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Lydia Teh and Louise Teh

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Email: lydia.teh@fisheries.ubc.ca

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Lydia Teh and Louise Teh

Sea Around Us, Fisheries Centre, University of British Columbia, 2202 Main Mall, Vancouver, BC, V6T 1Z4, Canada
lydia.teh@fisheries.ubc.ca; l.teh@fisheries.ubc.ca

Abstract

We reconstructed marine fisheries catches for Peninsular Malaysia and the state of Sarawak from 1950-2010, and incorporated previously reconstructed catches for Sabah. Annual national landings statistics report catches from licensed fishers and fishing vessels only, resulting in underestimation of total catches. Although there are some discrepancies between national data and data presented by the FAO, the two datasets are generally similar and thus it is assumed that the FAO data are an underestimate as well. We identified four sources of unreported catch and added them to the baseline data– i) unlicensed traditional fishers; ii) unlicensed commercial fishing vessels; iii) discards at sea; and iv) marine recreational fishers. Our reconstruction suggests that from 1950-2010, marine catches in Peninsular Malaysia and Sarawak were underestimated by factors of 1.8 and 1.6, respectively, and by a factor of 3.3 for Sabah, in relation to the baseline reported data that we had allocated to each. Unlicensed fishing potentially resulted in an additional 25.9 million and 2.4 million tonnes of fish taken from the waters of Peninsular Malaysia and Sarawak, respectively, in the period under consideration. Our findings indicate the need for improved understanding and monitoring of unlicensed fishing in Malaysia, which is crucial to facilitate successful ecosystem based fisheries management, and for securing economic benefits and marine ecosystem health in the future.

Introduction

Fisheries are an integral part of Malaysian society. They provide an affordable source of protein for up to two-thirds of Malaysia's population (Saharuddin 1995), and are crucial sources of income and employment in rural coastal fishing villages throughout the country, both historically and in present time (Firth 1966; Raduan *et al.* 2007). Uncontrolled expansion of commercial fishing from the mid-1960s through to the 1970s resulted in the overexploitation of Malaysia's inshore fisheries by the late 1970s (Omar *et al.* 1992; Saharuddin 1995; Abu Talib *et al.* 2003a). This was driven in part by the national government's production-oriented policies following national independence. Efforts to manage Malaysia's fisheries have been hampered by lack of data on biological stocks, conflicting goals of government agencies involved in different aspects of fisheries, and lack of political support (Abdul Majid 1985; Yahaya 1988; Omar *et al.* 1992).

Overcapacity in the fishing fleet is a key factor underlying the current degraded state of Malaysia's fisheries resources (Abdul Majid 1985; Mohd Taupek 2003). It is likely that this arose from historical and present levels of fishing that were, and still are, higher than accounted for by fisheries regulatory agencies. Thus, we aim to reconstruct the marine fish catches of Malaysia from 1950-2010 to obtain a clearer picture of historic and present sources, and levels of exploitation–information that fishery managers can use in making decisions that start to move towards more effective and future oriented fisheries management in Malaysia.

Background

Malaysia is divided into two geographical regions: Peninsular Malaysia and East Malaysia. East Malaysia is separated from the Peninsular by 640 km of the South China Sea, and includes the states of Sabah and Sarawak, situated on the island of Borneo (Figure 1). This reconstruction covers the fisheries of Peninsular Malaysia and Sarawak, as the reconstruction for Sabah has previously been completed (Teh *et al.* 2009).

Figure 1. Map of Malaysia showing Peninsular Malaysia, Sarawak and Sabah.

The east and west coasts of Peninsular Malaysia are different. The east coast faces the South China Sea, and has a sandy bottom due to the presence of patchy coral reefs that occur along the coast. The coast consists of long sandy beaches which are broken up intermittently by estuaries and mangroves. The east coast is subject to severe weather during the north-east monsoon (November to March), during which no fishing, or a very limited amount, takes place. In contrast, the west coast, which is bordered by the Straits of Malacca, is less exposed. There are few sandy beaches; instead, the coast is characterised by extensive mangrove lined areas with shallow muddy waters less than 100 m deep (Kesteven 1949; Abu Talib *et al.* 2003b). Eight of Malaysia's thirteen states are located on the west coast.

Sarawak's EEZ covers an area of about 160,000 km^2 in the South China Sea. Its continental shelf covers 125,000 km^2 and slopes to 200 m in depth (Garces *et al.* 2003). In the north, a 2,000 to 2,500 m deepwater trench stretches towards Sabah waters (Gambang *et al.* 2003). The inshore area is characterized by mangrove swamps and mudflats, with stretches of sandy and exposed shoreline. Fishing effort in Sarawak is concentrated in near-shore muddy areas, and productive fishing grounds can be found in the southern bays and in the north. The fishing season in Sarawak is determined by the northeast monsoon from November to February, during which conditions are usually too rough for most small-scale fishers to go fishing.

Sabah's total catches were previously reconstructed (Teh *et al.* 2009). This work suggested that Sabah's marine catches were 3.3 times the reported landings determined to represent Sabah's reported catch. This discrepancy is likely due to a poor knowledge about existing sources of fishing pressure. From the mid 1990s until 2006, the number of small-scale fishers in Sabah may have been up to 3 times higher than the number of officially reported fishers. In addition, the presence of unlicensed trawl vessels also led to reported commercial landings being underestimated.

Malaysia's marine fisheries are primarily inshore (30 nautical miles from shore), and can be split into two sectors – "traditional" (i.e., small-scale) and "commercial" (i.e., industrial). The Malaysian Department of Fisheries (DoF) classifies trawl and purse seine as commercial gears, while traditional gears include drift/gill nets, hook and line, traps, fishing stakes, bag nets, lift nets, and barrier nets. Marine capture fisheries in Malaysia are multi-species, with over 100 species reported from the catch. Both pelagic and demersal species are targeted. Pelagics formed the mainstay of fisheries on both coasts of Peninsular Malaysia in the early period (Pathansali 1961; Firth 1966; Pong 1992), and continue to make up substantial portions of marine landings (up to 40% in 2010). In Sarawak, demersal fishes make up the largest part of marine catches; pelagic fisheries are relatively small compared to those in Peninsular Malaysia due to the low numbers of purse seiners operating in Sarawak (Gambang *et al.* 2003). Overall, shrimps are the most important demersal species group because of their high economic value (Nuruddin and Urn 1994), and the majority of shrimps are caught off the west coast of Peninsular Malaysia. Until the introduction of trawlers, prawns and shrimps were caught with traditional gears such as trammel nets, push nets, and bag nets.

Historical development

Fishing activities prior to the 1960s were mainly small-scale, making use of traditional fishing gears in shallow inshore areas (Firth 1966; Ooi 1990). The majority of boats during this period were non-motorised. Despite the small-scale nature of fisheries, marketing and trade of fishes and other marine resources was already widespread and well established when Malaysia (then called Malaya) was still under British colonial rule in the 1950s (Stead 1923; Kesteven 1949; Firth 1966; Butcher 2004). Likewise in Sarawak, there was already an established fish market system before World War II in the administrative centre of Kuching, where professional fishers from the Chinese Henghua community operated on a largely artisanal scale. The presence of fish carriers from Singapore further reinforces that there was active regional trade in fish products (Elliston 1967), although fishing in other remote areas of Sarawak were still primarily subsistence based.

Peninsular west coast fisheries have historically been more heavily capitalised and intensely exploited compared to the east coast, which was, and continues to be, less developed economically (Labon 1974; Ooi 1990). The fisheries sector was characterised by technological change in the 1960s. Boats became increasingly motorised, and trawling was introduced in 1963. The initial profitability of trawling, which targeted prawns, attracted many participants, leading to a sizeable population of unlicensed trawl vessels. In fact, there were 5 times more unlicensed than licensed trawlers in 1967 (Abu Bakar and Ch'ng 1987). The rapid modernisation and expansion of Malaysia's fisheries sector during this period was encouraged by the Malaysian government as part of the New Economic Policy, which viewed fisheries development as an important component of national food security, and as a means of alleviating rural poverty. Increases in fishing effort were therefore fuelled by government programmes that provided subsidies and introduced more efficient gears (Fredericks and Wells 1980; Saharuddin 1995; Raduan *et al.* 2007). Fish landings (national data) in Peninsular Malaysia subsequently increased by over 300% between 1960 and 1980, from 150,650 to 623,987 t, while in Sarawak the increase was around 1000%, from about 7,000 t in 1960 to 77,070 t in 1980.

By the late 1970s, the trawl sector was already considered to be overcapitalised (Yahaya 1988; Mohd Taupek 2003). The marine ecosystem was also showing signs of overexploitation, with 'trash fish' (i.e., small marine fishes with no commercial value)[1] making up an increasing proportion of total fish landings (Abdul Majid 1985; Mohammad Arriff and Mohammad Raduan 2009). Prior to the late 1970s, miscellaneous small fish from commercial operations were mostly discarded at sea, and only those from the last haul were landed (Abu Talib *et al.* 2003a). However, since the late 1970s the majority of trash fish have been landed due to the high demand from fish meal factories and marine cage culture operators (Ali and Johari 1997).

[1] We use the term 'trash fish' in this paper to be consistent with terminology used by Malaysia's Department of Fisheries, although we think that this is a misleading term (e.g., see Pauly 1996 for uses of low value fish in Southeast Asia).

The rapid expansion of trawling also led to considerable conflict between traditional and commercial fishers over competing uses of inshore fishing grounds, which included important prawn habitat (Goh 1976; Raduan *et al.* 2007). This culminated in the Fishery Licensing Policy of 1981, which imposed a spatial zoning plan that reserved inshore fishing grounds exclusively for traditional fishers. In addition, trawl licenses were no longer issued to small vessels, but only to vessels that were capable of operating in offshore areas (Yahaya 1988).

