RECONSTRUCTION OF MARINE FISHERIES CATCHES FOR MAURITIUS AND ITS OUTER ISLANDS, 1950-2008[1]

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ABSTRACT

Total marine fisheries catches by Mauritius and its outer dependencies were estimated from 1950 to 2008, and include unreported catches from the small-scale fisheries carried out around the islands of Mauritius, Rodrigues, Agalega and St. Brandon, recreational marine catches, estimates of catches taken by the Mauritian fleets along the Mascarene Ridge, and discards of the tuna purse-seine fishery. Summed for 1950-2008, total marine fisheries catches for Mauritius and its dependencies were estimated to be 682,392 t, which is 42 percent larger than currently reported landings of 478,305 t presented by FAO on behalf of Mauritius. This discrepancy was largely due to better accounting of small-scale catches carried out around Mauritius and Rodrigues islands by part-time fishers. This study illustrates the need for improved reporting of catches including all fisheries sectors in Mauritius, especially for the small-scale sector, which provides food security and a source of income for a large portion of the local population.

INTRODUCTION

Mauritius is an island of volcanic origin located between 20°10′S and 57°31′E about 850 km east of Madagascar (Figure 1). It covers a land area of approximately 1,860 km² and shelters a population of around 1.2 million people. Mauritius is an island state including several dependencies in the Southwest Indian Ocean, namely the island of Rodrigues, the St. Brandon (or Cargados Carajos) group of islands and islets, and the twin islands of Agalega. Mauritius was uninhabited when it was first colonized by the Dutch in 1638, and it has later been under French (1715-1810) and British (1810-1968) rule. The colonization period coincided with large-scale deforestation of the islands for sugar cane farming and the introduction of alien species which have severely damaged the islands' ecosystems and indigenous species (Paul, 1987; Sobhee, 2004; Turner and Klaus, 2005). At the time of independence in 1968, the economy was dominated by the sugar industry, and it has later undergone rapid growth and diversification with the development of the textile manufacturing industry and tourism.

Mauritius includes a large Exclusive Economic Zone (EEZ) that is approximately 1.7 million km² (Figure 1). The fishing sector includes small-scale fisheries in the lagoon and non-lagoon areas around Mauritius, Rodrigues, Agalega and St. Brandon islands, offshore semi-industrial fishing on the oceanic banks along the Mascarene Ridge stretching from St. Brandon to Saya de Malha and around the Chagos Archipelago, and on the high seas targeting migratory tuna stocks. Of late, a semi-industrial fishery targeting pelagic swordfish resources has been active since 1999, and two local vessels recently operated a deep sea demersal trawl fishery in the Southwest Indian Ocean from 2000 to 2006 (Jehangeer, 2006; Anon., 2007a)

In terms of its contribution to GDP and employment (about 10,000 people), fisheries are of limited economic importance to the national economy. However, the lagoon and inshore fisheries are an important source of employment and food security to many coastal communities of Mauritius and on the island of Rodrigues (Hollup, 2000; Vogt, 2001; Sobhee, 2004; Anon., 2007b; Hardman *et al.*, 2007).

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Tourists, partly through their recreational fishing activities, also add to the fishing pressure on marine resources (Paul, 1987; Sobhee, 2006). However, catches of the recreational and small-scale fishing sectors are often underreported in the official statistics and especially for the Western Indian Region (Van der Elst, 2005). The FAO FishStat database, which currently offers time series data on marine fisheries landings from 1950 to the present, is based on national statistical data supplied by its member countries. Therefore, the quality of the FAO data depends on efficiency of statistical collection within these countries. FAO data have been the basis for many influential fisheries studies (Pauly *et al.*, 1998), but they are, in fact incomplete (Zeller *et al.*, 2006). On Mauritius and Rodrigues Islands, the lagoon and non-lagoon areas are exploited by many people from different sectors, who fish for commercial, subsistence and recreational purposes. Most are not professional but amateurs, people in search of a meal or to supplement what is generally a meager income. In addition, both professional and amateur fishers use illegal and destructive fishing techniques, such as fine meshed nets, illegal spearguns, dynamites and chemical agents (Ardill, 1979; Paul, 1987; Hollup, 2000; Sobhee, 2004, 2006). Although such catches are not ignored and have been mentioned in recent and past studies (Paul, 1987; Pearson, 1988), they have never been estimated over a long time period, even though long time series of fisheries catches are necessary to evaluate the ecological effect of fisheries on the marine ecosystems. In this context, the purpose of the present study is to reconstruct the likely total catches of marine resources for the 1950-2008 time period following Zeller *et al.* (2007), to serve as a scientific baseline in the face of climate change and potential threats to food security.

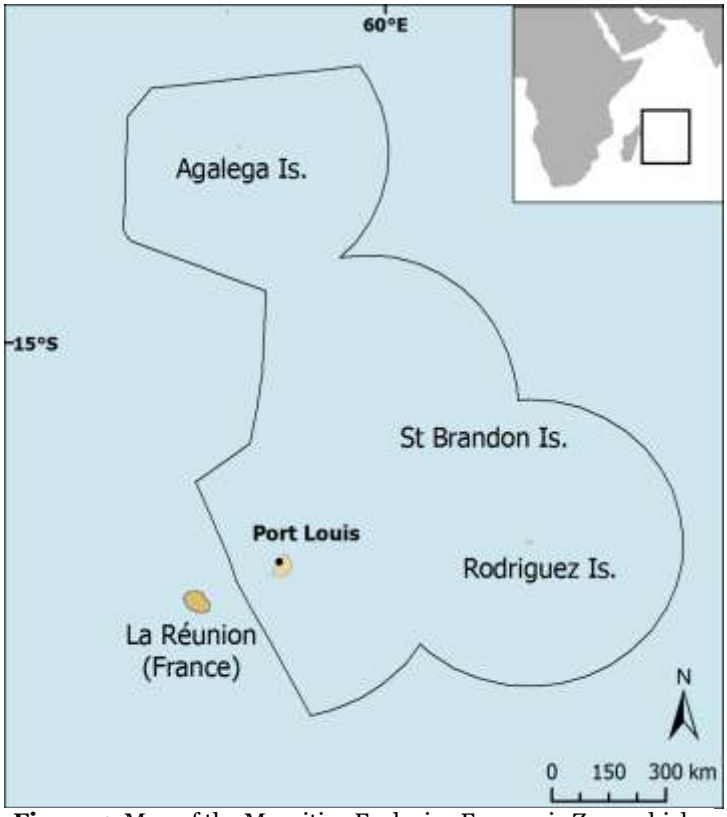

Figure 1. Map of the Mauritius Exclusive Economic Zone which includes Mauritius, Rodrigues, Agalega, and St. Brandon Islands.

METHODS

The existing reported catches were first examined. Such data were extracted from the FAO FishStat database, which currently offers time series data on marine fisheries landings from 1950 to 2008, and from national documents or from the Ministry on behalf of the Albion Fisheries Research Centre. For comparison of pelagic and non-pelagic species catches, we grouped Albacore (*Thunnus alalunga*), Bigeye tuna (*Thunnus obesus*), Black marlin (*Makaira indica*), Indo-Pacific sailfish (*Istiophorus platypterus*), 'Marlins, sailfishes, etc. nei', Striped marlin (*Tetrapturus audax*), Swordfish *(Xiphias gladius)*, 'Tuna-like fishes nei', Skipjack tuna (*Katsuwonus pelamis*) and Yellowfin tuna (*Thunnus albacares*) as 'pelagic species' and the remaining taxa as 'non-pelagic species'. We compared the FAO reported catches with those reported at the national level to identify discrepancies between the two. We then identified the missing components (i.e., sectors, time periods, species, gears) not covered by the existing reported catch time series through literature searches and consultations with local experts. After a search for other available and reliable sources to supply the missing catch data, we developed data anchor points in time for missing data. Time series data were reconstructed using interpolations and extrapolations. Data used to form these anchor points range from fisher and human population data, tourists arrivals, to catch per fisher data.

The marine environment of Mauritius and its outer islands has been exploited since first settlement, but this study is limited to the period of global FAO reporting, i.e., from 1950 onwards. Our reconstruction comprises the following components: a) 'unreported' catches of the small-scale, near-shore fisheries carried out around the islands of Mauritius, Rodrigues and St. Brandon; b) 'recreational' marine catches; c) estimates of the Mauritian banks fishery catches; d) illegal catches taken in the lagoon and non-lagoon waters of Mauritius and Rodrigues islands; and e) 'discards' of the industrial tuna purse-seine fishery. For the purpose of the present study, and according to the data that were available to us, we distinguished between three different categories of local fishers, namely the professional full-time fishers, the part-time professional fishers and the part-time subsistence fishers. Thus, we reconstructed the catches for each of these categories, separating the commercial and subsistence components for each. We reconstructed separately the catches for the different dependencies and fishing areas of the Mauritian state, although FAO data do not distinguish between them.

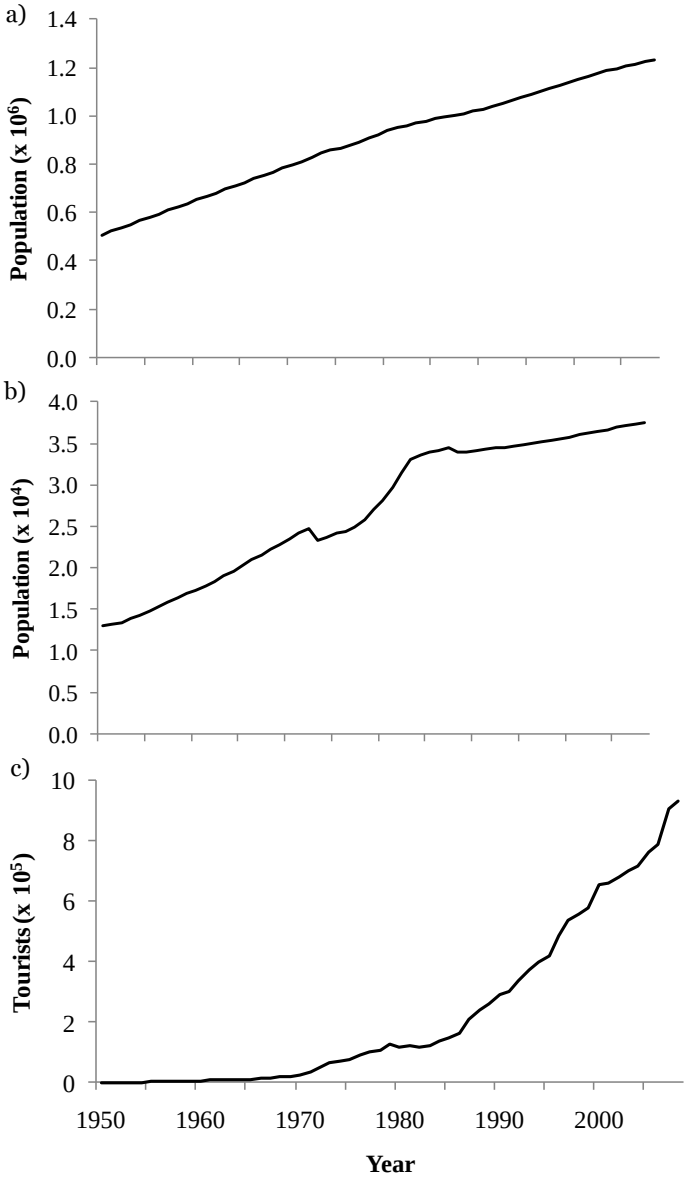

Figure 2. Human population data, 1950-2008 for: a) Mauritius Island; b) Rodrigues Island; and c) Tourist on Mauritius Island.

