. Pp. 53–65 *In* Le Manach F and Pauly D (eds.) Fisheries catch reconstructions in the Western Indian Ocean, 1950–2010. Fisheries Centre Research Reports 23(2). Fisheries Centre, University of British Columbia [ISSN 1198–6727].

[1] Insufficient wastewater treatment systems, increased sedimentation from erosion, and coastal development are polluting coastal ecosystems such as mangroves and the lagoon. In the most densely populated urban areas around Grande Terre and Petite Terre, some of the fringing coral reefs have an average of only 5% live coral cover (Guézel *et al.* 2009a; Thomassin *et al.* 2011).

[2] Mayotte, La Réunion and eight other entities in the Indian Ocean (the *Terres Autrales et Antarctiques Françaises*) are sovereign to France and collectively known as France's Indian Ocean Territories (see Le Manach and Pauly, this volume). These territories occupy an important fishing zone for France, as they add 2.7 million km² to its EEZ (Bouchard 2009), making it the world's second largest (www.seaaroundus.org).

As a result of increasing pressures affecting the marine environment (e.g., demography, pollution, exploitation, urbanization), many developments have occurred in recent years. Among the most significant, is the creation of the *Parc Naturel Marin de Mayotte* in 2010, which encompasses the entire EEZ. Rather than an integral reserve, it aims to protect the sensitive areas within the lagoon system, while developing better-monitored inshore artisanal fisheries as well as domestic and foreign offshore pelagic fisheries (www.aires-marines.fr). Increased tourist activities such as scuba diving, whale watching and recreational fishing also provide further incentives for marine protection measures and create alternative job opportunities for locals (Guézel *et al.* 2009a).

Mahorans (the island's native citizens) and immigrants have always depended on marine resources from the lagoon as their primary source of protein (Anon. 2004; Aboutoihi *et al.* 2010) and most of the population has concentrated in villages along the coast (Jacquemart 1980; Maggiorani *et al.* 1993; Guézel *et al.* 2009a). For generations, they have been fishing in *pirogues* (locally-crafted wooden canoes) with handlines in the surrounding lagoon (Fourmanoir 1954; Biais *et al.* 1987; Herfaut 2006; IEDOM 2011). However, perhaps due in part to decreasing catches in the lagoon (Anon. 1994; Guézel *et al.* 2009a), there have been major changes to Mayotte's small-scale fisheries the last few decades. Polyester motorboats, outboard motors, and anchored fish aggregating devices (a-FADs) were introduced (Table 1); consequently, offshore pelagic species have become more important in the total catch over time, as evidenced by the shift in species in the official FAO statistics (FAO 2014).

Table 1. Major developments in Mayotte's fisheries.

Period	Changes	Source
1970s	Appearance of outboard motors	Jacquemart (1980)
1977	Creation of first fishing school, *l'École de Pêche*	Anon. (1994)
1978	Creation of COPEMAY[a] fishing cooperative	Anon. (1994)
1980s	Increased fishing effort of sites further outside of the lagoon	Maggiorani *et al.* (1993)
1980s	Increased motorization of *pirogues*	Jacquemart (1980)
1980s	Introduction of Yamaha polyester motor boats[b] (*barques*), imported from Japan	Biais *et al.* (1987), Minet and Weber (1992)
1985	Increased use of trolling to target pelagics[c] in areas up to 20 nautical miles offshore	Biais *et al.* (1987)
1989	Introduction of anchored FADs	Wendling and Le Calvé (1999)
1990s	Subsidies by Mayotte's *Service des Pêches* allowed acquisition of depth sounders and radios by the COPEMAY and the distribution of iceboxes to the local fleet	Anon. (1994)
1990s	a-FADs are more commonplace with 15 sites located in and outside lagoon	Wendling and Le Calvé (1999)
1995	10 village cooperatives (COVIPEM) in operation at this time	Guézel *et al.* (2009a)
2001	Appearance of first artisanal longliner targeting swordfish and tuna	Abellard and Herfaut (2004)
2004	Importing *barques* is banned[d]	Guézel *et al.* (2009a)
2009	Industrial tuna fleets are restricted to fishing in areas that are within 24 nautical miles of Mayotte's coast	Guézel *et al.* (2009a), Busson (2011)

[a] The COPEMAY has the goal of professionalizing the artisanal fishing fleet by commercializing the catch and improving the fleet through access to better equipment, boats, motors, and fuel subsidies (Anon. 1994; IEDOM 2011).
[b] The artisanal fishery changed significantly with the introduction of *barques* which allowed fishers to operate further offshore and for longer trips, leading to an increased effort targeting pelagics. Since the introduction of these *barques*, the number of *pirogues* has declined (Maggiorani *et al.* 1993; Herfaut 2006; Guézel *et al.* 2009a).
[c] Target species were *Thunnus albacares* (yellowfin tuna), *Katsuwonus pelamis* (skipjack tuna), *Istiophorus platypterus* (Indo-Pacific sailfish), and other Istiophoridae (e.g., marlins; Biais *et al.* 1987).
[d] In order to update the fishing fleet, subsidies of up to 80% were offered for new boats built between 2008 and 2014. As a result, new boats and longliners as well as several shipyards have appeared on the island in recent years (Guézel *et al.* 2009a).

Being located in the productive Mozambique Channel, Mayotte's waters have also attracted industrial tuna purse-seiners and longliners from France, Spain and the Seychelles (but actually owned by Spanish interests; see Le Manach *et al.*, this volume). However, these foreign fleets have increasingly been perceived by the artisanal fleets as competing for local resources (Busson 2011), and industrial purse-seiners have been banned from the 24 nautical miles (nm) zone since December 2009 (République Française 2009).[3]

Other major developments have shaped Mayotte's fisheries since 1950 and are summarized in Table 1. From these developments and the obvious lack of official catch data before 1989, it was clear that the official statistics for Mayotte were incomplete. This is not unique to Mayotte, as small-scale fisheries are frequently underreported or missing from official statistics (see e.g., Van der Elst *et al.* 2005; Jacquet *et al.* 2010; Le Manach *et al.* 2012). Rather than accepting these missing catches as 'zero catch', a re-estimation of the missing components was completed using a catch reconstruction method, following the rationale highlighted in previous studies (Pauly 1998; Pauly and Zeller 2003; Zeller *et al.* 2007). These catch reconstructions have proven useful for assessing the extent of marine fisheries catches in various places (Pauly 2007), and increasingly serve as a more realistic baseline of historic catches for policy and management decisions (Pauly 1998; Zeller *et al.* 2007). In some cases, such new baselines were even used by official institutions to improve their records, as has been observed in Mozambique (Doherty *et al.* this volume). As part of the effort of the *Sea Around Us* to reconstruct global fisheries statistics, a reconstruction of Mayotte's catch was completed by determining the missing and underreported sectors and by adding them to official statistics to improve their overall quality.