In the mid 1980s, with inshore fisheries showing signs of strain, the Malaysian government started to encourage deep sea fishing in waters beyond 30 nautical miles from the coast. Efforts to increase catches from the deep sea fishing sector continued to intensify in the 1990s and 2000s (Anon. 1997). Although marine fish landings showed an increasing temporal trend, the proportion of food fish in the catch has declined, whereas trash fish made up on average 30% of reported landings from 2000-2010 in Peninsular Malaysia and 19% in Sarawak. Malaysia's inshore fisheries resources remain overexploited (Omar *et al.* 1992; Mohammad Arriff *et al.* 2011).

Recreational fishing

Recreational fishing is reportedly a growing industry in Malaysia (Tan 2003; Zakariah 2008), but there is very limited information on the marine recreational fishing industry in terms of participation rate and fishing effort. However, the presence of numerous recreational fishing websites and forums, as well as advertisements for chartered fishing trips and game fish competitions suggests that recreational fishing is quite a popular leisure activity in Malaysia.

Fisheries statistics – data collection

The Department of Fisheries Malaysia is responsible for monitoring fishing activities in Peninsular Malaysia, and compiles all statistics into an Annual Fisheries Report. Until the 1980s, marine fish landings were estimated through interviews that District Fisheries Assistants conducted with fishers. They also collected data on the number of gears in operation, types of species caught, and price of fish at landing sites. However, due to the multiple duties demanded of Fisheries Assistants (Anon. 1970), it is likely that reported data in this period may not be as reliable as later periods.

An improved data collection system was put in place in 1981. Presently, data on landings of marine fish and fishing effort are collected monthly at major landing centres. Sampling involves at least 20% of the number of fishing gears in use (Mohd Taupek 2003). Boats are selected at random, and the weights of all landed species, including trash fish, are recorded. Information recorded include: type of gear, number of gears in operation, number of fishing days, number of sets/hauls per day, fishing hours, total weight of the catch, and catch by species. Samples are stratified by fishing gear (commercial or traditional), and commercial gears are further stratified by vessel tonnage class (for Peninsular Malaysia only).[2] Data from these samples are then raised to the entire population. Information on the number of licensed fishing gears, fishing boats, and fishers are obtained from license records compiled by the State Fisheries Department. A frame survey is carried out every two years to estimate the number of gears in operation in order to account for unlicensed fishing activity and inactive gears.

Although Malaysia's fisheries data collection system is considered to be sound, it is acknowledged that there is a major gap in the coverage of small-scale (traditional) fisheries (Stobberup 2011). Moreover, other researchers have noted inconsistencies in data reported in the Annual Fisheries Reports, and have questioned the reliability and accuracy of these statistics (Anon. 2008).

The presence of unlicensed fishers is a long standing issue that is openly acknowledged, but has not been properly addressed. This has been in part due to the poor socio-economic status of traditional fishers, which has led to an informal policy among fisheries agencies to not require traditional fishers to obtain fishing vessel or gear licenses (Anon. 2008). In addition to the gap in coverage of small-scale fisheries, statistics in Annual Fisheries Reports also do not report catches from marine recreational fisheries.

It is therefore reasonable to assume that for the period 1950-2010, official fish landings are under-reported due to:

i) The high number of unlicensed small-scale fishers who live in rural fishing villages away from landing centres, and who land their catches in private jetties or beaches;

ii) The high number of unlicensed trawlers during the early years of the trawl fishery;

iii) The presence of a marine recreational fishery which is not monitored by the Fisheries Department;

iv) Discards from commercial trawlers that were not landed until a market for fishmeal developed in the mid to late 1970s.

[2] This data is available for Sarawak only in the 2010 Annual Fisheries Statistics.

Methods

Reported landings

Statistics on reported landings, number of gears, number of fishers, and species composition were extracted from Annual Fisheries Reports published by the Malaysia Department of Fisheries (DoF). These are available at the DoF website,[3] and cover the years 1950 to 2010. This information was used along with the FAO data to determine a reporting baseline for each of the four different EEZ areas (Peninsular Malaysia west, Peninsular Malaysia east, Sarawak, and Sabah). Portions of the FAO data were also allocated as catches outside of EEZ waters. Those catches are not considered further in this report. All further references and comparisons to reported landings are in relation to the newly determined reporting baseline for each EEZ entity unless otherwise stated.

Unrecorded catch

All catches were assumed to be traditional from 1950 until the development of the trawl fishery in 1965. There were four sources of unreported catches: 1) unlicensed traditional fishers; 2) unlicensed trawlers; 3) discards; and 4) marine recreational fishers. The catches from each of these four categories were estimated for 1950-2010, and added to the baseline reported data.

Unlicensed traditional catch

We estimated the number of unlicensed fishers and applied a catch rate to obtain the unlicensed traditional catch per year.

Peninsular Malaysia

Number of unlicensed traditional fishers

The number of unlicensed fishers was estimated by applying a ratio of unlicensed to licensed fishers for each year. These ratios were based on 3 points:

1950: Firth (1966) observed that a substantial number of people participated in fishing part time, and that this number may have been up to 50% of the number of licensed fishers. Although these observations were made in 1940, we assumed it was reasonable to apply the same ratio of 0.5 to 1950.

i) 2005: It was reported that there were about 500 unlicensed fishers in Penang (a state in northern Peninsular Malaysia), the majority of whom operated trawlers or beach seine (Anon. 2005). In the 2005 Annual Fisheries Report, there were 271 and 260 registered fishers under the trawl and 'other seine' (beach seine is not reported separately) gear categories in Penang, thereby generating a conservative unlicensed ratio of 0.94 (500 unlicensed to 531 licensed fishers). We assumed that the situation in Penang was applicable to other states in Malaysia.

ii) 2008: It was reported that out of around 4,500 small outboard engine boats operating in the state of Johor, only a handful were licensed (Anon. 2008). According to the 2008 Annual Fisheries Report, there were 2,455 outboard engine boats (40 GRT) operating in Johor in 2008. This produced an unlicensed to licensed ratio of 0.83.

Starting from 1950, the unlicensed fisher ratio of 0.5 was linearly increased to 0.94 in 2005, and then decreased slightly to 0.83 in 2008. We assumed a constant rate from 2008 to 2010.

Catch rate of unlicensed traditional fishers

Firth's study of 1940 suggested that prior to the development of commercial fisheries, unlicensed fishers were mainly those who had other primary occupations, and fished only for subsistence purposes. Thus, we assumed that unlicensed traditional fishers used a subsistence catch rate for 1950-1965, after which we assumed that pure subsistence fishing declined, and increased the subsistence catch rate to an artisanal level. Our estimate for the subsistence level catch rate of unlicensed fishers from 1950-1965 was as follows:

Average consumption of fish was around 1 oz (30 grams) per capita per day in 1940 (Firth 1966), and an average household size was around 6 people. We assumed that a subsistence fisher went fishing every other day, for a total of 15 days per month. Due to the strong north east monsoon, fishing is not possible for about 3 months a year on the east coast of Peninsular Malaysia. Thus, annual subsistence catch (c_s) per unlicensed fisher on the east coast was estimated as:

[3] http://www.dof.gov.my [accessed 25 July 2012]

$c_s = f*e*m*h$

where f = fish consumption per capita per day

e= number of fishing days per month

m = number of fishing months per year

h = number of individuals in each household

The same approach was taken to estimate annual subsistence catch rates for unlicensed fishers on the west coast. The one difference was that fishing is possible all year round on the west coast, which is not affected by the monsoon. Thus, the west coast subsistence catch rate was one-third higher than the east coast rate.

The annual subsistence catch rate calculated above applied to 1940, the year Firth's study was done. We linearly increased the 1940 rate to 1965. In 1965, Firth (1966) reported that the average production for full-time east coast fishers had increased to 3 t·fisher^{-1}·year^{-1}. From 1965 onwards, we assumed that all fishers became increasingly market oriented, such that their level of production went up.

We had data on the catch rates of traditional gears in 1981 and 1983. The weighted average of these figures was used to represent the annual traditional catch rate (t·fisher^{-1}·year^{-1}) for 1981 and 1983 (Table 1). We interpolated the catch rates between 1965 and 1981, and 1981 to 1983. From 1983 to 2010 we applied a constant catch rate of 3.11 t·fisher^{-1}·year^{-1}. We assumed this was reasonable given that a previous study reconstructing the traditional fishery in Sabah, Malaysia, used a comparable catch rate (3.68 t·fisher^{-1}·year^{-1}) for this period.

Table 1. Average catch rates weighted by gears for Peninsular Malaysia traditional fishers in 1981 and 1983.

Gear	Catch rate (t·fisher^{-1}·year^{-1})		Proportion of total traditional landings	
	1981	1983	1981	1983
Drift/gill net	1.91	2.09	0.55	0.59
Lift net	10.98	11.26	0.20	0.12
Hook and line	2.72	3.30	0.25	0.29
Weighted average traditional catch rate (t·fisher^{-1}·year^{-1})	3.90	3.60	-	-

Sarawak

Number of unlicensed traditional fishers

The Chinese Henghua were professional fishers from South China who settled in Sarawak in the early 1900s. We subtracted the number of Chinese Henghua fishers from total licensed traditional fishers before applying an unlicensed to licensed fisher ratio to estimate the number of unlicensed traditional fishers. We subtracted Chinese Henghua fishers because they were largely market oriented and had substantially higher fishing effort (Elliston 1967). In 1960, Elliston (1967) reported there were 651 Chinese Henghua fishers out of a total of 4,387 fishers, a proportion of approximately 15%. We assumed that this proportion was likely reflective of conditions in the decade 1950-1960. Thereafter, we calculated the proportion of Chinese fishers out of total licensed fishers in the years 1980, 1985, 1990, 1995, 2000, 2005, and 2010, and linearly interpolated remaining years based on those anchor points.