Human population

Population statistics for Rodrigues and Mauritius Islands were extracted from the Census Statistics Office (CSO) website (www.gov.mu/portal/site/cso) and reports. For years when data were unavailable, population numbers were derived by interpolating linearly between adjacent figures. Thus, a complete time series of the human population was derived from 1950 to 2008 (Figures 2a, b). The numbers of tourist arrivals on Mauritius Island were extracted from several sources (Paul, 1987; Gabbay, 1988; Anon., 2008; Anon., 2009b). Although commercial flights to Mauritius began in 1946, we assumed that tourist's arrivals were zero in 1950. Linear interpolations were used to estimate tourist arrivals for intervening years when no data were available (Figure 2c). While the St. Brandon islands shelter no permanent human population, some 300 people live on the twin islands of Agalega (see below).

Mauritius Island small-scale fisheries

Mauritius Island is almost totally surrounded by a fringing coral reef enclosing a lagoon of more than 300 km². Small-scale fishing takes place within the lagoon and non-lagoon areas beyond the reef on the

narrow shelf area around the island. Fishers use a wide spectrum of fishing gears which ranges from hand collecting to large nets, gill nets, canard nets, hooks and lines, basket traps and harpoons. To this must be added unreported catches taken by illegal fishing methods such as dynamite and pesticides. The main taxa caught include Serranidae (groupers), Siganidae (rabbitfish), Lethrinidae (emperors), Lutjanidae (snappers), Scaridae (parrotfish), Mullidae (goatfish), Mugilidae (mullets), Acanthuridae (surgeon fish), octopus and lobsters. With the use of hands, sticks and other simple gears, part-time fishers can take small fishes, molluscs, crustaceans and other edible marine species. Many use small cast and mosquito nets to catch large numbers of immature fishes (Paul, 1987).

Professional full-time fishers

Professional full-time commercial catches: On Mauritius Island, artisanal fishery landings have been monitored since 1946 (Ardill, 1979). However, the method employed as well as the managerial efficiency has fluctuated over the years, thus changing the reliability of the reported landings over time. Therefore, in order to provide a more accurate estimate of total artisanal catches, we retained the more reliable estimates, which we used as anchor points for our reconstruction of the artisanal fishers commercial catches. Linear interpolations were used between anchors points to derive a complete catch time series for the artisanal catches from 1950 to 2008.

1950-1958: From 1946 to 1958, officials have added to the "controlled catch" an estimated amount of 560 t for the uncontrolled yield. This quantity included "*(1) an amount of fish artisanal fishermen retained for their own consumption, for their 'curry' or somewhere between 1 and 1.5 kg daily per fisher, (2) some 200 t thought to be landed at some 17 minor but uncontrolled landing stations and, (3) an estimated 50 t taken by sport fishers and countless amateurs*" (Paul, 1987). Therefore, we used the official estimates of total catch presented by Paul (1987), from which we subtracted the official estimated amounts retained by the fishers for their own consumption (310 t) and the official estimated catch of the sport and countless amateur fishers (50 t). These will be considered separately (see below).

1959-1976: Two different samples of catch data were available to us. The first represented the artisanal catches estimated from 1960 to 1970 by multiplying the catches gathered by the Protection Service by the raising factor of 1.7. The second referred to a later method, in which the total catch was estimated from 1960 to 1977 by multiplying the controlled catch by 3.44, a correction factor arbitrarily chosen to bring total yield to 'expected' levels (Ardill, 1979; Paul, 1987). Therefore, and given that the coverage of the landing stations became sporadic after 1967 (Ardill, 1979), we assumed that the earlier estimation method provided the more accurate and conservative estimates of catch from 1960 to 1966 and we retained those estimates as anchor points. For 1974, Moal (1975 in Paul, 1987) reported an estimate of 1,100 t, which was not consistent with our other data, so we assumed that this only represents a fraction of the total catch.

1977-2008: For this time period, we retained the artisanal catches estimated by the Fisheries Division as the more reliable estimates. Indeed, since 1977, a frame survey system for the collection of statistics on fish landings has been operational (Ardill, 1979), and the method was described in the literature (FAO, 1983; 1987; Samboo and Mauree, 1987; Anon., 2007b). Catch and effort data are collected on a monthly basis by a team of enumerators covering randomly selected landing stations divided into several strata, and raising factors are used to estimate catch and effort for each stratum separately. For 1982, Paul (1987) estimated the total catch of the professional artisanal fishers at 1,373 t. However, once the subsistence part of the catch was removed, the remaining amount, namely the commercial catch, was consistent with that reported by the Ministry for the same year. Therefore, landings collected by the Fisheries Division were taken as the best estimates for the artisanal commercial catches for this time period.

To estimate the taxonomic composition of the professional fishers' commercial catches, we used data from Paul (1987) which provided the estimated changes in species composition of total controlled catch from 1957 to 1982 (Table 1).

Table 1. Estimated species composition of total professional full-time fishers' catches on Mauritius Island, based on estimated changes in species composition of total controlled catch (Paul 1987).

Taxon Name	Common Name	1950 - 1957	1958 – 1964[a]	1965 - 1971	1972 - 1981[a]	1982 - 2008[a]
Lethrinidae	Capitaine	3.9	3.4	2.0	2.2	-
Lethrinidae	Dame Berri	5.4	4.4	4.0	3.1	9.9
Lethrinidae	Battardet/Caya	5.3	5.4	3.1	4.4	-
Siganidae	Cordonnier	17.4	17.0	19	10.9	12.8
Mullidae	Rougets	5.2	3.9	4.1	3.1	4.1
Mugilidae	Mulets	4.5	3.3	2.9	4.1	7.9
Serranidae	Vieilles	4.9	5.4	5.2	5.2	7.1
Acanthuridae	Licornes	8.6	8.6	9.6	15.6	7.0
Octopodidae	Octopus	13.2	16.4	17.5	15.8	11.7
Lobsters	Langoustes	1.8	2.1	1.6	0.5	0.3
Miscellaneous	Others	29.8	30.1	31.0	35.1	39.2

[a]Note change in time period coverage.

The 'others' category (Table 1) includes pelagic fishes. In the 1950s, the catch of clupeoids constituted an important seasonal activity of traditional fishers, but catch of those species followed a sharp decline while the catch of scombroid type fishes increased. Capture of sharks also occurred from the 1950s and 1970s, and 74 t of shark was caught in 1963 (Paul, 1987).

Professional full-time subsistence catches: The custom is for professional fishers to keep a small amount of their daily catch for their own consumption (Gonzalez Manero, 1971; Paul, 1987). This amount has been estimated between 1946 and 1958 as part of the uncontrolled landings. However, we assumed that this amount would not have been included in the official reported catches since 1958. The amount retained by fishers is fairly constant, independent of the size or value of the catch (Gameiro, 2003). Therefore, for the 1959-2008 period, rather than using a percentage of the total commercial catch, we used the number of artisanal fishers, an effort of 176 fishing days per artisanal fishers, and the average amount of 1.25 kg retained per fisher per day as reported by Paul (1987). For 1974 and 1982, we used 1,000 and 1,500 professional artisanal fishers, respectively, as reported in Paul (1987), while the number of active professional fishers from 1999 to 2008 were provided by the CSO (Anon., 2009a). For the period 1950-1958, we rely on the description of the uncontrolled catch by Paul (1987), and we concluded that a total standard of 310 t was yearly retained by the artisanal fishers during this time period for subsistence purposes.

We used linear interpolations between the figures reported or calculated as above to establish the subsistence catches of the artisanal fishers from 1950 to 2008.

Professional part-time fishers

In addition to the professional full-time fishers, numerous part-time fishers exploit the lagoon and non-lagoon environment. The common species in their catch are from the families Siganidae (rabbitfish), Serranidae (groupers), Lethrinidae (emperors) and Carangidae (jacks) (Samboo, 1987). A report by Roullot *et al.* (1988) mentioned that part-time fishers also visit Fish Attracting Devices (FADs), catching pelagic fish using trolling and hand lining. From 1977 to 2008, the official reported catches for the so-called 'amateur fishery' consisted of the constant amount of 300 t. In a recent survey, the Ministry of Fisheries on Mauritius found that 23,400 persons were involved in "recreational" fishing in the lagoon of Mauritius, from which about 1,000 were owners of a boat. Indications were that their catch could be more than the current estimate of 300 tonnes annually (Jehangeer, 2006). (Samboo and Mauree, 1987) mentioned that "*the quantities caught by the part-time fishers may exceed the catch by the commercial fishers*". Paul (1987) and Moal (1975 in Paul, 1987) differentiated between two categories of part-time fishers. The first represents people who directly consume as well as sell a part of their catch; the second consists of local people who fish only for their own consumption. For clarity purposes, we will use the terms part-time professional fishers and part-time subsistence fishers for the first and second categories, respectively. Furthermore, in his estimate of catches for the part-time subsistence fishers in 1982, Paul

(1987) included catches from the fishing tourist population, but excluding the pelagic sport fishery catches. However, as we aimed at discriminating between the commercial, subsistence and recreational sectors, we rather included the fishing tourist catches in the recreational catches.

Part-time professional fishers fish for their own consumption and sell the surplus of their catch. However, we assumed that their commercial catches are not included in the recorded commercial landings, for the following reasons. First, they are fishers who generally do not operate through a middleman[2] and many have developed their own sales outlets to commercialize the surplus of their catch (Paul, 1987). There are some indications that many hotels and restaurants which cater to the tourist trade are provisioned directly by contracted fishers, and that their catch escapes detection by the fisheries authorities and are unaccounted for in landings statistics (Paul, 1987; Sobhee, 2004). Moreover, many of them use illegal fishing gear. To respond to an increasing demand for seafood, reduced catches, and new regulations, many amateur fishers have currently resorted to illegal fishing methods, using fine meshed nets, illegal spearguns and landing of undersized fish (Paul, 1987; Hollup, 2000). Therefore, it was assumed that their commercial catches were not included in the reported artisanal catches.