Mayotte's Fisheries and Reconstruction Methods

The FAO data for the years 1950–2010 were extracted from FAO's FishstatJ software (FAO 2014). These data contained reported landings from 11 different taxon groups, 10 of which were pelagic. The remaining category

[3] However, since it became a French overseas department, Mayotte can request foreign fleets to be excluded from its 100 nm zone (i.e., the vast majority of its EEZ), according to the European common fisheries policy.

was 'marine fishes nei' and was the only category reported prior to 1994. For the purposes of this reconstruction, Mayotte's catch was considered to be all catches from fishing sectors which were owned and operated by Mayotte and fish in Mayotte's EEZ. Therefore, catches from foreign fleets registered[4] and/or fishing in Mayotte's EEZ[5] were excluded from the catch reconstruction outlined herein; rather, they were dealt with separately as part of the *Sea Around Us*' atlas of large pelagics fisheries (Le Manach *et al.* press). To do so, we used the "France Overseas Territories (France OT)" data published by the Indian Ocean Tuna Commission (IOTC), which matched total catches of pelagic taxa reported by Mayotte to FAO for years 1995–2010,[6] but which also included a breakdown by gear (IOTC 2012b). Based on our knowledge of the structure of the fishing sectors in Mayotte, we determined that the data corresponding to all purse-seiners (all years) and longliners (in 1998–99 and 2005; see below) were non-domestic, and were thus removed from the catch baseline used here.[7] The adjusted FAO landings data with the non-domestic industrial pelagic catches removed are referred to throughout as the 'domestic FAO landings' (Figure 2).

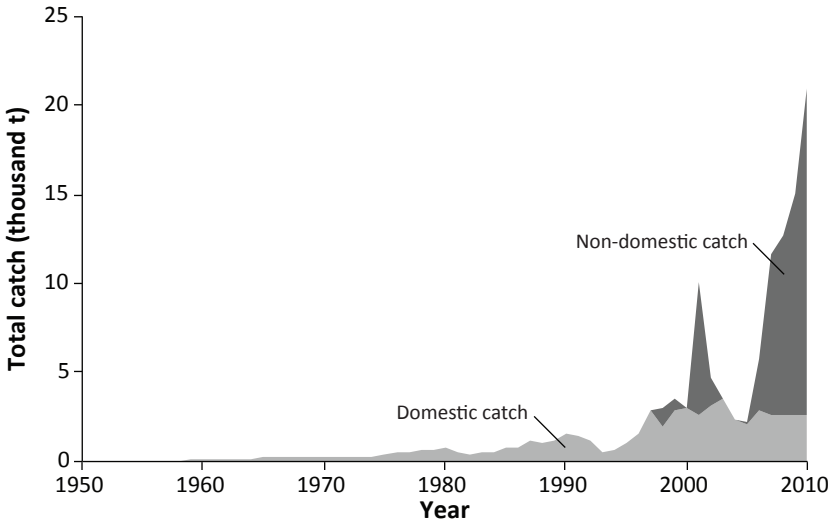

Figure 2. FAO reported catch data and the adjusted domestic FAO catch data for Mayotte, 1950–2010 (See Appendix Table A1 for annual catch data).

An extensive literature search and consultation with local experts provided additional sources of information, which allowed us to compare and improve the domestic FAO landings data, notably by developing anchor points for specific years to estimate the underreported (small-scale boat fishery) and unreported (shore-based and recreational) sectors.

Small-scale boat fisheries

The bulk of the small-scale fishing fleets and effort is carried out by *pirogues* (78% in 2005; Biais *et al.* 1987; Minet and Weber 1992; Herfaut 2006) and polyester motor boats (locally known as *barques*, generally ranging from 5 to 7 m; Herfaut 2006; Busson 2011):

- Typically non-motorized, small (3–5 m) and medium *pirogues* (5–7 m) are generally operated by one or two fishers in the lagoon and along the barrier reef (Biais *et al.* 1987; Minet and Weber 1992; Busson 2011). They are primarily used for subsistence purposes with only a small portion of their catch being sold (Minet and Weber 1992);
- Historically, large motorized *pirogues* (7–10 m) have been used for both artisanal and subsistence purposes (Biais *et al.* 1987; Service des Pêches 1990 in Minet and Weber 1992; Guézel *et al.* 2009a), usually with two to three fishers onboard (Service des Pêches, 1990 in Minet and Weber 1992). They are used both inside the lagoon and up to five nautical miles offshore of the barrier reef.
- Motorized *barques* are mostly operated by two to three artisanal fishers (Service des Pêches 1990 in Minet and Weber 1992; Herfaut 2006), up to five nautical miles outside the barrier. Since their introduction in the 1980s (Biais *et al.* 1987), they have increasingly occupied a larger percentage of the artisanal effort and catch.

Handlines remain the most common gear, accounting for 71% of effort and 57% of the catch in 2005 (Herfaut 2006). Nets and trolling occupy the bulk of the remaining effort (Biais *et al.* 1987; Maggiorani *et al.* 1993; Herfaut 2006) and have been commonly used since at least the 1980s (Jacquemart 1980; Biais *et al.* 1987). The proportion of the catch derived from trolling has increased dramatically over the years from 6% in 1992 (Maggiorani *et al.* 1993) to 32% in 2005 (Herfaut 2006), and is likely the result of increased motorization of vessels and effort targeting pelagic species.

[4] Some French operators flagged their vessels in Mayotte. This may be motivated by several factors such as benefiting from tax breaks, or being able to build new vessels without scrapping older ones (the EU's Common Fisheries Policy applies to Mayotte only since it became a French Department in 2011). There were between two and five such vessels from 2000 to 2010 (Anon. 2007a; IOTC 2006, 2011, 2012a). La Réunion had one Mayotte-registered vessel in 2009, and three in 2010; the other ones were operated by companies from France mainland (IOTC 2012a).

[5] A number of Spanish and Seychellois seiners (both requiring licenses) and French seiners (requiring a license since 2010; République Française 2010; see Le Manach and Pauly, this volume) have also been regularly fishing in Mayotte's EEZ between 2000 and 2010 (Anon. 2007b; Busson 2011). Their catches were not included in the Mayotte's FAO landings data, nor the reconstructed catches presented here. Prior to 2009, Mayotte received no compensation from the French purse-seiners fishing in their waters as profits from their annual fishing licenses went to the *Terres Australes et Antarctiques Françaises* (Busson 2011).