The ratios for unlicensed to licensed traditional fishers were based on the following:

i) 1950: The reported number of traditional fishers likely only accounted for those who sold all or part of their catch to markets, while subsistence fishers were not included. As with Peninsular Malaysia, we assumed that approximately 50% of traditional fishers sold their fish, while the other 50% fished solely for subsistence in the 1950s. Therefore, we increased the number of licensed traditional fishers by 50% to account for subsistence fishers.

ii) 1987: The Annual Fisheries Report stated that the 7,482 licensed fishing vessels reported for 1987 was inclusive of boats not licensed. In fact, there were only 4,091 licensed fishing vessels reported in the actual Annual Fisheries Statistics data table, suggesting that the difference between these two numbers, about 83%, was due to unlicensed boats. We used this proportion as our second anchor point for estimating the number of unlicensed fishers.

iii) 2008: it was estimated that the unlicensed traditional fleet was at least 50% of the licensed fleet (Anon. 2008). We assumed that this ratio applied from 2008 to 2010.

Starting from 1950, the unlicensed fisher ratio of 0.5 was linearly increased to 0.83 in 1987, then decreased to 0.5 again in 2008. We assumed a constant rate from 2008 to 2010.

Catch rate of unlicensed traditional fishers

Porritt (1997) stated that in 1948, traditional coastal fishers caught an average of 1 ton of fish per year. We applied this catch rate to 1950, and assumed that it remained the same until 1968 when fishers became more market oriented and increased their effort of catches. Due to a lack of Sarawak specific data, we used the Peninsular Malaysia catch rate of 3.11 t·fisher^{-1}·year^{-1} in 1983, and kept this rate constant from 1983-2010. We linearly interpolated the catch rate between 1968 and 1983.

Unreported catch from Chinese Henghua 'Kotak' fishing vessels

The unreported catch from Chinese Henghua fishers was estimated by applying a catch rate to the number of kotak gillnet fishing vessels in the Chinese Henghua fleet. In 1961 the fleet consisted of 411 kotak vessels of which 300 were actively engaged in fishing, and in 1966, 400 out of 548 licensed kotak vessels were in regular use (Elliston 1967). We assumed that it was possible for inactive kotak vessels to return to fishing at any time, so there could potentially be a maximum of 30% more vessels fishing (difference between number of active and total registered kotak vessels). In addition, enumeration of kotak fishing vessels from Porritt (1997) and Elliston (1967) referred to those in the Kuching area. In 1970, there were 10,642 Chinese Henghua in Sarawak, of which 4,806 (45%) were in Kuching (T'ien 1983). We assumed that the proportion of Chinese Henghua who were fishers in and outside the Kuching area were similar, thus there was potentially up to 45% more kotak vessels that may not have been enumerated. To remain conservative, we raised the number of licensed kotak vessels by 30% in the 1960s and 1970s, and kept this ratio constant from 1950-2010 due to a lack of other information sources.

The number of kotak vessels was reported in Annual Fisheries Reports from 1970-1986. In addition to data points of 300 and 400 kotak vessels in 1961 and 1966, respectively (Elliston 1967), Porritt (1997) stated that there were nearly 200 Chinese drift-net fishing vessels based in Kuching in 1948, which we applied to the year 1950. We used linear interpolation to fill gaps in the number of kotak vessels between 1950 and 1970. After 1986, the 'kotak' category was removed from the Annual Fisheries Reports and all vessels were classified according to engine type (inboard/outboard) and vessel size in metric tonnes. Since we had no way of extracting kotak vessels from the broader classification scheme, we calculated the average annual change in number of kotak vessels from 1950-1980 (-3%), and applied this rate to calculate year on year change in the number of kotak vessels from 1981 to 2010. The decreasing trend is reasonable given that after World War II the Chinese Henghua community began to shift from fishing towards private business enterprise (T'ien 1983).

Chinese Henghua kotak catch rate

The catch rate of the kotak gillnet fishing fleet was based on the following:

i) 1948/1949: About 21,000 piculs of marine fish were landed (Elliston 1967) from 200 Chinese Henghua kotak fishing vessels (Porritt 1997). This worked out to an annual catch rate of 6,353 kg·kotak^{-1} (1 picul = 60.5 kg), which we used as our starting anchor point in 1950;

ii) 1964: Total estimated marine fish catch from Chinese Henghua fishers was 60,000 piculs (3,630 t), which represented 42% of total landings in Sarawak (Elliston 1967). The catch rate was calculated as 10,083 kg·kotak^{-1}, based on 360 kotak fishing vessels in 1964;

iii) 2004: the catch rate of gillnets operated by boats 10-39.9 GRT in size was approximately 26 t·year^{-1} (Anon. 2013). Due to lack of other data, we made the conservative assumption that the catch rate of smaller kotak fishing vessels (10GRT) was half that of the larger vessels, that is, 13 t·year^{-1}.

iv) All years with missing data were linearly interpolated between the three anchor points.

Unlicensed trawl catch

Peninsular Malaysia

Number of unlicensed trawlers

Similar to the traditional sector, an unlicensed to licensed ratio was applied to the number of licensed trawl gears to obtain an estimated number of unlicensed trawlers. The different years for which we had unlicensed trawler data were:

i) 1964: Monitoring of trawl fishery landings started in 1965; however, it was estimated that there were already 900 unlicensed trawlers operating in northwest Malaysia in 1964 (Ooi 1990);

ii) 1966: There was an estimated 452 unlicensed, as opposed to 138 licensed trawlers in 1966 (Anon. 1968). This generated an unlicensed:licensed ratio of 3.28;

iii) 1967: The same study estimated 910 unlicensed to 180 licensed trawlers in 1967, generating a ratio of 5.06;

iv) 1998: In the 1998 Annual Fisheries Report, there were a total of 3,915 licensed trawlers in Peninsular Malaysia, whereas 5,724 trawlers were estimated to be in operation. This gave an unlicensed to licensed ratio of 1.46.

The number of unlicensed trawlers was estimated for 1964-2010, starting with 900 unlicensed trawlers in 1964. For each subsequent year, the unlicensed:licensed ratio was applied to the number of licensed trawlers. We assumed that the 1966 ratio was also applicable to 1965. Ratios for the intervening years between data points were

linearly interpolated. An exception was 1965, a year in which only 20 trawlers were licensed. Applying the unlicensed ratio produced only 66 unlicensed trawlers. It is unlikely that the number of unlicensed trawlers would decrease from 900 in 1964 to 66 in 1965. Thus, to remain consistent, we carried forward the 900 unlicensed trawlers in 1964 to 1965, resulting in an estimated 966 unlicensed trawlers. From 1965 onwards, the number of unlicensed trawlers was estimated based on the unlicensed ratio. The 1998 ratio was carried forward to 2010, since unlicensed fishing by trawlers was still reported along the East Coast in the mid 2000s (Anon. 2008).

Unlicensed trawler catch rate

Trawl catch rates for the periods 1967-1972, 1981, 1982, 1983, and 1990-2005 were obtained from published literature (Table 2). The 1967 rate was applied to all preceding years (1964-1966), while the rate used for 2006-2010 was set at the average catch rate from the previous 5 years (2001-2005). The catch rates for intervening periods were interpolated.

Table 2. Catch rates (t·trawler^{-1}·year^{-1}) used for estimating unlicensed trawl catches from 1964-2010 in Peninsular Malaysia.

Year	Catch rate (t·trawler^{-1}·year^{-1})	Source
1967	90.20	Khoo (1976)
1968	74.20	Khoo (1976)
1969	42.00	Khoo (1976)
1970	20.30	Khoo (1976)
1971	18.90	Khoo (1976)
1972	16.30	Khoo (1976)
1981	53.12	Hotta and Low (1985)
1983	52.90	Hotta and Low (1985)
1990[1]	39.00	Nurul Islam et al. (2011)
1991	44.00	Nurul Islam et al. (2011)
1992	50.00	Nurul Islam et al. (2011)
1993	49.00	Nurul Islam et al. (2011)
1994	50.00	Nurul Islam et al. (2011)
1995	55.00	Nurul Islam et al. (2011)
1996	56.00	Nurul Islam et al. (2011)
1997	55.00	Nurul Islam et al. (2011)
1998	64.00	Nurul Islam et al. (2011)
1999	57.00	Nurul Islam et al. (2011)
2000	60.00	Nurul Islam et al. (2011)
2001	56.00	Nurul Islam et al. (2011)
2002	52.00	Nurul Islam et al. (2011)
2003	64.00	Nurul Islam et al. (2011)
2004	66.00	Nurul Islam et al. (2011)
2005	51.00	Nurul Islam et al. (2011)

[1] Catch rates for 1990-2005 were weighted averages of the east and west coast rates provided in Nurul Islam et al. (2011).

Sarawak

Number of unlicensed trawlers

We set 1968 as the starting point, given that the first trawlers appeared in Sarawak only in 1965. We found few statistics to help us quantify the unlicensed to licensed ratio of trawlers in Sarawak, although illegal trawlers were recognised as a contributing problem to overexploitation of prawn stocks in the early 1980s (bin Rajali and Ahmad Arshad 2001). We assumed that illegal trawl activity was present at the same level as that in the neighbouring state of Sabah, where unlicensed to licensed ratios of 1.58, 0.35, and 0.81 had been estimated for the years 1976, 1979, and 2003 respectively (Teh *et al.* 2009). We used the ratios from 1976 and 2003 for Sarawak. We left out the ratio of 0.35 in 1979, as that was near the peak year of Sarawak's prawn fishery and it was unlikely that the number of trawlers would have decreased. We applied the 1.58 ratio for the period 1968-1986. By 1987, the Fisheries Department had stopped issuing new licences to fish in coastal waters in response to depleted prawn stocks (bin Rajali 1994). We assumed that illegal trawlers followed the trend in prawn stocks and similarly declined in numbers. Thus, from 1987 onwards we started to linearly decrease the unlicensed to licensed ratio to the 2003 ratio of 0.81, which was then held constant to 2010.