Table 2. Data sources and method used to estimate the part-time professional fishers population of Mauritius Island from 1950 to 2008. These data were converted to percentage of the total population which we used, together with assumptions and the total human population time series, to derive estimates of the part-time professional fishers population from 1950 to 2008.

Year	Number of part-time professional fishers	Human population	Ratio (%)	Source and method
1950	1,566	506,663	0.31	25% decrease in ratio from 1950 to 1974
1974	2,000	857,063	0.23	Moal 1975 (in Paul, 1987)
1982	2,000	960,994	0.21	Paul (1987)
2008	2,562	1,230,995	0.21	1982 ratio maintained unaltered

Professional part-time fishers' population: Paul (1987) and Moal (1975, in Paul, 1987) reported 2,000 part-time professional fishers in 1974 and 1982. We converted these figures to ratios of the total population for the corresponding years. The calculated ratios, together with the total island's population time series and assumptions as described below, were used to derive complete time series estimates of part-time professional fisher population from 1950 to 2008 (Table 2). We assumed that the proportion of the Mauritian population involved in such fishing activities decreased by 25% from 1950 to 1974. A greater proportion of the population likely relied on fishing for food or income purposes in the earlier time period. The progressive diversification of the economy away from sugar cane after independence in 1968 (Paul, 1987; Houbert, 2009), together with new and cheap supply of frozen fish from the offshore banks fishery in the late 1960s (Christy and Greboval, 1985; Ardill, 1986) would have contributed to reduce the need to fish for food or income complement. We also assumed that the same proportion of the population was involved in this activity from 1982 to 2008. This is a conservative estimate when we consider the ever-growing population and worsening poverty in the coastal regions (Sobhee, 2004). A high unemployment rate was also of concern in the 1980s as well as in the more recent period (Paul, 1987; 2010).

Professional part-time fishers' catch rate: According to Moal (1975 in Paul, 1987), 2,000 part-time fishers caught 700 t in 1974. This suggests a catch rate of 0.35 $t \cdot fisher^{-1} \cdot year^{-1}$ in 1974. Paul (1987) presented the change of the average catch rate for an artisanal fisher from 1948 to 1982. From the catches and number of artisanal fishers reported by the CSO (Anon., 2009b), we derived estimates of catch rates for the period 1999-2008. We assumed that the productivity of the part-time fishers would have changed similarly to that of the professional. Indeed, it is very likely that their productivity has declined similarly, as a consequence of increasing numbers of fishers exploiting the same areas. To the reported and calculated catch rates, we applied an exponential model. Using the growth constant of this model and the

[2]On Mauritius, a large number of professional fishers are dependent on middlemen for equipment. Middlemen usually buy the entire catch, and finance the fishers who are then indebted due to these cash advances. Locally named *banyan*, middlemen are usually Muslim traders from the urban areas.

catch rate of 0.35 t·fisher^{-1}·year^{-1} for 1974, we derived estimates for part-time professional fisher's catch rates for the whole time period (Figure 3), declining from 0.56 tonnes·fisher^{-1}·year^{-1} in 1950 to 0.18 tonnes·fisher^{-1}·year^{-1} in 2008.

Finally, using the fisher population and catch rates as estimated above, we derived the catches of the part-time professional fishers from 1950 to 2008.

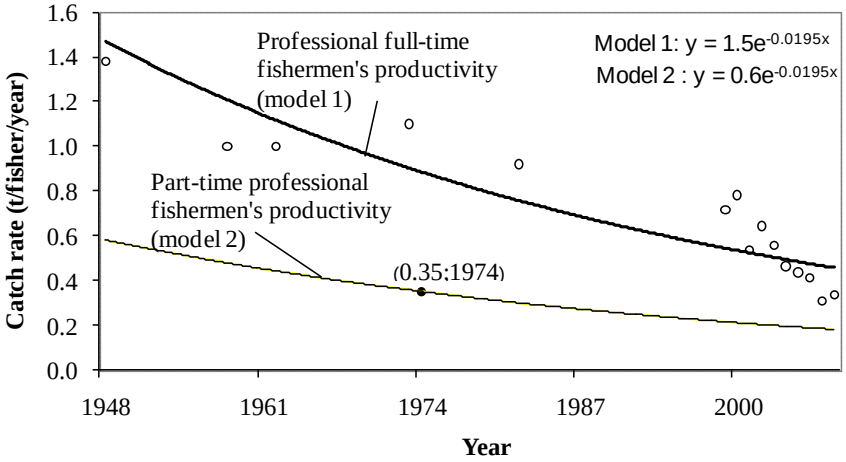

Figure 3. Data points and fitted models used to estimate part-time professional fishers' productivity for Mauritius, 1950-2008. Data points are represented by open circles (for professional full-time fishers) or dark circles (for part-time professional fishers). Data sources: Paul (1987); Moal (1975 in Paul 1987); Anon. (2009a).

Professional part-time fishers' commercial vs. subsistence catches: For 1974, Moal (1975 in Paul, 1987) divided the part-time professional fishers' total catch into subsistence and commercial components, being 29 and 71 percent of the total catch, respectively. We assumed that the subsistence part of the catch was higher in the earlier time period, thus reflecting the increasing development of the tourism industry which likely provided new employment opportunities as well as new sale outlets for the part-time fishers. Also, in the late 1960s, the development of the banks fishery contributed to provide a supply of local frozen fish at relatively low prices (Christy and Greboval, 1985; Ardill, 1986) which would have reduced the need to fish for subsistence by the low income population. Therefore, we inverted those percentages for 1950 so that the subsistence and commercial catches represented 71 and 29 percent of the total part-time professional fishers' catch in 1950, respectively. Linear interpolations were used to estimate the percentages for 1950-1974, while the 1974 percentages was carried unaltered to 2008.

Part-time subsistence (only) fishers

Part-time subsistence fishers fish only for their own consumption. Most of them are coastal residents. This category of fishers likely comprises a substantial proportion of owners of the many houses along the island's shores (Paul, 1987). They usually fish close to shore with rod and reel or as a group on a boat.

Part-time subsistence fishers' population: In 1982, a sample survey of the entire coast indicated that about 10,000 people were fishing only for their own consumption (Paul, 1987). This amount was taken as a percentage of the total human population of Mauritius Island for the same year and came to about 1 percent. Moal (1975 in Paul, 1987) reported a larger estimate of 65,000 people or 7.6 percent of the island's population. However, Moal's estimate was considered unreliable. Indeed, to obtain this figure, Moal (1975 in Paul, 1987) simply added the coastal population based on the 1972 census and subtracted the estimated size of the vegetarian and artisanal fishing population. Therefore, we retained the one percent figure as the more conservative estimate. However, while we applied this percentage for 1982-2008, we assumed that it would have decreased from 1950 to 1982, similarly to that of the part time professional fishers, where the percentage of the number of part-time professional fishers to the total population declined from 0.31 to 0.21 percent from 1950 to 1982. This proportional decline of 67 percent was then applied to the reported 1 percent figure for 1982 back to 1950, so that the percentage of local people fishing only for their subsistence declined from an assumed 1.55 percent in 1950 to a reported 1 percent in 1982. Linear interpolations were used to estimate the percentages in the intervening years.

Using the human population data for Mauritius Island, we derived the number of local people fishing only for their own consumption for each year from 1950 to 2008.

Part-time subsistence fishers' catch rates: For 1982, Paul (1987) estimated the catch rate of a local part time subsistence fisher at 10 kg·fisher^{-1}·year^{-1}. We maintained this catch rate unaltered from 1982 to 2008. However, we assumed that it would have been decreasing since 1950. From our precedent calculations, we derived that the part-time professional fishers' catch rate declined from 0.56 to 0.30 t per fisher per year from 1950 to 1982. This proportional declined of about 54 percent was then applied to the reported rate of 10 kg per fisher per year for 1982 back to 1950, so that the catch rate of the local people fishing for their subsistence declined from an assumed 18.7 kg·fisher^{-1}·year^{-1} in 1950 to a reported rate in 1982 of 10 kg·fisher^{-1}·year^{-1}. Linear interpolations were used to estimate the catch rates in the intervening years. Using the fisher population as estimated above, these derived annual catch rates were expanded to determine the part time subsistence fishers' catches from 1950 to 2008.

Other unreported catches

Catches taken by illegal methods are common on Mauritius Island and are largely unreported (Ardill, 1979; Paul, 1987; Hollup, 2000; Sobhee, 2004). Ardill (1979) mentioned that sampled landings, aside from ignoring part-time fishers' catches, also excluded estimates of catch taken in illegal nets and by dynamite fishing, which are landed all along the coast. Other illegal and destructives fishing practices include fine meshed nets, illegal spearguns, night fishing, capture and landing of undersized fish, and pesticides. These practices involve both part- and full-time fishers, and have been rising due to the dwindling resources, reduced catches and new regulations (Hollup, 2000; Sobhee, 2004). In the absence of quantitative information specific to Mauritius Island, we relied on the knowledge acquired for Rodrigues (see below). We assumed that these illegal fishing methods evolved similarly on the two islands, and therefore used the same method as we did for Rodrigues to estimate this component of the unreported catch. Although underwater fishing was forbidden in 1982 in Mauritius, this practice is still used today (90 interventions occurs in 2006). Underwater fishers are also said to be responsible for the use of dynamite and anesthetics, and fishing at night (Paul, 1987). Estimated catches ranged from 150 t in 1974 (1975 in Paul, 1987) to 397 t in 1982 (Paul, 1987), but we assumed that such catches were included in our estimates of unreported catches.

Rodrigues Island small-scale fisheries

Rodrigues Island (19°43'S-63°25'E, 110 km^2, 37,500 inhabitants) is located some 586 km northeast of Mauritius and it is a semi-autonomous island since 2001. Unemployment, poverty and illiteracy are high compared to the main island of Mauritius, and tourism is in its infancy. As a consequence, the lagoon fisheries are very important to Rodrigues, but they are currently severely overexploited (Blais *et al.*, 2007). The island is surrounded by 90 km of fringing coral reef, enclosing a shallow lagoon of 240 km^2. Small-scale fishing takes place within and outside the lagoon, with the use of seine nets, hand-lines, basket traps and spears or harpoons for octopus and large fish.