[6] This is not surprising, given that none of the French Îles Éparses (Tromelin, Glorieuses Archipelago, Juan de Nova, Bassas da India and Europa) have any permanent population or their own administrative units (they are administered by the *Terres Australes et Antarctiques Françaises* since 2007; see Le Manach and Pauly, this volume), and since La Réunion's catch is recorded in a separate category by the FAO/IOTC. Therefore, Mayotte is the only 'legitimate France OT' that can be included under this name.

[7] In the *Sea Around Us* database, catches by purse-seiners were re-allocated to either La Réunion or the French mainland, based on the origin of the operator in any given year and assuming equal catches for each vessel. Catches by longliners were entirely re-allocated to the French mainland.

The first extensive survey of the *pirogue* and *barque* fisheries was completed in 1989 by Mayotte's *Service des Pêches*. Since 1989, additional surveys have taken place and catch data were also available for 1992 (Maggiorani and Maggiorani 1990) and 1997–2005 (Herfaut 2004, 2005b, 2006). We used the national survey data to reconstruct catch from 1989 and 1997–2006, and the domestic FAO landings for 2006–2010.

We disregarded the 1992 survey (Maggiorani *et al.* 1993), because many demonstrations against Anjouan fishers working illegally in the fishing sector occurred that year. This forced many Anjouan fishers to land their catches at non-traditional landing sites in a clandestine manner (Maggiorani *et al.* 1993), which was likely not captured by the national surveys (Anon. 1994). Prior to 1989, FAO data were likely based on independent estimates from research for various years between 1962 and 1981 studies (Jacquemart 1980; Maggiorani and Maggiorani 1990) and catch data from the cooperatives from 1981 to 1983 (Maggiorani *et al.* 1993).[8]

To reconstruct catches for data-limited years, we compiled boat effort data from national surveys, grey literature and unpublished datasets (Table 2). These data were converted to a boat per-capita rate[9] for each boat type and linear interpolation was used to estimate boats per capita for years without data. A boat time-series from 1950 to 2010 was created by multiplying the boat per-capita time-series by annual population data (Figure 3).

Table 2. Anchor points for the number of boats in Mayotte, used to reconstruct fishing effort from 1950–2010.

Year	Small *pirogues*	Medium *pirogues*	Large *pirogues*	*Barques*	Source
1962	147	91	56	0	Moal (1962)[a]
1982	486	303	272	-	Le Gall (1986)
1985	419	297	289	-	
1987	-	-	-	30	Biais (1987)
1989	536	144	197	114	Maggiorani and Maggiorani (1990); Minet and Weber (1992)
1990	-	-	-	140	Minet and Weber (1992)
1992	580	221	185	175	Maggiorani *et al.* (1993)
1995	365	437	108	250	(unpub. data, J Herfaut)[b]
1997	481	575	142	240	
1998	446	770	124	235	
1999	411	965	107	230	
2000	411	817	126	248	Herfaut (2004)
2001	411	668	145	267	
2002	410	520	163	285	
2003	410	371	182	303	
2005	361	326	149	303	Herfaut (2006)
2006	334	301	138	319	(J. Herfaut; unpub. data)[c]
2010	325	293	134	297	(J. Herfaut; unpub. data)[d]

[a] 238 small/medium *pirogues*; proportions estimated based on 1982 data.
[b] 910 *pirogues*; proportion of small, medium and large estimated based on 1997 data.
[c] 773 *pirogues*; proportion of small, medium and large estimated based on 2005 data.
[d] 752 *pirogues*; proportion of small, medium and large estimated based on 2005 data.

To reconstruct catches from 1950–1988 and 1990–1997, the boat time-series was then multiplied by annual catch per unit of effort (CPUE) estimated from the 1989 and 1997 surveys: 0.3, 0.6, 3.6, and 5.9 t·boat^{-1}·year^{-1} in 1989 (Minet and Weber 1992) and 1.6, 0.5, 4.3, and 5.0 t·boat^{-1}·year^{-1} in 1997 (Herfaut 2004), for small, medium and large *pirogues*, and *barques*, respectively. We used linear interpolations to estimate catch rates in between 1989 and 1997, and maintained a constant catch rate from 1950–1989, given that there was no annual survey CPUE data prior to 1989. Thus, we did not account for annual variations in CPUE prior to 1989, but the 1989 CPUE estimates seemed reasonable for earlier years given the occasional observations of catch rates in the 1950s (Fourmanoir 1954) and 1970s (Barbaroux 1977; Jacquemart 1980). However, this is difficult to confirm

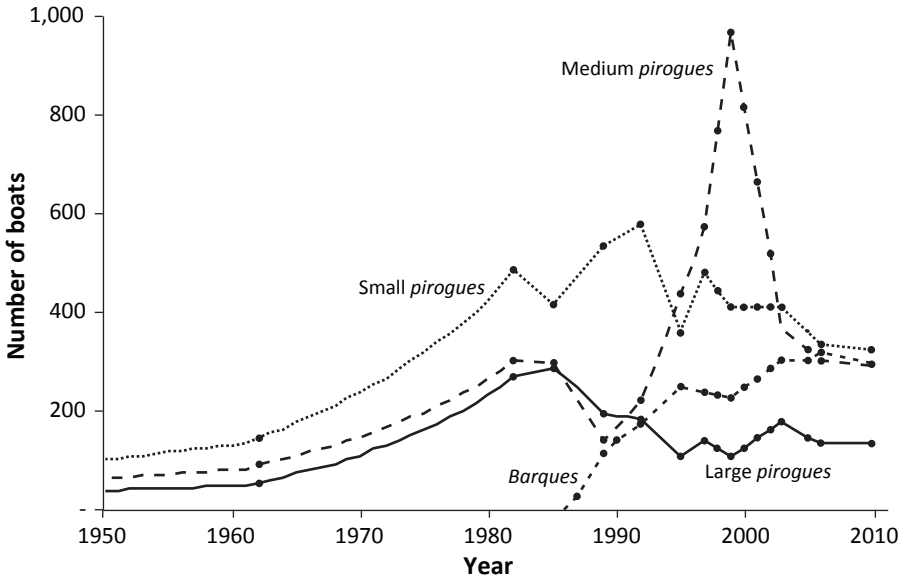

Figure 3. Evolution of the number of *barques* and *pirogues* in Mayotte since 1950. Solid dots represent anchor points from the literature.

[8] Population data from 1961–2012 were extracted from the Food and Agriculture Organization statistics (faostat.fao.org) and for 1958 from France's *Institut national de la statistique et des études économiques* (www.insee.fr). Missing years in the 1950s were linearly interpolated.