Unlicensed trawler catch rate

We based catch rates for unlicensed trawlers on rates obtained from experimental trawling. We applied a catch rate of 149 kg·hr^{-1} obtained from a 1972 study to the period 1968-1972, and had further data points in 1977, 1980, 1984, 1989, 1991, and 1998. Gap years from 1973 until 1989 were filled in using linear interpolation. We kept the 1989 rate constant from 1989-1998, except for 1991 in which a data point was available, as the 1989 rate was sourced from a study of small-scale fisheries in Sarawak rather than experimental trawling. Thereafter, the 1998 catch rate was maintained until 2010. Experimental trawls were carried out by large research vessels (85 GRT), while most commercial trawlers are 70 GRT (typically 30-40 GRT) with less catching capacity. We thus used two catch rates, whereby smaller trawlers were allocated a catch rate that was 1/5 of the bigger trawlers (Table 3). We determined this proportion based on Merlijn (1989), who reported that trawlers with smaller engines (100 hp) had annual catch rates of 20-40 t·year^{-1}, while trawlers with bigger engines (100 hp) caught 100-200 t·year^{-1}. We equated smaller engines (100 hp) with trawlers 70 GRT in size, and bigger engines (100 hp) with big trawlers 70 GRT in size. Taking the midpoint of the two catch rates, bigger trawlers caught about 5 times more fish than smaller trawlers.

Table 3. Catch rates for trawlers in Sarawak.

Year	Catch rate (kg·hr^{-1})		Source
	'Small'	'Big'	
1972	40	‡200	Abdul Latiff et al. (1976)
1977	30	149	Gambang and Bejie (1986)
1980	31	154	Gambang and Bejie (1986)
1984	15	75	Rumpet (1994)
1989	20-40*	100-200*	Merlijn (1989)
1991	47	236	Rumpet (1994)
1998	23	§114	Garces et al. (2003)

Italicised 'small' catch rates are derived from 'big' catch rates (see text).
‡ midpoint of average catch rate of 150-250 kg·hr^{-1} from experimental trawls in Sarawak.
* Catch rate refers to annual catch (t·yr^{-1}). 20-40 t·yr^{-1} refers to trawlers with engines <100hp, and 100-200 t·yr^{-1} for trawlers with engines >100hp.
§ Catch rates from trawl surveys in 1998 decreased an average of 43% from 1972 levels. We applied this reduction to the averaged catch rate of 200 kg·hr^{-1} in 1972.

We then had to determine the proportion of all trawlers that were big and small. Data on trawl vessels by tonnage class were not available for Sarawak until 2010. The next best information we had was the number of licensed fishing vessels with inboard engines categorised by horsepower. We assumed that the latter broader breakdown was representative of trawlers. The proportion of licensed fishing vessels with inboard engines that were 100 hp for the years 1989, 2000, and 2010 were 6%, 8.5%, and 32%, respectively. These represented the proportion of 'big' trawlers out of total licensed trawlers. We could not find this level of breakdown in the Annual Fisheries Reports for years prior to 1989. To fill in gap years from 1968-1988, we assumed that the proportion of big trawlers in 1968, the year we started including commercial trawl fishing in Sarawak, was zero. We then linearly increased the proportion of 'big' trawlers to 6% in 1989.

Annual catch rate was calculated by multiplying annual hourly catch rate by annual trawl fishing effort (no. of hrs). Each year, total average catch rate was calculated as the sum of catch rates of small and big trawlers weighted by their respective proportions. We assumed fishing effort in Sarawak to be similar to that in Sabah, where in 1962 trawlers fished an average of 1,608 hrs·vessel^{-1}·year^{-1} (Mohammad Arriff 1999) and in 1976, 1,214 hrs·vessel^{-1}·year^{-1} (Snell 1978). We used the former value to be representative of fishing effort in 1968, and then linearly decreased it to the 1976 level. Thereafter, we followed the example of the Sabah reconstruction and kept fishing effort constant from 1976-2010.

Discards

The DoF categorises miscellaneous small fish that have no commercial value or are too small to be eaten (i.e., by-catch) as 'trash fish' in the Annual Fisheries Reports. Before the late 1970s, trash fish from commercial operations were mostly discarded at sea (Abu Talib *et al.* 2003a). Thereafter, a market for trash fish emerged when fish processing plants were set up. We therefore assumed a minimal amount of discards from 1976 onwards. Prior to that, we assumed that discarding was dominant among trawlers, thus we started to account for discards in 1965 for Peninsular Malaysia and 1968 for Sarawak. We found it reasonable to assume no discarding before trawling started because the inedible (i.e., too small) fish caught with traditional nets were used as 'offal fish' to feed pigs and ducks (Stead 1923).

From 1976 to 2010, the average trash fish component of annual reported landings was 30% and 17% for Peninsular Malaysia and Sarawak, respectively. We assumed that trash fish would have made up the same proportion of total landings in preceding years (1965-1975), although a large proportion of this would have been discarded. Landed (reported) trash fish as a proportion of total landings was calculated for each year from 1965-1976 for Peninsular Malaysia, and 1968-1976 for Sarawak. The difference between the reported trash fish proportion and the overall average trash fish proportion (estimated from the 1976-2010 data) was then assumed to be discarded at sea. Hence, annual discards (d) from 1965-1975 were estimated as:

$d = (t_a - t_i)*l_i$, where

t_a = average trash fish proportion from 1976-2010;

t_i = trash fish % in year i (reported trash fish/total landings);

l_i = reported landings and unlicensed trawl catches in year i.

To account for the marginal amount of discarding that occurs in fishing villages where there are no facilities for processing trash fish (Chee 2004), we applied a discard rate of 1% as per Kelleher (2005) to total reported landings plus unlicensed trawl catches from 1976-2010.

Marine recreational catch

Number of participants

One study in 1997 estimated that there were one million recreational fishers in Malaysia (Nik Mustapha 1997), but did not indicate what proportion of these fishers fished in marine waters. As recreational fishing in inland waters is popular in Malaysia, and we had no other information to go by, we arbitrarily assumed that half of the estimated one million (i.e., 500,000) recreational fishers fished in marine waters in 1997. Su (1985) indicated that people had participated in marine recreational fishing in Sarawak at least since the 1970s. Thus, we started the analysis for marine recreational catches in 1970.

We assumed, given that recreational fishing is a leisure activity, the number of recreational fishers followed the general trend of GDP growth. From the single point estimate of 500,000 marine recreational fishers in 1997, we filled in the time series by extrapolating backward and forward according to the rate of GDP growth or decline per year (Anon. 2012).

Catch rate

We had no information on fishing effort or catch rates for marine recreational fishers. Recreational fishing surveys conducted in Puerto Rico and Australia led to estimated catch rates of approximately 6 and 8 kg of finfish[4] caught per participant per year in Puerto Rico and Australia, respectively (Henry and Lyle 2003; Garcia-Sais *et al.* 2008). As both these studies involved tropical water fisheries to some extent, we found it reasonable to apply an average of these rates to Malaysia, given the lack of alternative estimates.

Annual marine recreational catch

The number of participants was multiplied by the catch rate to estimate the total annual marine recreational catch for 1970-2010 in the whole of Malaysia. The total catch was then allocated to Peninsular Malaysia and Sarawak according to each region's contribution (%) to Malaysia's total annual reported landings.

Species composition

The species composition of catches from unlicensed vessels and unlicensed traditional fishers was assumed to resemble those from reported landings. Data on landings by species and gear type were reported in the Annual Fisheries Reports from 1968 onwards. Catches were assumed to be all traditional from 1950-1965 in Peninsular Malaysia, and from 1950-1968 in Sarawak. The catch species composition for these years was based on the traditional sector composition of 1968. For Peninsular Malaysia we linearly increased or decreased the % contribution of each fish category to the 1970 (all sectors) level starting in 1965 to account for the development of trawling (Table 4). Total annual catch was broken down into the following categories:

Table 4. Composition of annual catch by major fish groups in Peninsular Malaysia.

Fish group	% of catch	
	1950-1965	1970
Crustaceans	0.13	0.18
Demersals	0.11	0.12
Medium/large pelagics	0.33	0.23
Misc. marine fish	0.14	0.26
Small pelagics	0.28	0.19
Molluscs and misc. invertebrates	0.01	0.02

Crustaceans – prawns, shrimps, lobsters, crabs;

1) Medium/large pelagics – mainly *Rastrelliger* spp., carangids, and scombrids;
2) Small pelagics – herrings, anchovies, *Selar* spp., *Decapterus* spp.;
3) Demersals – mainly *Pennahia* spp., *Nemipterus* spp., *Saurida* spp., *Arius* spp.;
4) Molluscs and miscellaneous invertebrates – squids and cuttlefish, jellyfish, shellfish;
5) Miscellaneous small marine fishes – trash fish (juveniles of commercial fish species) and mixed fish (species that are naturally too small to be of commercial value). A breakdown of trash fish based on a study by Matsushita and Ali (1997) is provided in Appendix Table A5.

Sectoral breakdown

The reconstructed catch was split into 4 sectors: artisanal (small-scale commercial), subsistence, industrial (large-scale commercial), and discards. Traditional catches were allocated to either the artisanal or subsistence sectors. In the present time, small-scale fishers keep approximately 20% of their catch for food (Teh *et al.* 2007). Our estimated subsistence catch by unlicensed fishers in 1950 (see Results section) was around 40% of total traditional catch that year. Bearing in mind that this was the estimated catch from part-time fishers, and taking into account that artisanal fishers also kept a portion of fish for their own consumption, we found it reasonable to assume that up to 50% of total traditional catch in 1950 was subsistence based. We linearly decreased the subsistence portion of total traditional catch from 50% in 1950 to 20% in 2010. The difference between total traditional and subsistence catch was allocated to the artisanal sector. The commercial sector consisted of catches from trawlers and purse seiners.