Professional fishers

Professional commercial fishers: Total catches reported by the FAO on behalf of the Ministry do not distinguish between Mauritius and its outer dependencies. Nevertheless, comparison of the FAO data with other reports (Fisheries Division annual reports, 2003-2007; Harris, 1988) indicated that from 1977 to 2000, artisanal catches for Rodrigues have been estimated between 1,200 and 1,500 t annually. In Rodrigues, monitoring of artisanal catches started in 1994 (Reshad Jhangeer-Khan, Shoals Rodrigues, pers. comm.). Broad catch and effort data are collected at fish landing stations around the island on a regular basis by the Fisheries Research and Training Unit (FRTU), collated annually and transmitted to the Albion Fisheries Research Centre (Anon., 2007b)(E. Hardman, Shoals Rodrigues, pers. comm.). For the period 1994-2008, we obtained sampled catch data from the CSO annual digests of statistics on Rodrigues and from Dr Emily Hardman (for the octopus and lagoon fish catches reported by the CSO from 1994 to 2006). However, these reported catches refer to the registered fishers catches, and do not include unofficial catches landed by the amateurs and illegal catches (Anon., 2009c) (Dr Emily Hardman,

Shoals Rodrigues 2005-2008, pers. comm.; Reshad Jhangeer-Khan, Shoals Rodrigues, pers. comm.), and we retained those sampled catches as anchor points for the professional fishers' catches. For the earlier period, professional fishers' catches were compiled from various sources, using the more reliable estimates as anchor points. For 1955, 1962 and 1968, catches reported by Pearson (1988) were equivalent to the export data. Therefore, those amounts were only used as minimum. We interpolated linearly between our anchors points, in order to estimate the professional fishers' catches for the whole time period.

Taxonomic breakdown: In order to determine the taxonomic composition of the artisanal commercial catches taken on Rodrigues Island, we used data from the Fisheries Research and Training Unit (FRTU) (unpublished data) and Central Statistics Office reports. The FRTU data provided the species composition of the seine net fishery for the years 1994 to 1999, and 2004 to 2006. We interpolated linearly between the 1999 and 2004 available figures to estimate the species composition of the seine net fishery for the period 2000-2003, while the 2006 figures were maintained unaltered until 2008. For the period 1994-2008, CSO data provided the total controlled catch on Rodrigues, discriminated by type of fishery, namely the octopus, lagoon and non-lagoon fisheries. This allowed us to calculate their respective contributions as percentages of the total controlled catch from 1994 to 2008. Similarly, for the period 1994-2006, FRTU data provided the seine net controlled catch, which we converted into percentage of the total controlled catch on Rodrigues. The calculated percentage for 2006 has been carried forward to 2008. Thus, knowing the respective contribution of the seine net, octopus, lagoon (other than seine net) and non-lagoon fisheries, we adjusted the FRTU data on the seine net species composition to estimate a breakdown of the total artisanal commercial catch on Rodrigues for the period 1994-2008 (Table 3). Furthermore, Sauer *et al.* (2011) indicate that the octopus fishery on Rodrigues is dominated by *Octupus cyanea* with the remaining catch being mainly *O. vulgaris*. The catches presented in Sauer *et al.* (2011) correspond to the CSO data for octopus.

Professional fishers' subsistence catches: Registered fishers will also keep some of the fish and octopus that they catch for their own consumption (Dr Emily Hardman, Shoals Rodrigues, pers. comm.). Therefore, these retained amounts were estimated and added to our total subsistence catches. We used the estimate of 1.25 kg of fish retained by each fisher per fishing day, which we multiplied with Paul's estimate of 176 fishing days for the professional fishers to obtain a catch rate of 0.22 $t \cdot fisher^{-1} \cdot year^{-1}$. This number of fishing days was consistent with these reported by (Pearson, 1988). Indeed, for 1987, he mentioned that the number of fishing days for the trap and handline fisheries rose to about 290 and 238 days, respectively, while that of the seine-net fishery fell from about 200 days in the earlier time period to 163 in 1987, due to regulations being implemented for this fishery. The professional fishers' population was reconstructed using various sources (Gonzalez Manero, 1971; Moal, 1971 in Paul 1987; Ardill, 1979; Paul, 1987; Pearson, 1988; Anon., 2010). Finally, the 0.22 $t \cdot fisher^{-1} \cdot year^{-1}$ catch rate estimate as calculated above, together with the artisanal fisher population data, were used to derive the subsistence catches amounts for the whole time period.

Part-time fishers

Fishing by part-time fishers, mainly for subsistence, on Rodrigues Island is unmonitored, although it is likely to be considerable, and it currently includes in and off-lagoon fin fishing using lines and traps, in-lagoon octopus fishing and shell fishing (Reshad Jhangeer-Khan, Shoals Rodrigues, pers. comm.). In addition to the registered fishers, there are many part-time fishers (Gonzalez Manero, 1971; FAO, 1983; Paul, 1987; Anon., 2009c). Some of them are regular fishers who fish to feed their family or to sell, while others have a full-time job and fish for pleasure and their own consumption (Dr Emily Hardman, Shoals Rodrigues, pers. comm.). Therefore, their catches likely comprise commercial as well as subsistence components. However, catches of the part-time fishers were assumed to be mostly of subsistence purpose. In order to estimate these catches, we first assessed the annual number of part-time fishers, then we estimated the catch rates of those fishers, based on Pearson (1988).

Table 3. Estimated taxonomic composition of the total small-scale commercial catch for Rodrigues Island. Sources: Fisheries Research and Training Unit (FRTU) (unpublished data), Anon (2009a), Central Statistics Office of Mauritius.

			Portion of total catch (%)														
Fishery	**Common name**	**Taxon**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Seine net	Rabbitfish	*Siganus* spp.	1.7	1.1	1.5	1.9	2.6	2.1	2.6	2.8	4.7	3.4	4.8	3.2	5.0	5.0	5.0
	Spangled emperor	*Lethrinus nebulosus*	2.1	1.1	1.3	1.1	1.0	0.2	0.6	1.0	2.3	2.1	3.8	4.1	3.3	3.3	3.3
	Unicornfish	*Naso* spp.	1.6	0.9	1.6	1.0	1.1	0.4	0.9	1.3	3.0	2.8	4.9	2.4	4.1	4.1	4.1
	Mullet	Mugilidae	2.2	3.3	1.6	1.5	1.9	2.7	2.9	2.8	4.1	2.5	2.9	1.8	2.7	2.7	2.7
	Trevally/jacks	Carangidae	1.8	2.2	1.0	1.6	1.0	1.0	1.1	1.1	1.6	1.0	1.3	1.1	1.3	1.3	1.3
	Strongspine silver-biddy	*Gerres longirostris*	1.8	1.1	0.8	0.5	0.3	1.2	1.3	1.3	2.0	1.3	1.7	1.4	2.1	2.1	2.1
	Goatfish	Mullidae	1.0	1.7	1.0	0.7	0.4	1.3	1.4	1.4	2.2	1.4	1.7	1.7	3.2	3.2	3.2
	Parrotfish	Scaridae	0.9	0.2	0.5	0.3	0.2	0.1	0.2	0.2	0.4	0.3	0.5	0.6	0.9	0.9	0.9
	Blackspot emperor	*Lethrinus harak*	0.8	0.4	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
	Yellowfin bream	*Rhabdosargus sarba*	0.9	0.2	0.5	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Rudderfish	*Kyphosus* spp.	0.8	0.5	0.6	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Milkfish	*Chanos chanos*	0.8	0.7	0.4	0.3	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.0	0.0	0.0
	Striped threadfin	*Polydactylus plebeius*	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Others	Misc. marine fishes	0.6	0.6	0.9	0.4	0.2	0.0	0.1	0.3	0.8	0.8	1.4	1.7	2.2	2.2	2.2
Octopus	Octopus	*Octupus* spp.[b]	51.1	51.1	42.4	44.7	31.9	23.7	23.6	17.0	27.3	34.7	26.9	27.4	25.0	16.7	16.0
Other	Lagoon fishes	Lagoon fishes	31.0	34.0	43.0	45.0	48.0	53.0	50.0	46.0	39.0	41.0	46.0	36.0	35.0	33.0	36.0
	Non-lagoon fishes	Pelagic and non-pelagic species[a]	1.0	1.0	2.0	-	11.0	15.0	15.0	25.0	13.0	9.0	4.0	18.0	15.0	25.0	23.0

[a]including Serranidae, Lethrinidae, Lutjanidae, Acanthuridae, Labridae, sharks and pelagic species such as small tunas or barracudas (from Rodrigues' Offshore Cooperative Society Landings, 1982-1983, in Paul, 1987); [b] *Octopus* spp. caught were *O. cyanea* (80%) and *O. vulgaris* (20%) based on Sauer *et al.*(2011).

Part-time fishers' population: 1950-1979: We used the estimate of 7,000 part-time fishers given by (Ardill, 1979). This represented about 26% of the island population in 1979. We assumed that this percentage would also apply to the years before 1979, as most of Rodriguan people likely relied on subsistence fishing and agriculture at this time, and thus we maintained this percentage unaltered from 1950 to 1979.

1980-2008: For 1987, Pearson (1988) estimated that 10 percent of the population practiced occasional line-fishing (or about 4,000 Rodriguans). However, it is very likely that part-time fishers also used other gears such as traps and harpoons to catch fish and octopus and so that their population was underestimated by Pearson (1988). A more recent estimate consisted of 2,000 part-time fishers in 2008 (Blais *et al.*, 2007) or about 5% of the island's population. However, some believe that more than twice the number of full-time professional fishers are engaged in part-time fishing activities (Anon., 2009c), which would give an estimate of more than 3,500 people. To remain conservative, we retained the estimate of 2,000 part-time fishers provided by Blais *et al.* (2007) and we interpolated linearly between the percentages of the total population in 1979 (26%) and 2008 (5%). Using the total island's population, we estimated the number of part-time fishers on Rodrigues Island from 1982 to 2008 (Table 4).

Table 4. Data sources and method used to estimate the population of part-time fishers for Rodrigues Island from 1950 to 2008.

Year	Number of part-time fishers	Human population	Ratio (%)	Sources and method
1950	3,353	12,971	25.8	1979 ratio maintained
1979	7,000	27,081	25.8	Moal (in Paul, 1987)
2008	2,000	37,570	5.3	Blais *et al.* (2007)

Part-time fisher's catch rates: 1987-2008: We used the catch rate of 0.1 t·fisher^{-1}·year^{-1} estimated by Pearson (1988). We maintained this catch rate unaltered for the period 1987-2008, assuming that the productivity of the part-time fishers would not have changed during the last two decades. This is likely to be a conservative estimate, as Pearson's catch rate estimate for 1987 referred to line-fishing, while subsistence fishers also use traps and fish octopus inside the lagoon (Reshad Jhangeer-Khan, Shoals Rodrigues, pers. comm.).