[9] Unofficial figures suggest that around 35 *barques* (J. Herfaut; unpub. data) fish year-round around Zélée (Mayotte) and Geyser (Glorieuses Archipelago) banks. France is rather worried about this fishery and about a possible steep decline in demersal biomass, which will be assessed thanks to a European Development Fund unlocked for the implementation of the Mayotte's Parc Naturel Marin.

since catch rates vary widely depending on the area fished (e.g., interior, barrier or exterior reef) and fishing gear (e.g., hand line or troll).

Most FAO landings are reported as 'unidentified marine fish' (100% of landings prior to 1995) and taxonomic breakdowns by family [1989: Maggiorani and Maggiorani (1990); 2003 and 2005: Herfaut (2004, 2006) and by species (1989: Maggiorani and Maggiorani (1990); 2003–2005: *Service des Pêches*, unpub. data)] were developed to disaggregate catch into more specific taxonomic groups (Table 3).). These breakdowns were used to estimate the historical taxonomic composition of catches. The 1989 breakdown was used for years 1950-1989, and the 2003-2005 averaged composition for years 2003-2010. Catch compositions between 1990-2002 were linearly interpolated.

Since 1999, the taxonomic detail in the FAO landings has improved, reporting catches for 8 taxonomic groupings of large pelagics. These FAO landings of large pelagics were left unadjusted, with one exception: Elasmobranchii were unreported until 2006, at which time they were still considered underreported. As an alternative to the FAO data, catches of Elasmobranchii were estimated based on the 1989 and 2003-2010 taxonomic breakdowns (Table 3). Catches of 6 other taxa (Acanthocybium solandri [wahoo], Istiophorus platypterus [Indo-Pacific sailfish], Istiophoridae [billfishes], skipjack tuna, Scombridae [other tuna-like species], and yellowfin tuna) were estimated by linear interpolation between the 1989 estimate (Table 3) and the first year reported in FAO landings (1995 for Scombridae and 1999 for all others). Catches of Xiphias gladius (swordfish) are only reported in the 2005 FAO domestic catch and no further additions were made.

Table 3. Taxonomic breakdowns for the *pirogue* and *barque* fisheries.

Family	Taxon	1989	2003-2010[a]
Carangidae	*Caranx sexfasciatus*	-	3.3
	Elagatis bipinnulata	-	2.1
	Other Carangidae	7.5	7.8
Hemiramphidae	*Hemiramphus far*	1.8	-
Holocentridae	*Myripristis* spp.	5.9	-
Lethrinidae	*Gnathodentex aurolineatus*	1.8	-
	Lethrinus obsoletus	8.9	-
	L. rubrioperculatus	-	4.0
	Lethrinus. spp.	-	3.4
Lutjanidae	*Aphareus furca*	2.4	-
	Aprion virescens	4.7	2.1
	Lutjanus bohar	4.4	2.3
	L. gibbus	-	2.5
	L. kasmira	1.7	-
Scaridae	Scaridae	-	1.9
Scombridae	*Acanthocybium solandri*	-	2.7
	Katsuwonus pelamis	-	15.3
	Other Scombridae[b]	15.1	9.1
	Thunnus albacares	-	9.7
Serranidae	*Epinephelus* spp.	-	2.4
	Plectropomus pessuliferus	4.1	-
	Serranidae	4.3	-
	Variola louti	3.3	-
Sparidae	Sparidae	5.9	-
Sphyraenidae	*Sphyraena* spp.	4.3	6.9
Others[c]		23.9	24.5

[a] The 2003- 2010 taxonomic breakdown was estimated based on the average between the 2003 and 2005 catch compositions.
[b] It should be noted that a significant portion of Scombridae catches are likely composed of Indian mackerel (*Rastrelliger kanagurta*), which represented 9% of the total catches in both 1989 (Maggiorani and Maggiorani 1990) and 2005 (Herfaut 2006).
[c] Contains species belonging to 41 taxa, including Lethrinidae, Lutjanidae, Acanthuridae, Carangidae, Clupeidae, Mugillidae, Sphyraenidae, and Priacanthidae.

The *Sea Around Us* defines small-scale fishing as either 'artisanal' (i.e., small-scale commercial) or 'subsistence' (i.e., small-scale non-commercial with primary purpose being self- or family-consumption), within its global catch database to facilitate international comparisons. A subsequent split of 'small-scale' *pirogue* and *barque* catches was required to assign these catches to one of the two small-scale sectors in the database (Table 4). National estimates for total catch by boat type were available for 1989 (Minet and Weber 1992), 1997 to 2003 (Abellard and Herfaut 2004), and 2005 (Herfaut 2006). Based on this sectoral allocation, the average artisanal and subsistence components of the *pirogue* and *barque* catch were 60% and 40% (considered as our 2010 'anchor point'). Moal's 1962 catch estimate in Maggiorani *et al.* (1993) was approximately 47% as subsistence and 53% as artisanal; based on this estimate and the observed trend of increased artisanal caches in more recent years, it was assumed that 50% of the catch was artisanal and 50% was subsistence in 1950 (the 1951–2009 proportions were linearly interpolated between our anchor points).

Table 4. Sectoral allocation of artisanal and subsistence components of the *pirogue* and *barque* fleets between 1989 and 2005.[a]

Boat type	Catch Breakdown (%)	
	Subsistence	Artisanal
Small/Medium *pirogues*	90	10
Large *pirogues*	50	50
Barques	10	90

[a] These assumptions were based on the total effort and average catch rates from national surveys (Minet and Weber 1992; Herfaut 2004, 2006) and the 2004 survey of fishing households (Anon. 2004).

In addition to the lagoon and relatively nearshore fisheries, more *barques* have been fishing around offshore banks since the late 1990s (Wendling and Le Calvé 1999; Herfaut 2005a). In 2003, there were an estimated 405 trips by *barques* to offshore banks in search of demersal species to satisfy local demand. An estimated 244 of these trips were to banks outside of Mayotte's EEZ, such as Geyser Bank in the Glorieuses Archipelago and Castor banks in Madagascar's EEZ, accounting for an estimated 86 tonnes (3% of the annual *pirogue* and *barque* catch; Herfaut 2004; an estimate was done as part of the reconstruction of the Îles Éparses, though; see Le Manach and Pauly, this volume).

The YVALANN (a 12 nm fishing vessel) also fished the offshore banks of Zélée and Geyser between 1989 to 1992 and sold their catches to the COPEMAY (Maggiorani *et al.* 1994; see Le Manach and Pauly, this volume). Total catches over this period were 190 t (Maggiorani *et al.* 1994) and were included in the reconstructed artisanal estimates. Their main catches were *Lutjanus bohar* [two-spot red snapper], *Epinephelus fuscoguttatus* [brown-marbled grouper], *Gymosarda unicolor* [dogtooth tuna], and *Lutjanus rivuletus* [Blubberlip snapper; Maggiorani *et al.* 1994).