[4] Puerto Rico catch rate was estimated as follows: Garcia-Sais *et al.* (2008) reported a marine recreational catch of 1.97 million lbs in 2005. The number of recreational fishing participants for 2005 (141,742) was obtained from the NOAA Recreational Fisheries Statistics Queries website available at http://www .st.nmfs.noaa.gov/st1/recreational/queries/index.html. Dividing total marine recreational catch by number of participants provided a catch rate of 6.3 kg fisher^{-1} year^{-1}

Results

Peninsular Malaysia

The reconstructed catch for Peninsular Malaysia totalled 58.4 million t from 1950 to 2010 (Appendix Table A1). Our estimate was 85% higher than the reported landings, which amounted to 31.6 million t from 1950 to 2010 (Figure 2a). During this time period, we estimated that an extra 1.97 million fishers participated in traditional fisheries without a license, while up to 420,890 trawl vessels operated illegally (Appendix Table A2). This resulted in unlicensed (unreported) catches totalling 6.2 million and 19.7 million t for traditional and commercial fisheries, respectively. Discards totalled 808,800 t, while marine recreational catches contributed another 90,900 t (0.16%) to total reconstructed catch. Of the summed reconstructed traditional catches, 4.5 million t (27%) were considered to be for subsistence, with the remainder considered artisanal (12.3 million t, 73%; Figure 2a). Commercial fisheries made up the bulk (71%) of total catches from 1965-2010, contributing 41.5 million t to total reconstructed catches (Figure 2a).

The composition of reconstructed catches reflected the trend of reported landings, with an increasing amount of miscellaneous small fish and decreasing amount of crustaceans through time. The overall proportion of pelagics in the catch declined, whereas demersals increased. However, demersals mainly consisted of low value fish such as threadfin breams (Nemipteridae) and lizardfish (Synodontidae). The major contributing family to the catch was Scombridae with 20.2% of the catch (11.8 million t). Other important contributing taxa to the catch were Carangidae (14.2%), Penaeidae (12.1%), Engraulidae (8.0%), other crustaceans (7.1%), Loliginidae (3.9%), Nemipteridae (3.6%), and Clupeidae (3.1%; Figure 2b).

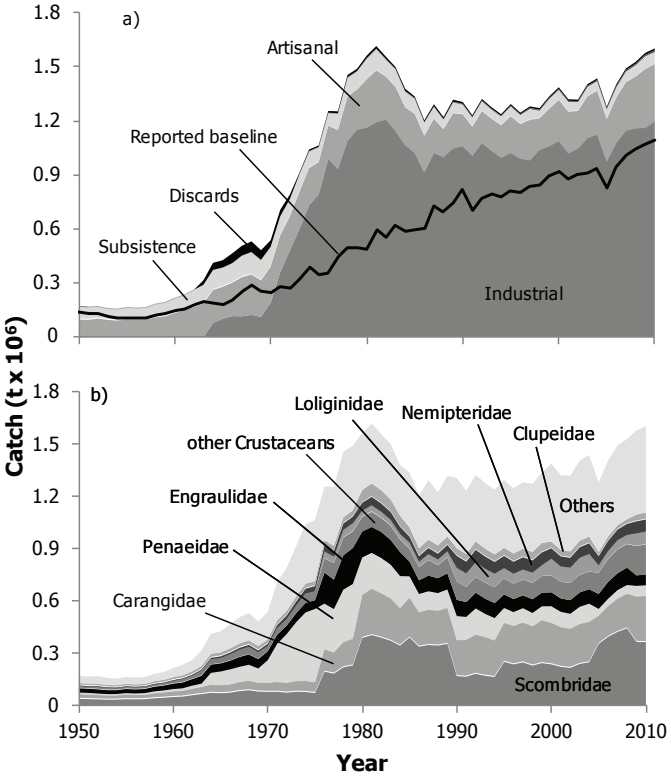

Figure 2. Peninsular Malaysia reconstructed catches for 1950-2010, a) by sector with discards shown separately. Recreational catches are not visible. The solid line represents reported landings; b) by major taxonomic group. "Others" represents 60 additional families and 4 higher taxonomic categories.

Sarawak

The reconstructed catch for Sarawak totalled 6.4 million t from 1950-2010, which was 59% higher than the total of 4.2 million t determined to be the reported baseline for that same period (Figure 3a). The difference between reconstructed and reported was highest in the period 1970-1983, when the average difference was about 2.2 times, and lowest in the most recent decade from 2000-2010, when the average difference was 1.3 times. We estimated that 314,700 unlicensed traditional fishers and 4,690 unlicensed artisanal kotak fishing vessels in Sarawak contributed 750,000 t and 50,000 t of unrecorded fish landings respectively, while 36,700 unlicensed commercial vessels caught another 1.6 million t from 1950-2010 (Appendix Tables A2). Subsistence catches contributed about 642,000 t (27%) to total traditional catch, with artisanal catches of 1.7 million t (73%) making up the remainder. Discards added 28,700 t and marine recreational catches contributed about 12,600t to the total reconstructed catch of Sarawak (Figure 3a).

Similar to Peninsular Malaysia, the composition of reconstructed catches in Sarawak showed an increasing amount of miscellaneous small fish and

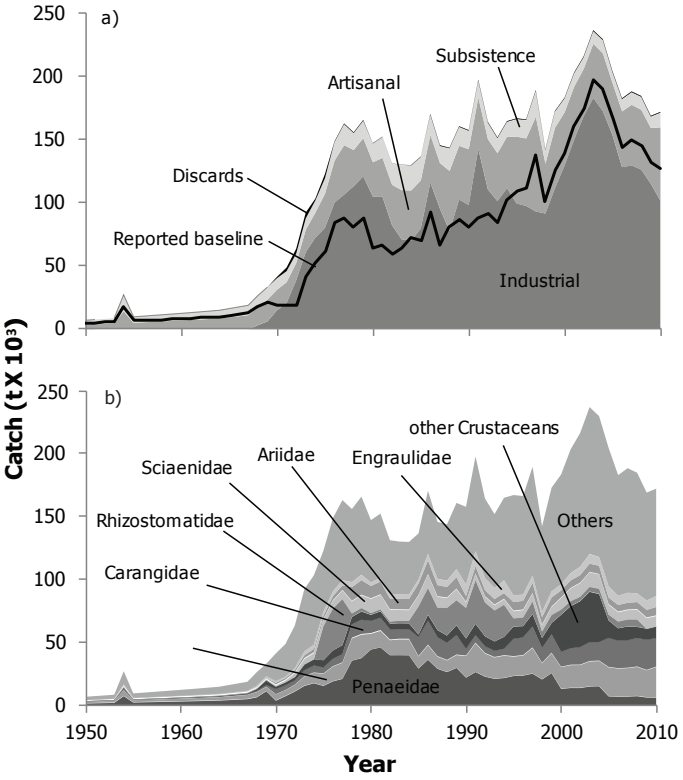

Figure 3. Sarawak reconstructed catches for 1950-2010, a) by sector. Recreational catches are not visible. The solid line represents reported landings; b) by major taxonomic groups. "Others" represents 58 additional families and 3 higher taxonomic groups.

decreasing amount of crustaceans through time. The proportion of small pelagics increased gradually in the past 20 years back to pre-commercial fisheries level, while the proportion of demersals increased overall. Penaeidae dominates the catch with 997,000 t (14.9%) of the total reconstructed catch for Sarawak (Figure 3b). Other important contributors to Sarawak's catch include Scombridae (9.9%), Carangidae (7.6%), other crustaceans (6.5%), Rhizostomatidae (6.4%), Sciaenidae (4.6%), Ariidae (3.9%), and Engraulidae (3.6%; Figure 3b).

Sabah

Teh *et al.* (2009) reported that Sabah's reconstructed catch totalled 13.7 million t from 1950-2006, which was 3.4 times the reported landings. We extended Sabah reconstructed catches to 2010 by tracking the year on year change in national marine catch landings, which declined an average of 4% from 2007-2010. In addition, we allocated a portion of total Malaysian marine recreational catch to Sabah based on Sabah's percentage contribution to Malaysia's total annual reported landings from 1970-2010. This resulted in reconstructed total catches of 15.8 million t for Sabah from 1950-2010, of which about 56% came from the commercial sector, 32% from the artisanal sector, 11% from the subsistence sector, and 0.1% from the recreational sector. Within these catches 978,500 t (6.2%) were discards. The major family groups in Sabah's total catch were Carangidae (15.0%), Scombridae (14.7%), Lutjanidae (9.2%), Clupeidae (4.3%), and Serranidae (4.1%).

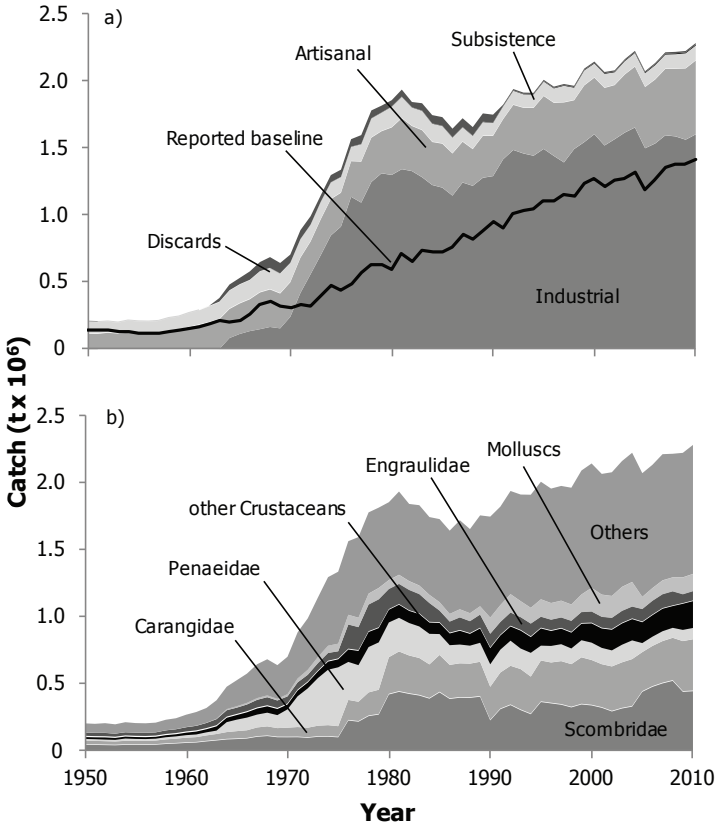

Figure 4. Malaysia reconstructed catches for 1950-2010 (Peninsular Malaysia, Sarawak and Sabah combined) a) by sector. The solid line represents reported landings; b) by major taxonomic groups. "Others" represents 63 additional families and 3 higher taxonomic groups.