1950-1986: Over-fishing in Rodrigues may date from the 1800s (Bunce *et al.*, 2008). The island has been affected by intensive land erosion and its heavy impact on the lagoonal fauna has been reported as early as 1962 (Baissac, 1962 in Paul, 1987). It has also been illustrated by a sharp downfall in exports to Mauritius since the 1970s (Paul, 1987; Pearson, 1988; Bunce *et al.*, 2008). Therefore, we assumed that the average productivity of the part-time fishers declined from 1950 to 1986 by a half, so that in 1950 it was equal to 0.2 tonnes·fisher^{-1}·year^{-1}. Therefore, we applied a catch rate of 0.2 t·fisher^{-1}·year^{-1} for 1950-1987 and 0.1 t·fisher^{-1}·year^{-1} for 1986-2008.

Other unreported catches

Additional catches taken in reserves, during the closed seasons (implemented for the seine net and sea cucumber fisheries) and using illegal gears such as undersized seine net mesh sizes, spearguns to catch octopus were unreported (Anon., 2009c) (Dr Emily Hardman, Shoals Rodrigues, pers. comm.; Reshad Jhangeer Khan, Shoals Rodrigues, pers. comm.). These catches are either consumed by the fishers themselves or sold - on the beach or directly to the markets (Reshad Jhangeer Khan, Shoals Rodrigues, pers. comm.). To estimate these unreported catches we assumed that illegal gears were not used prior to the 1960s (Reshad Jhangeer Khan, Shoals Rodrigues, pers. comm.). For 1987, Pearson (1988) estimated that 150 illegal nets may have been operating within the lagoon. Pearson (1988) conservatively estimated unreported catches taken by illegal methods amounted to 10% of total legal landings in the lagoon. In contrast, these catches may be equal to or greater than legal landings (Reshad Jhangeer Khan, Shoals Rodrigues, pers. comm.). To remain conservative, and to take into account the fact that illegal fishing practices are used by both part-time and full-time fishers, we assumed that most of this catch would be

included in our total reconstructed catch from the small-scale fishery carried out around the islands. Therefore, for the 1987-2008 period, we estimated additional unreported catches in the coastal waters of Rodrigues island as 10% of our total reconstructed small-scale fisheries catches, including both professional and part-time fishers' catches. Finally, we interpolated linearly between zero catch in 1960 and our first calculated value for 1987.

Recreational fisheries

Mauritius is well-known as a tourist destination. While it creates job opportunities for the local population, it also represents a potential threat to marine life (Paul, 1987; Sobhee, 2004). In Mauritius, the recreational fishery can be divided into two components, namely the extraction of marine resources for leisure purposes inside or close to the lagoon environment, and the pelagic sport fishery, which operates with boats in deeper waters. We estimated these catches separately.

Pelagic sport fishery

Mauritius is a popular destination for big game sport fishers. A number of leisure and sports fishers operate successfully around FADs (Roullot *et al.*, 1988; Venkatasami and Sheik Mamode, 1995). For this activity, a number of lines are used with rods and outriggers baited for the large migratory carnivorous species. The catch comprises mainly blue marlin (*Makaira mazara*), black marlin (*Makaira indica*), Indo-Pacific sailfish (*Istiophorus platypterus*), striped marlin (*Tetrapturus audax*) and yellowfin tuna (*Thunnus albacares*), albacore (*Thunnus alalunga*) and bigeye tuna (*Thunnus obesus*). Other species like wahoo (*Acanthocybium solandri*), shortbill spearfish (*Tetrapturus augustirostris*), skipjack tuna (*Katsuwonus pelamis*) – used as bait for marlins, sharks (*Sphyrna zygaena*, *Isurus oxyrinchus*, *Carcharinus albimarginatus*, *Carcharinus melanopterus*) and dolphinfishes (*Coryphaena hippurus*) are also caught (Cayre and Stequert, 1988; Norungee *et al.*, 2004; Jehangeer, 2006). Recently, a system of data collection has been set up at the Albion Fisheries Research Centre (Norungee *et al.*, 2004). However, examination of the Ministry reports showed that the currently reported sport pelagic catches consist of the constant amounts of 400 t from 1977 to 1987 and 650 t from 1988 to 2008. Such amounts do not reflect the increasing trend of the tourist population that reaches the island each year. Thus, catches from the sport fishery were re-estimated. We first extracted catch estimates for the sport fishery from other reliable sources. For each reported value, we calculated a per tourist rate using the time series of number of tourists arrivals. Sport fishery likely already existed in 1950. According to Paul (1987), the sum of the countless amateurs and sport fishermen catches were estimated at 50 t by the officials from 1946 to 1958. However, to remain conservative (and in the absence of more detailed information), we assumed that the pelagic sport fishery catches were null in 1950. For the period 1950-1987, we interpolated linearly between the per tourist rates. Between 1974 and 1988, the calculated per tourist rates declines from 2.9 to 2 kg per tourist arrival. In order to reflect the decreasing catches of pelagic species since the 1990s, we carried this decreasing trend forward from the 1988 catch rate figure to derive the catch rates for the 1988-2008 period. Pelagic sport catches were finally deduced by multiplying the catch rates as estimated above by the number of tourist arrivals.

Recreational catches in the lagoon

In addition to the tourists involved in big game fishing, a substantial part of the tourist population is involved in recreational fishing in the lagoon of Mauritius. For 1982, Paul (1987) assumed that a conservative estimate of the total number of fishing tourists involved in the exploitation of the island's waters would be approximately 20,000 people, or about 17% of the tourist arrivals during the year. We assumed that the number of fishing tourists was proportional to the tourist arrivals, and we carried the 17 percent figures for the whole time period. Thus, using the number of tourist's arrivals time series, we established the number of fishing tourists from 1950 to 2008. For 1982, Paul (1987) estimated the catch rate of a fishing tourist at 5 $kg \cdot tourist^{-1} \cdot year^{-1}$. We assumed that this catch rate would not have changed from 1950 to 1982, but that the increasing degradation of marine resources of the island, together with an increasing number of people fishing in the lagoon area, would have caused the tourist's catch rates to decrease from 1982 to 2008. Therefore, we used the proportional decline of 60% between the part time professional fishers catch rates of 1982 and 2008, so that the tourist catch rates decreased from a reported

5 kg·tourist^{-1}·year^{-1} in 1982 to an assumed 3 kg·tourist^{-1}·year^{-1} in 2008. We then established the catches using the fishing tourist population time series.

Agalega Islands

The twin islands of Agalega are located some 982 km north of Mauritius between 10°28'S and 56°40'E. The islands are of coralline origin and cover a total land area of 70 square kilometers.

Colonization took place in the early part of the 18th century and fishing was the mainstay of the settlement's diet (Paul, 1987). Since then, the exploitation of the coconut trees for copra production began, and it is still the main economic activity. Fish production being very limited due to the steep drop-off outside the reef, is only sufficient for consumption of the local workers. The current reported catches for Agalega consist of the constant amount of 30 t from 1977 to 2008. To arrive at these figures, it has been assumed that the *per capita* consumption of fish was 100 kg·person^{-1}·year^{-1}, giving an annual catch of 30 tonnes for a population of 300. The species composition of the catches is believed to be similar to that of Mauritius Island but this remains to be examined (FAO, 1983). As the population did not change much over the 1950-2008 period (Paul, 1987; Anon., 2006, Anon., 2010) and in the absence of contradictory information, we assumed that the current reported amount was accurate and we carried it back unaltered to 1950.

Table 5. Estimated taxonomic breakdown of the Mauritian banks handline fishery catches on the Nazareth, Saya de Malha, St Brandon and Chagos banks modified from Samboo 1989 (in Mees, 1996). In the Chagos, although it is avoided due to the potential of ciguatera, the red snapper *Lutjanus bohar* can represent up to 50 percent of the catch.

Taxon	Nazareth & Saya de Malha	St Brandon	Chagos
Lethrinus mahsena	88.00	84.0	50
other Lethrinidae	2.00	2.0	2
Serranidae	4.00	1.5	26
Carangidae	2.00	2.0	4
Aprion virescens (Lutjanidae)	1.00	-	6
Siganidae	-	2.5	-
Scaridae	-	2.0	-
Mugilidae	-	0.5	-
Naso spp. (Acanthuridae)	-	0.5	-
Lutjanus bohar (Lutjanidae)	0.75	-	(50)
Pristipomoides spp. (Lutjaidae)	0.75	-	10
Tuna	0.75	-	2
Others	0.75	5.0	-

The Mauritian Banks fishery

An important Mauritian fishery occurs on the shallow oceanic banks of the Mascarene Ridge. In addition to the banks located within Mauritius EEZ, the Mauritian fishing fleet fishes on the Saya de Malha bank (much of which is in international waters), and exercises traditional fishing rights within the EEZ of the British Indian Territory (BIOT, Chagos Archipelago). Since the 18th century, fishing on these grounds has been carried out by vessels engaged in inter-island trade, but it was not before the twentieth century that more systematic exploitation began when the Mauritius Fishing Development Company and its sister company the Raphael Fishing Company Limited gained control of the St. Brandon group. In the earlier years, the demersal stocks were exploited mainly for salting purposes, but since the Wheeler and Ommaney (1948-49) pioneer survey, these banks have gradually started to be the main suppliers of frozen fish to Mauritius (FAO, 1983; Ardill, 1986). Fishing on the banks is practiced using handlines from 7-8 m dories carried by refrigerated mother-vessels, 20-60m in length. The main targeted species is Dame Berri (*Lethrinus mahsena*) which contributes about 80% of the total catch, while the remainder of the catch is made up of serranids, lutjanids, siganids, and carangids. The catch is mostly gilled, gutted and frozen on board. In St. Brandon, however, temporary settlements of fishers continue to fish in the lagoon using seine nets and basket traps while the mother ships are away. Their catches are salted and dried while awaiting shipping to Mauritius (Moal, 1971 in Paul 1987; Samboo and Mauree, 1987). Also, 17 vessels are allowed to operate a semi-industrial chilled fishery on the Soudan, Albatross, St Brandon, Hawkins, Saya de Malha and Nazareth Banks. Their catch is either frozen or chilled at sea and comprises mainly emperors, snappers, groupers and tunas. Catch data for the banks fishery were obtained from the Ministry on behalf of the Albion Fisheries Research Centre (AFRC). However, such data only covered the

1977-2008 period. When compared to other sources, it also appeared that they represented landings in frozen weight, and for the greatest part of the time period, catches of salted-dried fish from St. Brandon were not included. Therefore, in order to assemble the most accurate estimates for the total banks fishery catches, we used data of the Ministry converted to wet weight, complemented or adjusted with data extracted from other reliable sources to supply the missing years and areas (Gonzalez Manero, 1971; Moal, 1971 in Paul 1987; Ardill, 1979; Paul, 1987; Samboo and Mauree, 1987; Mees, 1996; Anon., 2009a). Conversion factors of 1.2 and 2 were used to convert the frozen weight and salted-dried weight respectively, to wet weight as reported in Paul (1987), Gonzalez Manero (1971) and in the Conversion Factors FAO software. Although the Chagos Archipelago is part of the British Indian Ocean Territory (BIOT), we included catches from the Chagos' EEZ by the Mauritian fleet in our reconstruction of the banks fishery catches.