Longline fishery

A small-scale artisanal longline fishery started in Mayotte in 2001, and as of 2010, there were three active vessels (all less than 10 m; Kiszka *et al.* 2010; Bein *et al.* 2011). The longline fishery represents a small component of Mayotte's

annual catches at present, but is rapidly growing (Anon. 2007b; Kiszka *et al.* 2010) and as of 2012 there were two new vessels and plans to add larger vessels to fish further offshore (IOTC 2011). This fleet targets swordfish, *T. alalunga* (albacore tuna), *T. obesus* (bigeye tuna), and yellowfin tuna, but most of the bycatch species (Indo-Pacific sailfish, *Sphyraena* spp. [barracudas], *Coryphaena hippurus* [dolphinfish] and *Caranx* spp. [jacks]) are retained and sold (Abellard and Herfaut 2004; Kiszka *et al.* 2010; Bein *et al.* 2011).[10]

As previously mentioned, the IOTC longline catch reported for 'France OT' was not considered indicative of Mayotte's longline fishery in some years. The IOTC nominal catch database contains catch data for 'France OT' from 1998, 1999 and 2001–2005 for 'longliners (targeting swordfish)', which match the FAO landings data for Mayotte. Since the review of literature indicated that there were no longliners based in Mayotte prior to 2001 (Abellard and Herfaut 2004; Kiszka *et al.* 2010; Busson 2011), it was assumed that domestic longline catches prior to 2001 for Mayotte were zero. The IOTC also reported catches of 143 tonnes for 'France OT' in 2005, much higher than what was typically landed by the domestic fleet from 2001–2010 (Table 5). These catches could be attributed to the industrial longline vessel ALALUNGA, which was reported to have fished in the EEZs of France's Indian Ocean Territories during 2005 (Anon. 2007b). It is possible that the 1998 and 1999 catches reported by the IOTC may also be representative of similar vessels, however, no information was found to verify this.

Several sources of data, including national data, IOTC nominal catch data, and data from the national fishing cooperative (COPEMAY) were used to estimate the catches of Mayotte's domestic longline fleet (Table 5). For the taxonomic breakdown, most of the artisanal longline catch data were already separated to the species or family level and were accepted. However, note that:

- Catch recorded as 'non-target, associated and dependent species (NTAD)' or 'others' was assigned to the 'miscellaneous marine fishes' category;
- Adjustments were made to account for shark discards and assumed unreported elasmobranch catches in instances where the reported figures were low. For example, the COPEMAY catch data contained zero shark or ray catches from 2006–2009, but it is known that shark and ray catches were still occurring (Bein *et al.* 2011). The Bein *et al.* (2011) study of the Mayotte longliner MTWARO I recorded the number of shark and ray species captured, their average lengths and, if discarded, whether they were alive or dead. Using this information and length-weight conversions (www.fishbase.org; Forselledo *et al.* 2008; Ribeiro-Prado and Amorim 2008), it was possible to estimate the proportions of landed and discarded elasmobranch catch for years where they were underreported (Table 3). We did not estimate discard mortality of sharks released alive.

Table 5. Summary of longline catch data with assumptions and sources used.

Period	Reconstructed catch (t)	Shark and ray catch (%)		Sources	Comments
		Unreported	Discards		
Prior to 2000	0	0	0	Abellard and Herfaut (2004), Kiszka *et al.* (2010)	No domestic longline fleet
2001–2003	12–17	0[a]	6	Abellard and Herfaut (2004), IOTC (2012b)	Both sets of data were identical, suggesting that the artisanal longline fishery was properly reported to FAO
2004	17	4	6	IOTC (2012b)	-
2005	16[b]	4	6	Assumption[c]	-
2006–2010	16–46	4	6	Fraisse (2010)	The increase from 2008 to 2010 could be attributed to increased effort, from one to three vessels circa 2006 (Anon. 2007b)

[a] No adjustments were made for the landed sharks and rays for these years and the existing data were accepted.
[b] No data were available for 2005; catch was estimated as an average between 2004 and 2006 values.

Shore-based subsistence fisheries

Many shore-based fishing activities are conducted primarily for subsistence purposes. The primary shore-based fishing methods used throughout Mayotte include reef gleaning (hand collection of octopus, shellfish and fish on reef margins), *djarifa* fishing (using nets made from cotton sheets or mosquito nets), nets, traps and the use of toxic plants (locally known as *uruva*; Guézel *et al.* 2009b). *Djarifa* fishing is practiced exclusively by women (Dahalani 1997), and takes place predominantly in mangroves and shallow bays throughout the island (Aboutoihi *et al.* 2010). Aerial surveys of the island observed the frequency of these activities and show reef gleaning (89.5% of observations) and *djarifa* fishing (9.1% of observations) accounted for the majority of shore-based fishing effort (Guézel *et al.* 2009b).[11]

Catches by this sector are unreported in FAO landings and only a few recent studies have estimated fishing effort and catch (Dahalani 1997; Guézel *et al.* 2009b; Aboutoihi *et al.* 2010; Jamon *et al.* 2010, Anon. 2014). *Djarifa* catches were estimated at 121 t in 1997 (Dahalani 1997) and 26 t in 2009 (Jamon *et al.* 2010). Reef gleaning catches in 2012 were 38 t, 15 t and 5.5 for octopus, shellfish and fish, respectively (Anon. 2014). We convert these estimates to shore-based per capita rates and used Mayotte's population data to generate a preliminary estimate of these catches from 1950 to 2010 (Table 6). Given that there has not been a decrease in *djarifa* catch rates between 1997 and 2008 (Jamon *et al.* 2010), the difference in per-capita catch rates likely reflects a change in the proportion of the population practising this traditional activity (Anon. 2014).

[10] Elasmobranchii are mostly discarded, although *Isurus oxyrinchus* (mako shark) and *Pteroplatytrygon violacea* (pelagic stingray) have commercial value and are generally sold on the local markets. Sharks are reportedly not targeted for the Asian shark-fin trade (Kiszka *et al.* 2010).

[11] Although nets and *uruva* do not currently occupy a significant portion of fishing effort, this may not have always been the case. *Uruva* fishing has been banned since 1997 and net fishing has been regulated and banned in certain areas since 2004 (Guézel *et al.* 2009b). These activities may have been more prevalent in the past (Fourmanoir 1954; Maggiorani and Maggiorani 1992), providing further justification for increased shore-based catch rates in earlier years.