Malaysia

We estimated total reconstructed catch for Malaysia by summing reconstructed catches of Peninsular Malaysia and Sarawak, as well as of Sabah (see Teh *et al.* 2009). The total reconstructed catch for entire Malaysia totalled 80.9 million t over the period 1950-2010, compared to FAO reported landings (within the EEZ) of 40.6 million t (Figure 4a). Thus, total reconstructed catches were 99% higher over the entire time period.

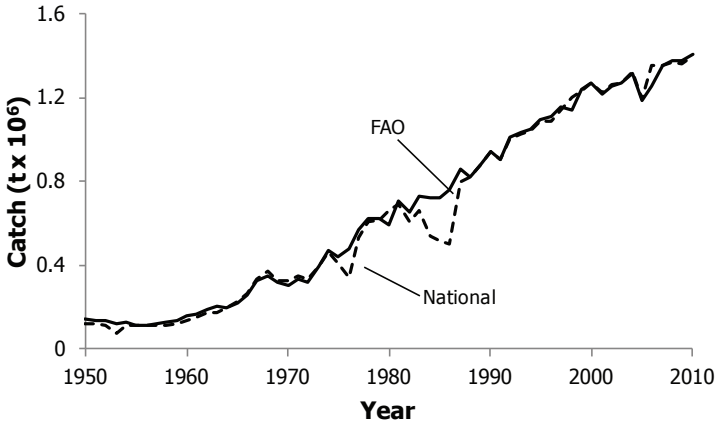

Figure 5. Malaysian marine landings reported by FAO (portion within the EEZ) compared to national statistics.Total reconstructed catch for Malaysia by EEZ area, 1950-2010.

Reconstructed catches were on average 106% higher than the reporting baseline over the period 1950-2010, with highest discrepancy occurring between the mid 1960s to mid 1980s, when reconstructed catches were on average 164% higher than that of reported catches. In comparison, total reconstructed catches were 67% higher than reported data in more recent times (2000-2010). Overall, unrecorded catch from unlicensed commercial vessels in Malaysia totalled 26.8 million t, while the unlicensed traditional sector contributed 11.6 million t of unrecorded catch. The commercial sector equated to 54.6 million t (67.5%) of the total reconstructed catch, while artisanal and subsistence portions of the traditional sector contributed 19.2 and 7.0 million t (23.8% and 8.6%), respectively, to total reconstructed catch (Figure 4a). Recreational catches contributed 118,000 t (0.2%). The amount of discards was low in Malaysia, totalling 1.8 million t from 1950-2010, or only 2.2% of the reconstructed catch (Figure 4a).

The composition of reconstructed catches in Malaysia showed an increasing amount of miscellaneous small fish and decreasing amount of crustaceans through time. Small pelagics experienced a gradual decline, while the proportion of demersals doubled. However, the increase in demersals was due mostly to a rise in low value fish such as threadfin breams (Nemipteridae) and lizardfish (Synodontidae). The overall taxonomic breakdown of Malaysia was dominated by Scombridae with 14.8 million t (18.2%). Other important contributing taxonomic groups included Carangidae (13.8%), Penaeidae (10.7%), other crustaceans (6.3%), Engraulidae (6.0%), and molluscs (5.1%; Figure 4b).

Overall, FAO statistics matched the DoF's Annual Fisheries Statistics, which reported 41 million t of catch from 1950-2010 (Figure 5). Geographically, the west coast of Peninsular Malaysia falls under FAO's Eastern Indian Ocean fishing area (Area 57) while the east coast of Peninsular Malaysia, Sabah, and Sarawak fall under the Western Central Pacific fishing area (Area 71). Fifty-two percent of FAO reported landings for Malaysia originated from the Eastern Indian Ocean fishing area and 48% from the Western Central Pacific fishing area. Overall, the west coast of Peninsular Malaysia comprised 48% of total reconstructed catch, east coast Peninsular Malaysia 24%, Sabah 20%, and Sarawak 8% (Figure 6).

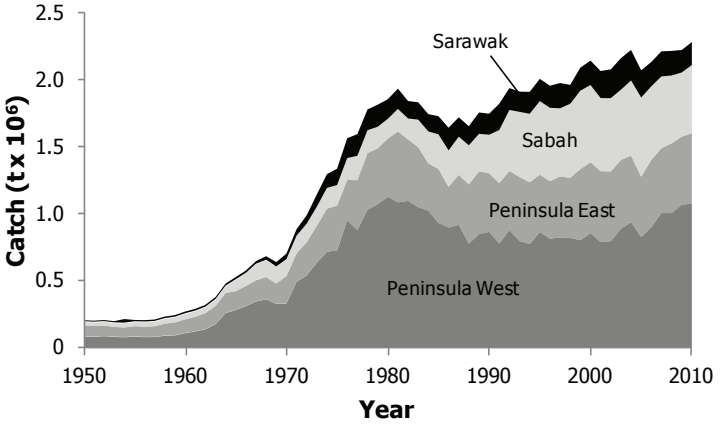

Figure 6. Total reconstructed catch for Malaysia by EEZ area, 1950-2010.

Discussion

Ensuring the sustainability of a fishery requires a good understanding of how much fish is taken from the marine ecosystem. Our study showed that this aspect of Malaysian fisheries management is not fully adequate, as reconstructed catches were estimated to be 85% higher than reported landings in Peninsular Malaysia from 1950-2010, 59% higher in Sarawak, and 99% higher in Malaysia as a whole, including Sabah. Under-reporting of catches has been a problem in the past, and persists to the present time, due mainly to the presence of unlicensed traditional fishers and unlicensed vessels.

Unlicensed trawlers accounted for the bulk of unreported catches in both Peninsular Malaysia and Sarawak. The greatest difference in reconstructed and reported catches coincided with the period of rapid trawl expansion from the mid 1960s to 1980s, when reconstructed catches were on average 164% greater than reported statistics in Peninsular Malaysia. It is thus not surprising that such serious social and economic conflict developed between traditional fishers and trawlers in this period (Goh 1976; Ooi 1990; Raduan *et al.* 2007); clearly, traditional fishers perceived the 'true' amount of catch that trawlers were taking. In fact, this situation is characteristic of how trawling has affected small-scale fisheries in neighbouring Thailand and Indonesia as well (Panayotou 1980; Bailey 1997).

Similarly, Sarawak reconstructed catches were highest in the period 1970-1983, when they were 120% higher than reported landings. Between 1968 and 1981, when commercial exploitation of prawns was just beginning until its peak and subsequent decline, the number of licensed trawlers increased from 20 to over 1,000 vessels, and prawn landings increased from 2,840 t to 18,480 t (bin Rajali 1994). It is likely that uncontrolled fishing effort driven by unlicensed trawlers contributed to the rapid decline in prawn stocks during this period in Sarawak. Accurately estimating the true magnitude of fishing effort is all the more urgent today given the sharp decline in Sarawak catch landings since 2003, despite increased numbers of licensed fishers and fishing vessels. This indicates that inshore fisheries resources may be reaching a point of exhaustion, and warrant stringent management of all sources of fishing effort.

The traditional fishing sector plays an important role in supporting food security and livelihoods for Malaysia's rural coastal communities (Firth 1966; Yahaya and Wells 1980), and our reconstruction emphasised this point. First, we showed that from 1950-2010, an average of 73% and 62% more fishers may have been involved in small-scale fishing in Peninsular Malaysia and Sarawak, respectively. Fishing is still seen as a fall-back occupation. For instance, many people who lost their jobs during the 1997 economic crisis returned to their fishing villages to fish (Anon. 2008). Second, we provided perhaps the first quantification of subsistence fish catch in Malaysia, as the DoF does not keep track of subsistence fish landings. We estimated that from 1950-2010, a total of 4.5 million t and 642,000 t of fish were caught for subsistence in Peninsular Malaysia and Sarawak, respectively. Although this amount is not high compared to commercial catches, the social contribution of subsistence fisheries is significant, as the increasing proportional catch of 'trash fish' has raised concerns about the capacity of fisheries to support food security in Malaysia (Mohammad Arriff *et al.* 2011). Even in 1951, demand for fish in Sarawak already exceeded local supply (Porritt 1997), and Malaysia is now a net importer of fish.

Estimated discards from the mid-1960s to 2010 amounted to 808,800 t in Peninsular Malaysia, and 28,700 t in Sarawak. Discarding does not appear to be a big issue for Malaysia's fisheries because there was historically, and presently, a use for 'trash fish' as animal feed (Kesteven 1949), or for processing into fish balls, crackers, and fish cakes (Pauly 1996). Since the late 1970s, increasing demand for fishmeal and 'trash fish' to support aquaculture and marine cage culture resulted in a ready market for trawler by-catch. Despite minimal wastage of by-catch, government policies aimed at promoting aquaculture as a means of fulfilling Malaysia's food security requirements should nevertheless consider the ecosystem consequences of creating demand for trawler by-catch.

The proportion of 'trash fish' in Sarawak's reported landings is close to half that of Peninsular Malaysia's. This lower value may be because the average proportion of 'mixed fish' landed in Sarawak from the period 1976-2010 was almost equal to the proportion of 'trash fish'. In contrast, 'mixed fish' and 'trash fish' made up on average 4% and 30% of landings in Peninsular Malaysia, respectively. Mixed fish include species that are naturally too small to be of commercial value but are suitable for human consumption. In the period 1968-1975, the average proportion

of 'mixed fish' in Sarawak's reported landings was 11% compared to 9% for 'trash fish'. The presence of more 'mixed fish' in Sarawak's catch may explain the significantly lower quantity of discards in the reconstructed catch.