Table 6. Estimated taxonomic breakdown of the salted-dried fish catches taken in the St Brandon lagoon (Anon., 1971; 2009a).

Family or group	Taxon name	Common name	Catch (%)
Lethrinidae	*Lethrinus mahsena*	Dame Berri	75.0
Lethrinidae	*Lethrinus nebulosus*	Capitaine Gueule Longue	10.0
Siganidae	*Siganus* spp.	Cordonnier	2.5
Acanthuridae	*Naso* spp.	Licorne	2.5
Scaridae	*Callydon* spp.	Cateau	2.5
Serranidae	*Epinephelus* spp.	Vieilles/Babones	5.0
Octopus	-	-	2.0
Lobster	-	-	0.5

The estimated species composition of the Mauritian banks fishery catches was based on a report by Samboo (1989 in Mees, 1996) for the Nazareth, Saya de Malha, St Brandon, Albatross and Chagos banks (Table 5), while the taxonomic breakdown of the St Brandon salt and dried fish, octopus and lobsters catches was based on Gonzalez Manero (1971) and Anon. (2009a; Table 6).

Mauritian purse seine fishery

Large-scale commercial purse seining was introduced in the Indian Ocean in 1979 as a Mauritian and Japanese joint venture, using a traditional Japanese technique of fishing schools of tuna associated with logs, developed in the Pacific Ocean. The reported landings from Mauritian purse seiners reached a peak of over 10,000 t in 1991. Since then, there has been a gradual decline of this fishery until 2001 when production dropped to zero, as all the seiners left the fishery (Jehangeer, 2006). Catch data for the Mauritian purse seiners were provided by the Indian Ocean Tuna Commission (IOTC). Amande *et al.* (2008) provided estimates of tuna discards and bycatch by large groups of species of the European purse seiners operating in the Indian Ocean for the 2003-2007 period. Discards and bycatch were presented as tuna production ratios, for three different fishing methods. As the Mauritian purse seiners operated exclusively on artificial logs (Norungee and Lim Shung, 1995), we used the discards and bycatch ratios corresponding to the FAD-associated fishing mode. To estimate discard rates for each group of species, we multiplied the percentage of bycatch to tuna production by the percentage of discarded bycatch (Table 7). As no indications were provided regarding the amount of discarded bycatch for shark, and to remain conservative, we assumed that sharks species were accounted for in the landings and thus we did not

Table 7. Data and methods used for estimating discards of the Mauritian tuna purse seine fishery from 1979 to 2000. To calculate the discard rate (ratio to tuna production) for the bycatch species, we converted the bycatch rate expressed in tuna production ratio into a percentage, which we multiplied by the reported percentage of discarded bycatch specific to each species group (except sharks). Source: Amande *et al.* (2008).

Species or group	Bycatch/tuna production (t/1000 t)	Discarded bycatch (%)	Discard rate (%)
Tuna nei	26.5	100	2.65
MMF[a]	19.7	80	1.58
Sharks	6.0	-	0.00
Billfishes	0.7	65	0.05
Rays	0.2	100	0.02

[a] MMF = miscellaneous marine fishes

include them in our discard estimates. Through this method, our total estimated discards for the Mauritian tuna purse seiner was consistent with the discard rate of 5% reported by Kelleher (2005).

Shark fishery

Shark catches were presented by the FAO for the years 1977-2008. A review of the independent literature found no information regarding a shark fishery in Mauritius. These might have been incidental catches associated with the longline fishery, but which do not appear in the IOTC data. However, we accept the FAO landings data for the 'sharks, skates and rays' category as it is presented in FAO FishStat and add it to the industrial component of our total reconstructed catch.

Sea cucumber fishery

On Mauritius, the commercial exploitation of sea cucumbers started on a trial basis in late 2005 (Conand, 2008) and around 2006 on Rodrigues (Dr Emily Hardman, Shoals Rodrigues, pers. comm.). Species harvested are *Actinopyga echinites* (brownfish), *A. mauritiana* (surf redfish), *Bohadschia marmorata* (brown sandfish), *Stichopus chloronatus* (green fish), *S. variegatus* (curry fish), *Holothuria scabra* (sandfish), *H. nobilis* (black teatfish) and *Holothuria* spp. (Anon., 2009d). Although fishers regularly collect sea cucumbers in Mauritius Island mainly for domestic consumption (Laxminarayana, 2005), the harvesting is done by a limited section of the Mauritian population – mainly local Chinese people – and those catches were thus thought to be negligible (Chantal Conand, pers. comm.). Current management measures of the commercial sea cucumber fishery include collection restrictions, both spatial and temporal, and size limits (Anon., 2007a) (Dr Emily Hardman, Shoals Rodrigues, pers. comm.) although illegal fishing continues to occur in the closed season on Rodrigues (Dr Emily Hardman, Shoals Rodrigues, pers. comm.). We accepted the sea cucumber landings data presented by FAO on behalf of Mauritius, although it likely that this is an underestimate of actual catches.

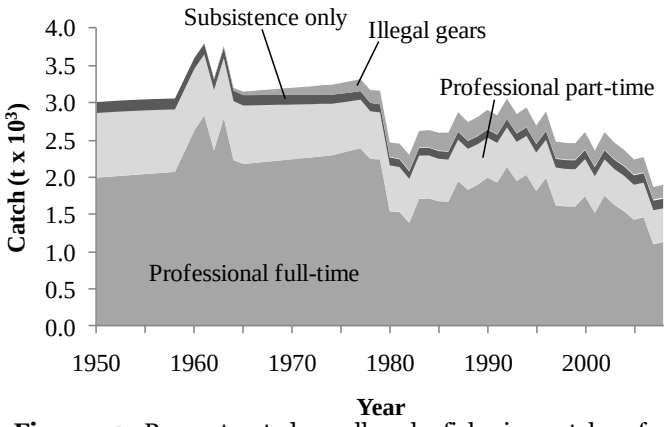

Figure 4. Reconstructed small-scale fisheries catches for Mauritius Island. Professional full- and part-time catches include both artisanal and subsistence components.

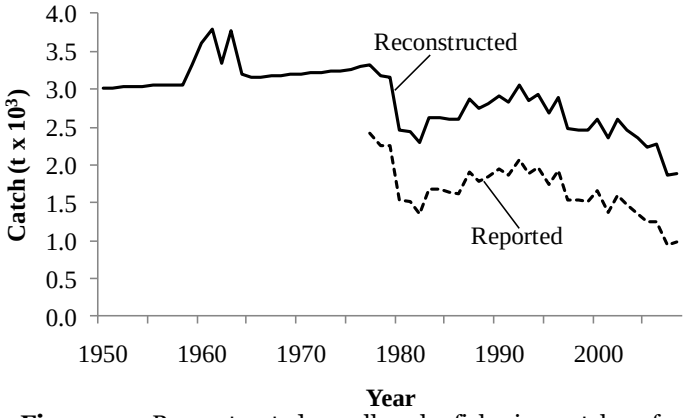

Figure 5. Reconstructed small-scale fisheries catches for Mauritius Island compared to reported national landings data.

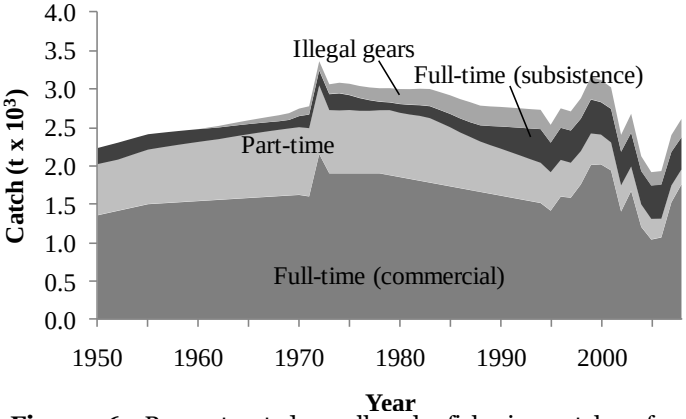

Figure 6. Reconstructed small-scale fisheries catches for Rodrigues Island, with commercial and subsistence catches taken by full-time fishers, catches taken by part-time fishers whose catch is for subsistence purposes only and unreported catch from illegal gears.

RESULTS

Total reported landings by the FAO from 1977 to 2008 followed the same pattern as those of the Ministry reports, implying a good data transfer mechanism between the Mauritius national level and FAO. The same conclusion was drawn from the comparison of the non-pelagic reported catches from both sources. The catch rate data combined with the fisher population data yielded the reconstructed small-scale catches for 1950-2008, which are presented here for Mauritius and Rodrigues Island. Also represented are estimated catches for the recreational sector including both pelagic and lagoon fisheries, the Banks fishery, and tuna catches and associated discards from the purse seine fishery. Finally, we compare our total reconstructed catch estimate for the Republic of Mauritius for 1950-2008 to total marine landings presented by the FAO on behalf of Mauritius.

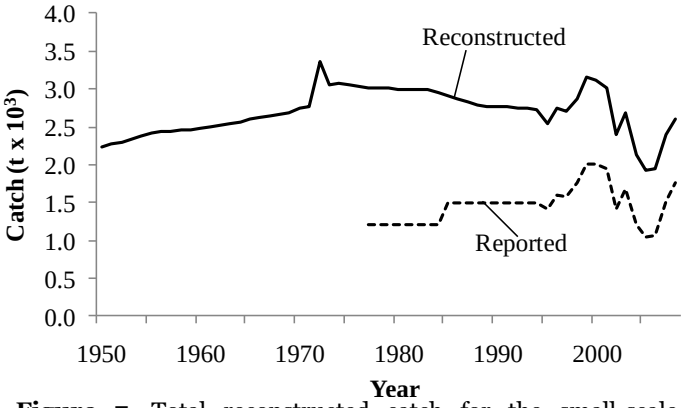

Figure 7. Total reconstructed catch for the small-scale fisheries of Rodrigues Island, 1950-2008 compared to the nationally reported landings, which start in 1977.