Recreational fishing

Increased tourism and immigration of French expatriates in recent years has led to an increase of recreational fishing activities (Guézel *et al.* 2009a; Busson 2011). Recreational fishing can be broken down into two sectors: sport fishing and spearfishing.

There are currently only two commercial boats offering sport fishing trips and their annual catch for 2008 was estimated at 4.8 tonnes (Guézel *et al.* 2009a). This estimate was considered conservative as it did not take into account the catch from individuals who fished recreationally on their own boats, nor tourists who may have rented a boat from locals.

Table 6. Methods and sources used to derive per-capita catch rates for Mayotte shore-based fisheries, 1950–2010.

Year or period	reef gleaning	djarifa[b]
2010	Anon. (2014)	Jamon *et al.* (2010)
2009	Linear interpolation	
2008–1998		Linear interpolation
1997		Dahalani (1997)
1996		Maintained 1997 rate
1995	Increased shellfish catch rate by 200%, maintained 2010 rate for other taxa[a]	
1950–1994	1995 rate maintained	

[a] Shellfish collectors said catch rates were 4 times higher circa 1995 (Aboutoihi *et al.* 2010; K. Saindou, pers. comm., Agence des aires marines protégées)
[b] *Djarifa* catches were assigned to taxonomic families based on surveyed catch composition from Jamon *et al.* (2010).

Spearfishing has been regulated since 1991, when it was banned in the interior of the lagoon (Guézel *et al.* 2009a). It has been practiced for at least 20 years and now mostly takes place on the exterior slope of the barrier reef and in the open ocean. Based on information from Guézel *et al.* (2009a), a conservative estimate of 50 spearfishers and an average catch rate of 8.5 kg·fisher^{-1}·trip^{-1} were used for 2008. An assumption was made that recreational spearfishers were active once every two weeks (i.e., 26 trips per year).

Little recreational fishing took place prior to 1985, as there were few outboard motors at this time (Biais *et al.* 1987) and few French expatriates living on the island (IEDOM 2006). Due to no other available data, we made a simplifying assumption that recreational catches for 1985 and earlier years were zero, and that catches increased linearly between 1985 and 2010.

Catches were allocated evenly among the target taxa, as no other information is available regarding catch composition. These boats generally target pelagic and demersal species such as barracuda, billfishes, dolphinfish, *Gymnosarda unicolor* (dogtooth tuna), jacks, Lutjanidae (snappers), Lethrinidae (emperors), Selachimorpha (sharks), Serranidae (groupers), Sparidae (sea breams) skipjack tuna, tuna-like species, and wahoo (Guézel *et al.* 2009a). Spearfishers target dogtooth tuna, groupers, jacks, Scaridae (parrotfish), sharks, snappers, swordfish, tuna-like species, and wahoo (Guézel *et al.* 2009a).

Holothurian fishery

Despite the lack of any holothurians in the FAO data, historic evidence indicates the presence of such catches in Mayotte for export to Asian markets since as early as 1916 (Anon. 1916, in Eriksson *et al.* 2010). There is little information on the extent of harvesting after this, other than that harvesting of holothurians occurred from the mid-1990s until 2004 when it was declared illegal (Eriksson *et al.* 2010). Pouget (2004) documented exports of 5.4 tonnes of processed dried holothurians (*trepang*) in 2002. The species most often targeted when Mayotte's fishery was active was *Holothuria nobilis* (black teatfish; Pouget 2004; Eriksson *et al.* 2010). There were only documented exports of 422 kg of processed holothurians in 2003, which suggested unrecorded exports (Pouget 2004). Other than that, there was no data available on this fishery, and it was therefore not included in the reconstructed catches.

Results

The total reconstructed catch for Mayotte was nearly 84,000 t from 1950 to 2010, a figure that is 1.4 times the domestic portion of the FAO landings of 58,000 t (Figure 4A). The total reconstructed catches ranged from 240 t in 1950 to 2,700 tonnes in 2010 and reached peaks of 3,000 t in 1997 and 1999. The reconstructed catches were allocated to 110 taxonomic groups for the 1950–2010 time period of which the families Sombridae (25%), Lethrinidae (12%), Lutjanidae (12%), Carangidae (11%) and Serranidae (8%) accounted for the bulk of catch (Figure 4B). An increase in the percentage of large pelagic fish (Coryphaenidae, Scombridae, and Istiophoridae) within the total catch has occurred since 1989.These large pelagic families occupied 15-16% of annual catch prior to 1990 and between 28–48% of annual catch between 1995 and 2010, most of which are Scombridae (Figure 4B).

The small-scale boat fleet accounted for 78,000 t over the 1950–2010 period (Figure 4A). Catches were mostly from the *pirogue* and *barque* fleet (77,600 t), followed by longliners (238 t) and the YVALANN (190 t). *Pirogue* and *barque* catches increased from 200 t·year^{-1} in 1950 to 2,600 t·year^{-1} in 2010 and peaked at 2,900 t in the late 1990s. Shore-based subsistence fisheries accounted for 5,000 t from 1950–2010, (Figure 4A). The total shore-based catches varied from 30 t in 1950 to 80 t in 2010 and peaked at 180 t in 1997.

The total recreational catches were an estimated 220 t, estimated for the 1985–2010 period (Figure 4A).

Discussion

The total reconstructed catches from 1950–2010 were 1.4 times the total domestic FAO reported landings. The main reason for this discrepancy was the missing catch data prior to 1989 and the assumed unreported portion of catches during the early 1990s. No system was in place prior to 1989 to record catches of the small-scale *pirogue* and *barque* fisheries, and these catches were considered underestimated. The *pirogue* and *barque* fleets were responsible for the bulk of the total landings (93%) between 1950 and 2010, most of which are locally consumed. As this fishery represents such a large component of total landings, it is important that it continues to be monitored. Although only available until 2005, national surveys of the *pirogue* and *barque* fleets are known to have continued until 2010. The *Service des Pêches* then ceased operations as part of Mayotte's transition to an Overseas Department of France, and future surveys are now being organized by Ifremer's *Système d'Information Halieutique* (d'Aboville 2007). It should be noted that the 'marine fishes nei' and pelagic catches recorded by the FAO are identical for 2007–2010 and 2006–2010, respectively, and thus have not been updated since 2005. These catches should be retroactively adjusted once the analyses of 2006–2010 national surveys are available. The reporting of catch statistics resumed in 2013 thanks to the implementation of Ifremer's *Système d'information halieutique* (d'Aboville 2007) and should be visible in the version of FishStat due to be released in 2015.