We provided the first attempt at estimating Malaysian marine recreational catches. Although admittedly rough, our estimate of 103,400 t since 1970 (for Peninsular Malaysia and Sarawak only) can only be improved upon if monitoring of Malaysia's marine recreational sector begins. The need for some baseline information on recreational fishing is even more important given that it was targeted as an activity for tourism development (Omar *et al.* 1992; Tan 2003).

The contribution of this study is that it is the first to piece together information from multiple sources of literature on Malaysia's traditional and commercial fishing sectors to produce a time series of marine fish catches from 1950 to the present. In doing so, we quantified the extent of unlicensed fishing in Malaysia, which, despite being a widely acknowledged problem, has not been appropriately addressed to date. This under-reporting is passed to international organizations such as the FAO, as we found that, on average, FAO statistics matched fairly closely to national reported fisheries statistics for 1950-2010.

The DoF attempts to capture unlicensed and inactive vessels in its frame surveys, which estimate the number of operating vessels (Stobutzki *et al.* 2006). Nevertheless, it is not clear to what extent these estimates are used to inform fisheries management. In any case, we based our estimates of unlicensed traditional fishers and trawlers on reported data so as to avoid potentially double counting. What is apparent is that a clearly defined and consistent method for quantifying the unlicensed fishing sector has to be implemented in the future. On the whole, our reconstructed catch estimate may still be considered conservative because we did not account for IUU fishing by foreign fleets, which was reportedly a common occurrence in the past (Yahaya 1988), and still continues in the present time (Anon. 2008).

Fisheries management in Malaysia has tended to be reactionary (Abdul Majid 1985), resulting in policies that were 'too little, too late' to benefit overexploited stocks. This study is a first attempt at filling knowledge gaps and has provided the baseline information that government agencies need to engage in more proactive and future oriented fisheries management in Malaysia.

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Appendix Table A1. Reported landings and reconstructed total catches for Peninsular Malaysia and Sarawak, 1950-2010.

Year	Peninsular Malaysia		Sarawak	
	Reported landings	Reconstructed total catch	Reported landings	Reconstructed total catch
1950	139,866	168,000	4,356	7,000
1951	132,271	164,000	4,719	7,000
1952	131,189	167,000	5,082	8,000
1953	116,082	156,000	5,445	9,000
1954	107,373	152,000	17,424	27,000
1955	106,884	162,000	6,171	10,000
1956	108,582	158,000	6,534	10,000
1957	108,876	161,000	6,897	11,000
1958	122,075	180,000	7,260	11,000
1959	128,270	189,000	7,623	12,000
1960	146,074	213,000	7,986	12,000
1961	158,371	231,000	8,349	13,000
1962	177,961	259,000	8,712	14,000
1963	195,957	313,000	9,075	14,000
1964	189,263	409,000	9,438	15,000
1965	177,548	423,000	10,499	16,000
1966	207,579	462,000	11,561	17,000
1967	257,762	504,000	12,622	19,000
1968	286,622	529,000	17,870	26,000
1969	255,263	480,000	20,646	33,000
1970	249,917	535,000	18,318	41,000
1971	277,027	704,000	18,573	49,000
1972	268,794	789,000	18,896	64,000
1973	320,399	910,000	40,992	92,000
1974	383,723	1,038,000	51,853	103,000
1975	343,281	1,061,000	61,976	123,000
1976	357,836	1,253,000	84,466	149,000
1977	441,008	1,251,000	88,034	163,000
1978	498,992	1,453,000	80,260	156,000
1979	492,112	1,488,000	87,351	166,000
1980	489,655	1,560,000	64,456	147,000
1981	593,330	1,614,000	66,449	152,000
1982	552,237	1,555,000	58,902	131,000
1983	615,291	1,497,000	63,647	130,000
1984	582,542	1,377,000	72,008	130,000
1985	590,628	1,334,000	70,133	136,000
1986	602,939	1,201,000	92,722	170,000
1987	724,237	1,290,000	66,464	146,000
1988	691,183	1,219,000	80,700	144,000
1989	745,620	1,316,000	86,180	161,000
1990	817,613	1,303,000	80,397	158,000
1991	704,454	1,229,000	87,417	198,000
1992	768,309	1,320,000	90,887	164,000
1993	791,500	1,274,000	84,027	152,000
1994	776,148	1,235,000	102,096	165,000
1995	807,964	1,291,000	109,222	167,000
1996	798,941	1,244,000	111,313	166,000
1997	831,121	1,278,000	137,213	189,000
1998	844,058	1,269,000	101,360	142,000
1999	895,909	1,333,000	126,307	173,000
2000	921,792	1,385,000	139,367	183,000
2001	873,275	1,318,000	160,461	203,000
2002	902,696	1,316,000	174,894	216,000
2003	909,407	1,402,000	197,142	237,000
2004	934,328	1,434,000	190,433	229,000
2005	827,790	1,277,000	165,949	204,000
2006	942,765	1,402,000	143,904	183,000
2007	1,010,101	1,490,000	149,047	188,000
2008	1,044,479	1,525,000	145,313	185,000
2009	1,066,724	1,575,000	131,222	169,000
2010	1,095,013	1,601,000	126,717	172,000

Appendix Table A2. Number of unlicensed fishers and vessels in Peninsular Malaysia and Sarawak, 1950-2010.

Year	Peninsular Malaysia		Sarawak		
	Traditional fishers	Trawlers	Traditional fishers	Kotak vessels	Trawlers
1950	24,859	-	2,191	60	-
1951	25,816	-	2,321	63	-
1952	26,789	-	2,454	65	-
1953	27,780	-	2,590	68	-
1954	28,789	-	2,728	71	-
1955	33,011	-	2,870	74	-
1956	27,735	-	3,015	76	-
1957	27,441	-	3,164	79	-
1958	29,052	-	3,315	82	-
1959	28,844	-	3,469	85	-
1960	29,977	-	3,626	87	-
1961	31,129	-	3,792	90	-
1962	32,989	-	3,962	96	-
1963	35,797	-	4,135	102	-
1964	37,494	900	4,311	108	-
1965	41,381	966	4,492	114	-
1966	37,672	1,392	4,676	120	-
1967	37,278	910	4,863	126	-
1968	36,695	1,620	5,054	132	32
1969	37,775	3,541	5,249	138	95
1970	40,221	2,730	5,448	143	278
1971	39,907	12,172	5,650	125	384
1972	39,685	13,096	5,856	122	684
1973	43,657	14,326	6,065	130	746
1974	40,832	16,236	6,278	110	757
1975	41,842	15,838	6,495	111	837
1976	41,691	15,413	6,716	113	899
1977	42,785	15,704	6,940	115	1,127
1978	47,052	15,640	7,168	104	1,176
1979	46,355	15,739	7,400	83	1,275
1980	49,510	15,461	7,636	89	1,430
1981	44,291	15,117	7,757	94	1,670
1982	40,678	14,377	7,878	86	1,499
1983	38,347	13,660	8,001	96	1,496
1984	38,324	16,801	7,669	93	1,515
1985	34,994	12,474	7,328	89	1,623
1986	29,508	11,744	6,976	85	1,763
1987	29,463	11,220	6,604	81	1,607
1988	20,032	11,003	7,638	77	937
1989	23,703	10,847	8,652	72	1,021
1990	23,258	10,072	8,163	68	1,107
1991	23,531	9,728	7,430	64	1,185
1992	21,858	9,288	6,511	60	1,117
1993	15,960	8,468	5,659	56	1,050
1994	14,793	7,842	4,871	52	986
1995	18,533	7,335	4,143	48	923
1996	16,011	6,748	4,208	43	853
1997	25,153	6,274	4,259	39	785
1998	13,118	5,720	4,296	35	721
1999	25,544	5,849	4,321	31	659
2000	25,855	5,992	4,335	27	600
2001	27,705	5,941	4,221	29	541
2002	27,200	5,818	4,107	31	486
2003	29,652	5,812	3,996	33	433
2004	29,743	5,707	3,886	35	407
2005	32,992	6,218	3,777	37	380
2006	33,736	5,589	3,969	35	361
2007	34,586	5,878	4,136	32	342
2008	36,238	5,789	4,279	29	323
2009	42,602	5,868	4,401	26	303
2010	38,949	6,028	7,342	24	284

Appendix Table A3. Peninsular Malaysia reconstructed total catch by major taxonomic groups, 1950-2010.