Mauritius Island

Reconstructed small-scale fisheries catches for Mauritius Island, including catches by professional full-time and part-time fishers, part-time subsistence (only) fishers and unreported catches taken by illegal gears and methods was estimated to be 170,825 tonnes over the 1950-2008 time period (Figure 4). Unreported catch taken by illegal gears and methods represented approximately 8,500 t over the period 1960-2008 (Figure 4). For the 1977-2008 period, our total reconstructed catches for the small-scale sector are about 1.6 times greater than nationally reported landings (Figure 5). Catches by part-time fishers' (professional and subsistence only) made up a substantial part of the reconstructed catch representing, for the whole time period, 27% of our total reconstructed catches for the small-scale sector on Mauritius Island.

The time series of catches taken by professional full-time fishers, the majority of which are artisanal, has two main periods. The first (1950-1977) represents a period where data were scarce, the second (1977-2008) corresponds to a period of improved sampling and collection of fisheries landings. Thus, the catch variability that appears in the latter time period may be more representative of a trend in catch levels. Catches taken by professional full-time fishers decreased substantially in 1979 from approximately 2,200 t to 1,500 t the following year (1980; Figure 4). The cyclone of 1980 may have played a role in this decrease e.g., through its impact on fishing effort. However, given

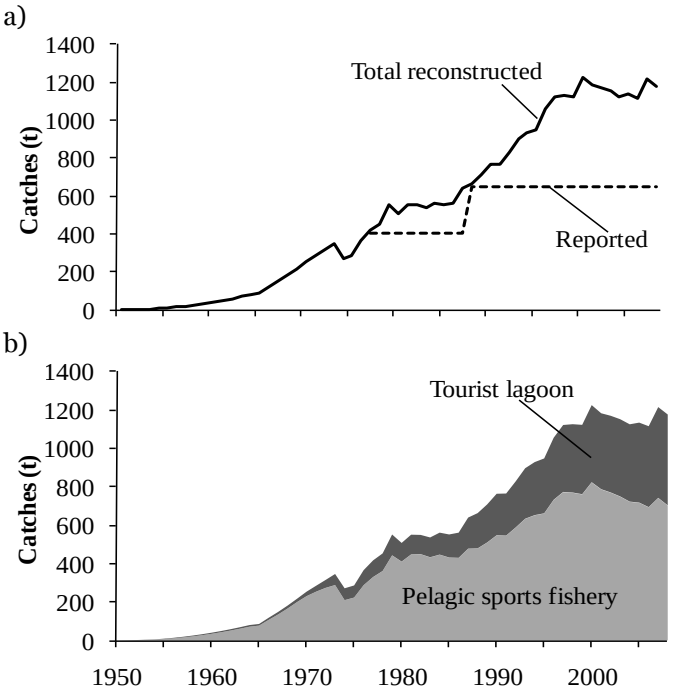

Figure 8. a) Reported and total reconstructed recreational catches for Mauritius state 1950-2008; b) Components of total recreational catch.

that the sampling methods for monitoring artisanal catches were implemented in 1977, these dropping catches could also be the result of adjustments to the method by the officials between 1977 and 1980.

Rodrigues Island

Catches by small-scale fishers on Rodrigues Island were estimated over the 1950-2008 time period to be approximately 159,000 t (Figure 6). This estimate included commercial catches by professional full-time fishers which amounted to about 96,000 t, subsistence catches taken by full-time and part-time fishers amounting to almost 54,000 t and unreported catch from illegal gears estimated to be 8,600 t. Subsistence catches taken by part-time fishers (i.e., people who fish only for subsistence purposes) were over 2.5 times larger than subsistence catches taken by full-time fishers as the 'take-home' portion (i.e., non-commercial) of their catch (Figure 6). However, this is mainly an artifact of the much larger number of part-time fishers than professional full-time fishers. The number of part-time fishers was up to 7 fold greater than the number of professional full-time fishers.

Summed for 1977-2008, reconstructed small-scale fisheries data suggested a 1.9 fold difference between reconstructed estimates and the statistics reported by the Ministry (Figure 7). As for Mauritius Island, this discrepancy between the reported and our reconstructed catches is mainly due to the inclusion of our estimated catches by part-time fishers, which, for the whole time period, represented 25% of our total reconstructed catches for the small-scale sector.

Recreational fisheries

Our total reconstructed recreational catch for Mauritius from 1950 to 2008 was estimated to be over 30,000 t, which is 1.7 times larger than the reported recreational catch (Figure 8a). Pelagic sports fishery catches accounted for approximately 21,800 t and tourist catches from the lagoon fishery representing the remaining 8,700 t (Figure 8b). It is worth noting the difference in the overall trend of the reported compared to the reconstructed recreational catch, especially since 1990 (Figure 8a). Due to the method employed, estimated catches of the fishing tourist population reflected the growing number of tourists visiting the island each year, thus showing an increasing trend for the whole time period (Figure 8b). Estimated pelagic sports fishery catches increased constantly from 1950 to a peak of 825 t in 2000, after which catches have been decreasing.

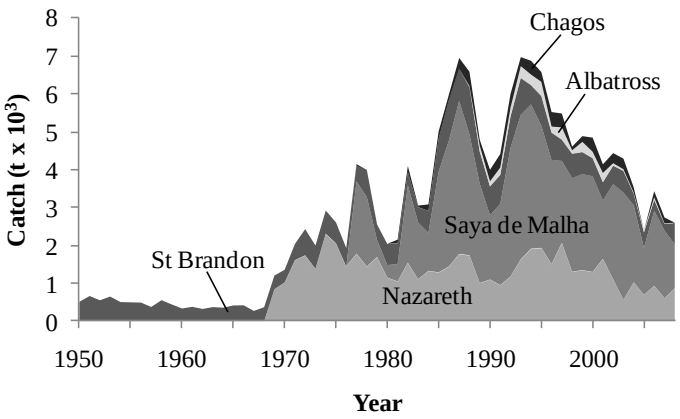

Figure 9. Total catches estimated for the Banks fisheries of Mauritius, 1950-2008. These include fisheries on St. Brandon, Chagos, Albatross, Saya de Malha and Nazareth banks.

Banks fishery

Total estimated catches from the banks fisheries were estimated to be approximately 167,000 t over the study period. The St Brandon banks fishery operated from 1950-2008, the Nazareth bank fishery started in 1969 and the Albatross, Chagos and Saya de Malha banks fisheries started in the late 1970s. The Saya de Malha and Nazareth banks fisheries were the largest with catches of over 70, 000 t and 54,000 t, respectively over the study period (Figure 9).

Mauritian purse seine fishery

Total catches of tuna taken by the Mauritian purse seine fishery were estimated for the period 1977-2008 to be approximately 127,000 t (Figure 10). The discarded bycatch associated with the tuna purse seine fishery were estimated to be 4,472 t (Figure 9).

Shark and sea cucumber fisheries

Total catches of shark and sea cucumber, taken directly from the FAO data were estimated to be 2,043 t and 1,055 t, respectively, over the 1950-2008 time period. Shark catches were considered part of the industrial sector while the sea cucumbers originate from the artisanal sector.

Total reconstructed catches

Total reconstructed marine fisheries catches for Mauritius and its outer dependencies was estimated for the 1950-2008 time period to be 682,392 tonnes. This suggests our reconstructed estimate was 42% higher than the landing statistics reported by FAO on behalf of Mauritius. The discrepancy between our total estimated catches and those currently reported is most substantial for 1950-1970 (Figure 11). Summed for this period, our total reconstructed estimates represent about 2.4 times the reported catches. This implies that under-reporting of catches was particularly substantial for the earlier time period.

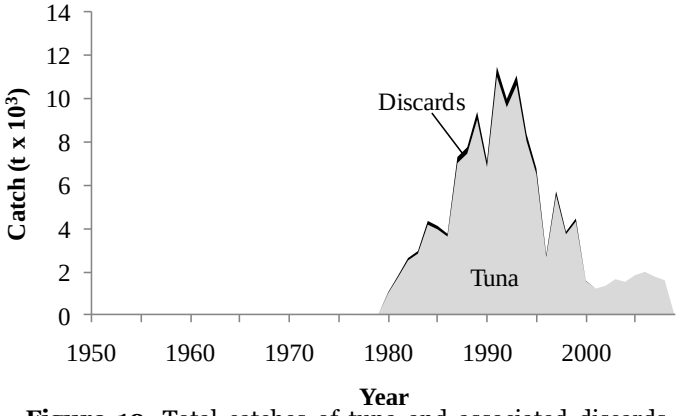

Figure 10. Total catches of tuna and associated discards from the Mauritian purse seine fishery, 1950-2008.

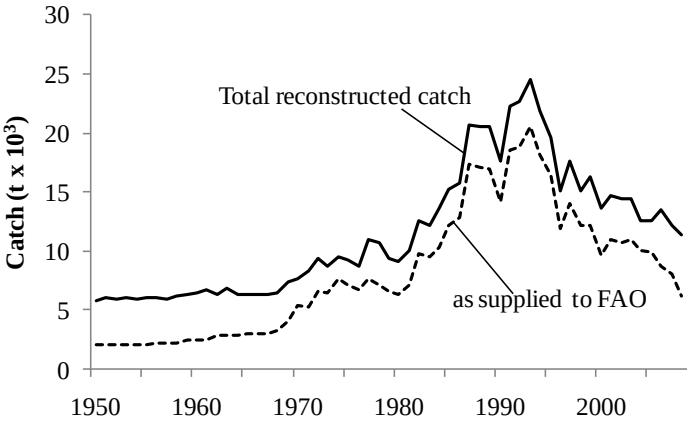

Figure 11. Total reconstructed catch for Mauritius Island and its dependencies and catches presented by the FAO on behalf of the Republic of Mauritius, 1950-2008.