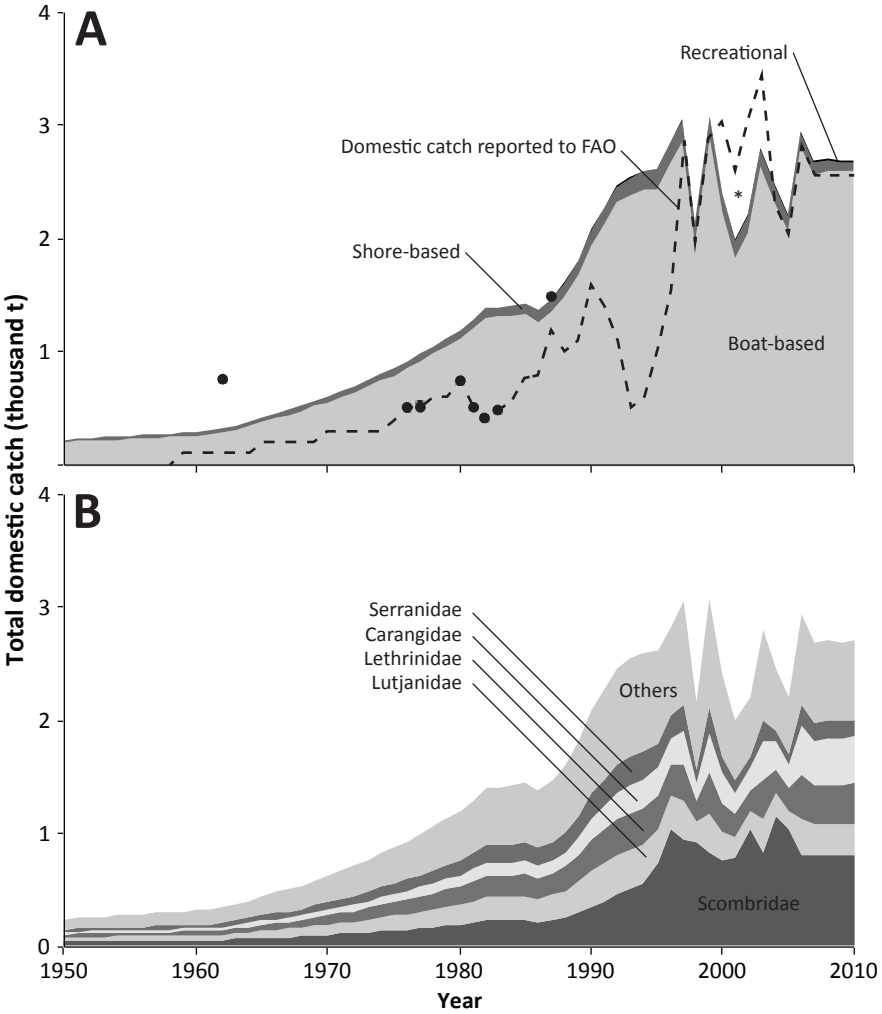

Figure 4. A) Total reconstructed catches for Mayotte by different marine fishing sectors. The 'boat-based' component includes catches by the pirogue and barque fleet, artisanal longliners, and the YVALANN. (see Appendix Table A1 for annual catches by sector). Solid dots represent historical estimates for small-scale *pirogue* and *barque* fleets (i.e., excluding shore-based fishing; Moal 1962; Jacquemart 1980; Biais 1987; Maggiorani *et al.* 1993). B) Taxonomic composition of major families in total reconstructed catches for Mayotte (See Appendix Table A2 for annual catches).
*FAO data are higher than reconstructed catches due to double-counting of pelagics.

The reconstructed catches were allocated to 110 taxonomic groups in the reconstructed time series, whereas there are only 11 taxa in the reported FAO data. It should be noted that the taxonomic disaggregation of unidentified and unreported catches is approximate and based on data from limited years (1989, 2003–2005). Several assumptions were necessary to estimate the catch composition data for the 1950–2010 period, and thus catch composition estimates will be less reliable for some years. For example, species documented in the 1989 survey may be overrepresented in earlier years. Despite the uncertainties in the allocation, this exercise is still valuable given the shifts in catch composition that have occurred as the fleet is 'professionalizing' and fishing further offshore. Our taxonomic disaggregation may prove more useful than the alternative of allocating the majority of catch as 'unidentified marine fish'. More specific information from annual surveys (Maggiorani and Maggiorani 1990, Maggiorani *et al.* 1993, Herfaut 2003, 2004, 2005) and historical observations (Fourmanoir 1954, Moal 1962, Maggiorani *et al.* 1994) may be used to improve the species disaggregation for specific years, and retroactively update landings data in the future.

Historically, Mahorans depended on the reef fisheries and shore-based fishing for much of their dietary needs (Aboutoihi *et al.* 2010). The reef resources within the lagoon had increased fishing pressure as Mayotte's population has grown, and interviews with fishers suggested that the resource may be overfished (d'Aboville 2007; Guézel *et al.* 2009a). Fishers now have to increase their effort and travel further offshore, regularly visiting neighbouring EEZs (Madagascar and Glorieuses Archipelago), to satisfy local demand for reef fish (Herfaut 2005a; Fraisse 2010). These fishers will often stay at sea for several days when fishing at offshore banks and risk dangerous sea conditions as well as being detained by foreign patrols, in order to remain profitable (Herfaut 2005a; Guézel *et al.* 2009a; Fraisse 2010). The plans to expand the artisanal longline fleet, operating within 20 nm of the coast (Busson 2011), and increase the effort targeting pelagics outside the lagoon may provide a safer and more economical alternative to the dangerous fishing conditions at offshore banks.

Fishing effort and catches by the *pirogue* and *barque* fleets have also increasingly moved outside the lagoon. This is reflected in shifts in species composition of catches, as Scombridae were not commonly targeted in the 1950s (Fourmanoir 1954), but now account for up to 50% of the *pirogue* and *barque* annual catch (Herfaut 2006). The 2009 decision to restrict industrial tuna fleets from fishing within 24 nm of Mayotte (Busson 2011) may help conserve the fishing resource and provide more fishing opportunities for the local population. However, it requires enforcing, and local enforcement capacity has historically been limited (Maggiorani *et al.* 1993; Guézel *et al.* 2009a; Busson 2011).

Due to the limited availability of data for the early part of the time series and for unreported sectors, there is some uncertainty associated with the estimated catches in this study. This is particularly the case for years prior to 1989 and for the shore-based and recreational fishing sectors, which have limited data. Recently completed studies by the *Parc Naturel Marin* (Guézel *et al.* 2009b; Aboutoihi *et al.* 2010; Jamon *et al.* 2010, Anon. 2014) suggest that *djarifa* fishing and reef gleaning are important subsistence fishing activities. The recreational fishery has increased rapidly in recent years (Busson 2011), and recording fisheries statistics from sport fishing operators may provide valuable information as it continues to grow.

This study attempts to provide an improved historical time-series of Mayotte's domestic fisheries catches for the 1950–2010 period, by including estimates of unreported (shore-based subsistence fisheries, recreational fisheries and discards) and underreported sectors (small-scale boat fisheries), and by disaggregating catches by foreign industrial fleets (e.g. longliners and purse seiners). This report may also serve as a resource to identify the existing sources of catch statistics for Mayotte's domestic fisheries and provides a comprehensive view of Mayotte's different fishing sectors.

Acknowledgments

The authors of this report would like to acknowledge the support of the *Sea Around Us*, a collaboration between the University of British Columbia and The Pew Charitable Trusts. BD, FLM and DZ also thank the Paul G. Allen Family Foundation for support.

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Appendix Table A1. Annual reconstructed catches (t) of domestic fleet by sector and FAO reported catches

Year	Boat-based	Recreational	Shore-based	Total reconstructed catch	Domestic FAO reported catch	Total FAO reported catch
1950	211	-	26	237	0.25	0.25
1951	220	-	27	247	0.25	0.25
1952	226	-	28	254	0.25	0.25
1953	231	-	29	260	0.25	0.25
1954	237	-	29	266	0.25	0.25
1955	242	-	30	273	0.25	0.25
1956	248	-	31	279	0.25	0.25
1957	254	-	32	285	0.25	0.25
1958	260	-	32	292	0.25	0.25
1959	269	-	33	302	100	100
1960	274	-	34	308	100	100
1961	280	-	35	314	100	100
1962	302	-	38	339	100	100
1963	326	-	39	365	100	100
1964	353	-	40	394	100	100
1965	393	-	43	436	200	200
1966	424	-	44	469	200	200
1967	453	-	46	499	200	200
1968	485	-	47	533	200	200
1969	533	-	50	583	200	200
1970	565	-	51	617	300	300
1971	617	-	54	671	300	300
1972	654	-	56	709	300	300
1973	706	-	58	764	300	300
1974	762	-	61	823	300	300
1975	803	-	63	865	400	400
1976	863	-	65	929	500	500
1977	924	-	68	992	500	500
1978	989	-	71	1,060	600	600
1979	1,054	-	74	1,128	600	600
1980	1,122	-	76	1,199	742	742
1981	1,215	-	81	1,296	516	516
1982	1,308	-	85	1,393	420	420
1983	1,318	-	89	1,407	480	480
1984	1,323	-	93	1,416	550	550
1985	1,344	-	99	1,442	780	780
1986	1,270	1	104	1,375	800	800
1987	1,360	1	110	1,472	1,200	1,200
1988	1,493	2	115	1,610	1,000	1,000
1989	1,698	3	121	1,821	1,100	1,100
1990	1,954	3	128	2,085	1,600	1,600
1991	2,136	4	136	2,276	1,400	1,400
1992	2,323	5	144	2,472	1,100	1,100
1993	2,386	5	153	2,545	500	500
1994	2,444	6	161	2,612	600	600
1995	2,450	7	169	2,626	1,033	1,033
1996	2,659	8	176	2,842	1,553	1,553
1997	2,867	8	181	3,056	2,867	2,867
1998	1,971	9	177	2,157	1,971	3,003
1999	2,892	10	173	3,075	2,892	3,452
2000	2,234	10	168	2,412	3,047	3,048
2001	1,831	11	161	2,003	2,621	10,052
2002	2,052	12	154	2,218	3,076	4,754
2003	2,641	12	146	2,799	3,464	3,464
2004	2,319	13	138	2,470	2,306	2,306
2005	2,072	14	128	2,214	2,051	2,194
2006	2,826	14	118	2,958	2,810	5,772
2007	2,573	15	107	2,695	2,560	11,661
2008	2,608	16	95	2,719	2,560	12,677
2009	2,603	16	82	2,701	2,560	15,006
2010	2,606	17	82	2,705	2,560	20,842

Appendix Table A2. Reconstructed catches (t) grouped by 5 most important taxa.

Year	Scombridae	Lethrinidae	Lutjanidae	Carangidae	Serranidae	Others
1950	35	30	34	19	25	94
1951	37	31	35	20	26	98
1952	38	32	36	20	27	100
1953	39	33	37	21	28	103
1954	40	33	38	21	28	105
1955	41	34	39	22	29	108
1956	42	35	40	22	30	111
1957	43	36	41	23	30	113
1958	44	37	42	23	31	116
1959	45	38	43	24	32	120
1960	46	39	44	24	33	122
1961	47	39	45	25	34	125
1962	51	42	48	27	36	134
1963	55	46	52	29	39	144
1964	60	50	57	32	42	154
1965	66	55	63	35	47	169
1966	72	60	68	38	51	181
1967	76	64	73	40	54	191
1968	82	68	78	43	58	203
1969	90	75	85	47	64	221
1970	95	80	91	50	68	233
1971	104	87	99	55	74	252
1972	110	92	105	58	78	266
1973	119	99	113	63	85	285
1974	128	107	122	68	91	306
1975	135	113	129	72	96	321
1976	145	122	138	77	104	343
1977	156	130	148	82	111	365
1978	167	139	159	88	119	389
1979	178	148	169	94	126	412
1980	189	158	180	100	135	437
1981	205	171	195	108	146	471
1982	220	184	210	116	157	505
1983	222	186	211	117	158	513
1984	223	186	212	118	159	518
1985	226	189	216	120	161	531
1986	214	179	204	113	152	513
1987	230	192	218	121	163	547
1988	252	210	240	133	179	596
1989	286	237	279	152	204	664
1990	342	265	331	184	233	730
1991	399	293	338	217	239	789
1992	458	320	350	253	244	848
1993	503	334	336	277	231	864
1994	541	342	332	299	223	875
1995	739	311	292	285	191	808
1996	1,040	296	270	285	171	780
1997	949	354	312	355	192	893
1998	921	194	166	204	99	573
1999	829	389	322	422	186	928
2000	763	282	226	317	126	697
2001	790	207	160	241	86	518
2002	1,023	207	155	248	80	504
2003	820	367	274	438	141	759
2004	1,154	236	177	283	91	529
2005	1,023	210	158	252	81	489
2006	794	410	307	490	157	799
2007	794	359	269	429	138	705
2008	806	359	269	429	138	717
2009	802	359	269	429	138	704
2010	810	359	269	430	138	699