DISCUSSION

For a better understanding of the fisheries impact on marine ecosystems, there is a great need for improved reporting and verification of landings and catches. The present study represents an alternative approach to estimate a more comprehensive total catch for the island state of Mauritius, including estimates of unreported landings of the small-scale fisheries sector, recreational catches, and discards. Summed for 1950-2008, marine fisheries catches for Mauritius and its dependencies as estimated in our reconstruction was 682,392 t, which is 42% larger than currently reported total catches of 478,305 t presented by FAO on behalf of Mauritius. This was largely due to the under-reporting of small-scale catches for Mauritius and Rodrigues islands. Estimated small-scale catches for Mauritius and Rodrigues islands represented respectively 25% and 23% of the total reconstructed catch, thus implying an important contribution of those fisheries to total national catches. Thus, our results confirmed that currently reported catches for the Republic of Mauritius are incomplete, and especially underrepresented catches from the small-scale fishing sectors. This situation of underreporting of catches for the small-scale sector is not specific to Mauritius and has been demonstrated for other countries (Zeller *et al.*, 2006; Jacquet and Zeller, 2007). Indeed, although they are highly important in terms of income and food security, small-scale tropical fisheries are often marginalized world-wide (Pauly, 1997). Consequently, their contribution in terms of catches is also often substantially underreported.

Nevertheless, it should be mentioned that the Mauritius government made efforts to decrease the pressure on lagoon fish stocks and to improve the fishers' livelihoods (such as the bad weather or closed net season allowances). Mauritius is also one of the few countries which accounts for recreational and 'amateurs' fisheries catches in their total reported catches, even though they are represented by constant estimates over the years. However, as demonstrated in the present study, more efforts should be dedicated to monitoring recreational and small-scale fisheries.

High levels of uncertainty are associated with reconstructions such as ours. However, as long as estimates for unaccounted catches are not substantially overestimated, the catch reconstruction will present a more accurate picture of total extractions in the marine environment compared to current practices of essentially allocating 'zero catch' to IUU components (Illegal, Unregulated and Unreported catches) for which no hard time series data are available.

The time series data presented do not include catches by foreign vessels which fish heavily – legally or illegally - the waters off Mauritius, which would likely add great amounts to the total extractions of marine resources in the Mauritius' EEZ. The Banks of the Mascarenes Ridge, for instance, have been, over the years, exploited by a number of foreign fishing units from diverse countries such as Korea, Japan, France (Reunion), Seychelles, Spain, Russia, Panama and Malaysia (Paul, 1987). Réunion based boats were fishing in the Soudan, Nazareth and Saya de Malha zone as early as 1962. Not all foreign vessels fishing on the banks use handlines but also longlines and trawls. The total catch of these foreign fishing vessels on the banks is not reported but estimated to be well in excess of 10,000 tonnes per year (Ardill, 1986; Paul, 1987).

Discards of the deep-sea demersal trawlers are also considered to be high in many deep-sea fisheries (Kelleher, 2005) and therefore they would likely add important amounts to our estimated total catches. Kelleher (2005) reported a discarding rate for deep water trawls of 39.6%. However, this discarding rate was from fisheries operating in the Northeast Atlantic and Chile, and no similar estimate has been made for the Western Indian Ocean. Therefore, attempts have not been made to quantify trawl discards.

In Mauritius as in Rodrigues Island, depletion of the marine lagoon resources is of concern and indications of growth overfishing were drawn early. One of the characteristics of growth overfishing is a decline in the mean size of a fish population, and this problem has been noted for Mauritius as early as the 1920s (Paul, 1987). Pearson (1988) also defined the lagoon of Rodrigues as clearly overfished, while (Bunce *et al.*, 2008) mentioned that overfishing in Rodrigues could have occurred since the 1800s. In Mauritius, the reduced catches have to some extent been compensated for by rising prices and a high demand for fresh fish, and as a result there has been no substantial reduction of the fishing effort (Hollup, 2000). An ever growing population and increasing tourist arrivals is leading to a greater demand for seafood, and subsequent increased pressure on fish stocks. Fishers have also resorted to illegal fishing practices that are highly destructive for the marine environment (i.e., dynamite and fine mesh nets). Combined, population pressure and destructive fishing practices suggest that 'Malthusian overfishing' (Pauly, 1997) is occurring on Mauritius Island. Although regulations have existed in the legislation since the colonial days, they only concern limitations on the use of specific gears, fish reserves and closed seasons for nets (Hollup, 2000). Pearson (1988) and Hollup (2000) both mentioned that regulations should include the limitation of access to the fish resources of the lagoon area. However, alternatives are needed for the numerous fishers who depend on these resources for their livelihoods.

This study illustrates the need for better reporting of catches for all the different fisheries sectors of Mauritius state. Accounting for all fisheries components is fundamental to effectively managing the fisheries, which provide food and income for a large coastal population. We hope that the present study will encourage management agencies and policy makers to work in this direction.

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Appendix Table A1: FAO landings vs. total reconstructed catch (in tonnes) for Mauritius, 1950-2008.

Years	FAO landings	Total reconstructed catch
1950	2,000	5,786
1951	2,000	5,982
1952	2,000	5,913
1953	2,000	6,057
1954	2,000	5,958
1955	2,000	5,995
1956	2,200	6,013
1957	2,200	5,920
1958	2,200	6,121
1959	2,500	6,300
1960	2,501	6,486
1961	2,501	6,757
1962	2,801	6,263
1963	2,801	6,783
1964	2,801	6,238
1965	3,000	6,274
1966	3,001	6,343
1967	3,000	6,258
1968	3,300	6,421
1969	4,001	7,328
1970	5,400	7,586
1971	5,200	8,337
1972	6,600	9,347
1973	6,400	8,663
1974	7,679	9,536
1975	7,038	9,248
1976	6,660	8,649
1977	7,667	10,932
1978	7,108	10,697
1979	6,525	9,362
1980	6,348	9,109
1981	7,132	10,032
1982	9,780	12,638
1983	9,434	12,222
1984	10,346	13,613
1985	12,175	15,248
1986	12,848	15,817
1987	17,279	20,656
1988	17,116	20,604
1989	16,896	20,530
1990	14,098	17,603
1991	18,576	22,298
1992	18,861	22,687
1993	20,576	24,595
1994	18,145	21,911
1995	16,395	19,620
1996	11,870	15,104
1997	14,025	17,707
1998	12,093	15,068
1999	12,205	16,264
2000	9,615	13,684
2001	10,986	14,748
2002	10,706	14,414
2003	10,968	14,836
2004	9,971	13,126
2005	9,855	12,995
2006	8,681	13,653
2007	8,087	12,627
2008	6,152	11,430

Appendix Table A2: Total reconstructed catch (in tonnes) by major taxa for Mauritius, 1950-2008. Others grouping includes 38 taxa.

Year	*Lethrinus mahsena*	Octopodidae	*Katsuwonus pelamis*	*Thunnus albacares*	Siganidae	*Thunnus alalunga*	Serranidae	Acanthuridae	Mugilidae	Others
1950	332	1,544	-		534	-	152	261	187	2,465
1951	460	1,563	-	0	539	0	155	262	188	2,503
1952	367	1,582	-	0	538	1	153	263	189	2,511
1953	449	1,602	-	0	542	2	155	264	191	2,543
1954	329	1,621	-	0	539	3	153	264	191	2,547
1955	322	1,640	-	1	540	5	154	265	192	2,566
1956	318	1,649	-	1	541	9	154	265	192	2,575
1957	220	1,656	-	2	538	12	152	265	192	2,571
1958	339	1,762	-	3	531	17	170	266	157	2,566
1959	257	1,813	-	4	574	22	183	289	165	2,682
1960	180	1,864	-	5	618	28	196	312	174	2,799
1961	226	1,907	-	6	653	35	208	329	181	2,903
1962	158	1,840	-	7	572	42	182	289	166	2,698
1963	218	1,925	-	8	647	50	206	327	181	2,912
1964	181	1,844	-	10	551	58	175	278	163	2,668
1965	215	1,883	-	10	607	63	167	305	149	2,565
1966	218	1,896	-	14	609	87	168	306	150	2,584
1967	128	1,909	-	18	608	110	167	307	150	2,590
1968	177	1,922	-	22	612	136	168	308	151	2,614
1969	895	1,937	-	27	613	163	202	309	152	2,699
1970	1,027	1,969	-	31	614	189	209	310	154	2,749
1971	1,568	1,986	-	34	617	208	233	311	155	2,826
1972	1,884	2,229	-	37	362	224	243	507	208	3,268
1973	1,520	2,079	-	39	362	236	229	510	202	3,118
1974	2,344	2,090	-	28	363	172	266	511	203	3,205
1975	2,083	2,088	-	30	365	183	257	514	203	3,187
1976	1,506	2,077	-	39	366	235	233	518	203	3,149
1977	3,460	2,072	0	46	368	270	333	523	204	3,346
1978	3,333	2,043	15	71	360	296	304	500	199	3,283
1979	2,055	2,042	41	59	350	362	253	498	197	3,183
1980	1,553	1,926	1,004	67	277	336	192	389	169	2,851
1981	1,589	1,923	1,746	76	274	367	217	387	168	2,907
1982	3,505	1,806	2,430	78	299	368	351	163	249	3,079
1983	2,684	1,842	1,421	1,191	342	361	304	185	275	3,344
1984	2,680	1,823	2,537	1,430	349	373	332	186	276	3,377
1985	4,212	1,798	2,080	1,081	348	360	402	184	273	4,081
1986	5,063	1,773	1,899	1,039	352	359	426	184	273	4,003
1987	5,917	1,785	4,397	1,845	383	443	519	203	293	4,439
1988	5,550	1,747	5,049	1,492	377	440	505	194	284	4,551
1989	4,085	1,749	5,614	1,955	379	476	397	199	288	5,007
1990	3,360	1,758	4,195	1,624	390	480	408	206	295	4,522
1991	3,716	1,744	6,735	3,043	382	472	429	200	289	4,940
1992	5,152	1,766	6,126	2,419	415	484	509	216	308	4,969
1993	6,047	1,736	7,074	2,768	394	522	500	201	292	4,765
1994	5,961	1,742	5,209	1,987	394	536	543	208	297	4,755
1995	5,720	1,614	3,936	1,891	372	544	483	191	303	4,313
1996	4,787	1,504	1,589	727	390	601	491	204	277	4,297
1997	4,737	1,503	3,150	1,281	338	640	459	175	242	4,966
1998	4,091	1,209	1,692	1,576	333	648	368	174	253	4,550
1999	4,328	1,037	2,481	1,333	336	685	391	174	283	5,060
2000	4,208	1,042	425	835	349	725	455	184	302	4,960
2001	3,627	791	140	769	319	716	376	167	275	7,393
2002	3,936	964	140	752	348	693	420	184	309	6,529
2003	3,816	1,221	140	784	332	779	409	175	267	6,808
2004	3,215	853	140	786	313	876	344	168	252	6,099
2005	2,240	792	133	787	299	853	258	158	216	7,184
2006	3,088	752	133	838	300	838	342	161	235	6,862
2007	2,491	622	133	823	246	866	293	132	215	6,758
2008	2,449	643	133	841	260	788	252	134	225	5,705