Year	Scombridae	Carangidae	Penaeidae	Engraulidae	other Crustaceans	Loliginidae	Nemipteridae	Clupeidae	Others
1950	41,300	21,800	14,500	24,300	13,000	620	2,700	9,070	40,300
1951	40,200	21,200	14,200	23,800	12,800	620	2,600	8,830	39,700
1952	38,400	20,200	13,400	23,900	14,700	830	3,000	8,390	44,200
1953	36,600	19,300	12,800	22,400	13,300	720	2,700	8,010	40,400
1954	36,700	19,400	12,900	22,000	12,300	620	2,500	8,060	37,700
1955	39,600	20,900	13,900	23,500	12,700	620	2,600	8,690	39,300
1956	38,500	20,300	13,600	22,900	12,600	620	2,600	8,460	38,700
1957	39,600	20,900	14,000	23,400	12,500	600	2,600	8,710	38,800
1958	44,800	23,700	15,800	26,200	13,800	640	2,800	9,860	42,900
1959	47,700	25,300	16,900	27,600	14,000	620	2,900	10,510	44,000
1960	51,900	27,400	18,300	30,800	16,800	830	3,500	11,390	52,000
1961	54,300	28,600	19,000	33,200	19,600	1,060	4,000	11,890	59,400
1962	62,100	32,800	21,800	37,400	21,000	1,080	4,300	13,640	64,500
1963	68,700	36,000	23,900	44,300	29,600	1,790	5,900	14,950	87,400
1964	75,800	42,000	72,500	46,900	30,600	1,670	8,300	17,390	114,000
1965	73,900	41,400	82,500	46,100	31,100	1,720	8,900	17,130	120,400
1966	76,300	42,900	90,700	49,300	35,900	2,120	10,100	17,730	136,600
1967	85,900	47,800	90,800	55,900	40,800	2,460	10,900	19,720	149,300
1968	90,700	50,400	95,400	58,800	42,600	2,540	11,400	20,840	155,900
1969	83,300	46,300	85,700	53,700	38,400	2,270	10,300	19,120	140,500
1970	81,600	47,400	133,000	51,200	30,700	2,050	12,000	19,500	157,100
1971	82,000	51,600	222,500	52,300	37,100	2,410	17,500	21,080	217,600
1972	76,900	51,900	282,600	48,600	37,500	2,320	20,400	21,070	247,300
1973	82,200	57,100	339,800	52,000	41,800	2,570	24,000	23,160	287,700
1974	81,000	58,800	395,700	54,800	52,000	3,380	28,500	23,730	340,600
1975	74,800	57,000	423,400	50,500	50,400	3,210	29,500	22,930	349,600
1976	197,500	124,700	263,500	177,800	82,300	42,190	31,900	27,050	305,900
1977	186,200	117,900	250,700	168,600	95,000	39,720	31,600	25,600	335,600
1978	222,500	141,600	301,500	197,100	102,400	46,780	36,100	30,730	373,900
1979	233,600	149,600	314,600	206,600	96,300	49,210	37,100	32,410	368,300
1980	391,200	245,000	213,500	149,400	85,700	37,590	45,100	68,640	324,000
1981	407,500	265,100	203,100	149,700	88,100	39,120	48,100	72,750	340,500
1982	393,400	252,600	200,500	150,500	81,500	38,040	46,700	71,650	319,600
1983	375,200	241,400	191,900	142,400	82,500	36,330	44,700	67,580	315,500
1984	347,000	212,500	183,400	138,600	73,100	34,090	40,300	59,350	288,300
1985	393,900	226,400	121,200	84,900	74,000	38,420	33,800	48,290	312,500
1986	340,700	195,400	104,800	78,900	75,400	34,050	31,100	41,650	298,900
1987	351,100	200,200	104,800	90,200	89,800	36,870	34,800	42,900	339,800
1988	347,300	197,900	100,800	85,200	74,300	36,280	32,900	42,630	301,800
1989	357,500	203,600	105,500	93,100	91,500	37,910	35,800	43,710	347,000
1990	172,200	202,900	139,300	93,100	104,600	81,340	68,600	39,230	401,500
1991	168,400	209,000	132,500	84,500	87,600	80,330	67,000	39,040	360,900
1992	185,600	221,400	151,200	90,500	89,300	87,610	71,800	42,650	379,700
1993	173,700	219,200	134,300	87,400	91,000	83,240	69,800	40,340	374,900
1994	167,100	206,300	129,700	86,000	91,500	79,620	67,300	38,320	369,400
1995	254,000	220,800	86,000	77,800	91,700	62,310	69,500	41,950	387,400
1996	239,400	218,200	79,800	74,800	87,800	60,500	68,000	42,080	373,000
1997	250,600	226,200	83,000	73,400	90,000	61,030	70,500	43,880	379,400
1998	232,500	223,100	76,500	79,300	93,100	62,040	69,500	43,600	389,100
1999	246,500	243,600	80,400	78,200	95,700	64,500	73,800	49,110	401,600
2000	239,600	235,600	95,600	80,100	96,300	99,250	59,700	33,660	445,100
2001	225,400	225,200	88,400	77,000	94,500	91,440	57,300	32,020	426,700
2002	219,200	221,600	86,900	78,000	98,700	90,830	55,900	31,520	433,200
2003	242,200	227,100	98,400	82,600	100,400	101,050	60,100	32,870	457,600
2004	251,600	229,400	104,300	83,300	100,600	104,700	61,000	33,520	465,700
2005	357,200	159,000	39,500	85,600	121,200	46,170	52,100	17,830	398,000
2006	397,800	173,500	42,100	96,900	130,700	49,190	58,300	19,970	433,500
2007	426,200	189,000	47,700	97,000	138,200	54,750	60,100	20,640	456,000
2008	446,300	196,700	49,100	100,000	135,400	55,390	62,800	22,300	457,500
2009	368,700	258,100	60,500	60,400	168,900	75,150	68,600	34,370	480,700
2010	367,500	263,100	59,800	62,600	172,700	76,920	68,600	35,560	493,800

Appendix Table A4. Sarawak reconstructed total catch by major taxonomic groups, 1950-2010.

Year	Penaeidae	Scombridae	Carangidae	Crustacea	Rhizostomatidae	Sciaenidae	Ariidae	Engraulidae	Others
1950	2,010	1,110	370	280	-	199	35	326	2,610
1951	2,160	1,190	390	300	-	215	37	351	2,810
1952	2,310	1,280	420	320	-	230	40	376	3,010
1953	2,470	1,360	450	340	-	245	43	401	3,220
1954	7,880	4,340	1,430	1,080	-	782	136	1,279	10,260
1955	2,780	1,530	510	380	-	277	48	452	3,620
1956	2,940	1,620	540	410	-	292	51	478	3,830
1957	3,100	1,710	560	430	-	308	54	504	4,040
1958	3,270	1,800	590	450	-	324	56	530	4,250
1959	3,430	1,890	620	470	-	341	59	557	4,460
1960	3,590	1,980	650	490	-	357	62	583	4,680
1961	3,760	2,070	680	520	-	374	65	611	4,900
1962	3,940	2,170	720	540	-	391	68	639	5,130
1963	4,120	2,270	750	570	-	409	71	669	5,360
1964	4,300	2,370	780	590	-	427	74	698	5,600
1965	4,680	2,580	850	640	-	465	81	760	6,090
1966	5,060	2,790	920	700	-	503	88	822	6,590
1967	5,440	3,000	990	750	-	541	94	884	7,090
1968	6,920	3,880	1,270	1,530	-	687	120	1,428	10,640
1969	11,780	3,140	1,710	3,820	-	739	319	1,815	9,840
1970	4,230	4,760	4,490	1,940	-	1,030	1,282	1,638	21,920
1971	7,750	4,500	4,120	2,360	2	1,506	1,264	1,413	25,760
1972	11,490	5,110	3,700	2,680	-	3,183	1,670	2,109	33,590
1973	15,980	7,220	5,170	4,590	-	4,424	2,321	3,387	49,150
1974	18,090	8,140	5,840	4,930	-	5,010	2,628	3,696	54,910
1975	15,990	9,450	5,080	5,670	27,050	5,185	2,614	3,347	48,320
1976	19,620	11,560	6,240	6,520	33,190	6,361	3,208	3,869	58,060
1977	21,580	12,680	6,840	7,050	36,510	6,996	3,528	4,193	63,470
1978	36,140	17,690	10,880	5,820	2,770	9,678	10,919	3,997	57,910
1979	38,120	18,700	11,480	6,420	2,930	10,210	11,519	4,363	61,880
1980	44,990	12,530	9,830	4,780	1,510	11,377	9,785	2,767	49,450
1981	46,690	13,220	10,020	5,010	1,700	11,524	10,084	3,044	50,840
1982	40,470	11,920	8,330	4,450	1,750	9,395	8,592	3,002	43,130
1983	40,510	12,530	7,860	4,590	2,110	8,618	8,403	3,484	41,880
1984	40,420	12,560	7,810	4,590	2,140	8,541	8,369	3,512	41,730
1985	29,820	9,480	15,190	2,010	22,330	8,741	9,125	3,262	36,450
1986	36,810	11,540	18,970	4,860	21,230	10,861	10,901	5,142	50,000
1987	29,650	9,540	15,300	5,540	17,880	8,741	8,827	5,023	45,080
1988	27,010	9,190	13,820	5,720	21,990	7,897	8,366	5,059	44,540
1989	30,330	10,140	15,670	7,780	19,860	8,923	9,119	6,289	52,530
1990	22,590	17,080	5,530	8,200	24,340	4,556	4,438	9,178	61,640
1991	27,060	22,790	6,180	8,960	34,560	5,199	5,907	11,822	75,030
1992	23,370	18,360	5,580	7,830	26,870	4,632	4,776	9,553	63,090
1993	21,650	16,880	5,200	7,360	24,580	4,307	4,391	8,832	58,550
1994	22,260	17,680	5,380	9,360	25,500	4,418	4,539	10,084	65,460
1995	23,890	15,330	13,930	9,680	6,580	5,806	6,711	5,405	79,540
1996	24,190	15,840	14,280	8,870	6,990	5,888	6,903	5,002	78,130
1997	25,770	20,330	16,790	9,850	10,060	6,362	8,216	5,721	86,140
1998	21,150	12,810	12,010	7,770	5,310	5,122	5,770	4,325	67,840
1999	26,230	15,670	14,810	8,950	6,470	6,348	7,120	4,993	82,120
2000	13,660	17,110	12,130	29,290	4,150	9,268	5,615	4,740	87,180
2001	14,320	18,070	13,330	33,250	4,020	10,224	5,940	5,777	98,090
2002	14,310	18,160	14,150	36,290	3,570	10,914	6,004	6,652	105,960
2003	15,510	19,810	15,220	39,840	3,950	11,700	6,496	7,617	116,470
2004	15,720	19,930	14,960	37,990	4,250	11,482	6,546	6,854	111,680
2005	7,650	23,010	23,290	13,750	4,680	8,057	5,101	9,088	109,640
2006	7,440	22,180	22,030	9,840	5,390	7,529	5,251	7,313	95,710
2007	7,500	22,510	22,050	10,840	5,680	7,491	5,372	7,963	98,760
2008	7,810	23,170	22,860	8,740	5,990	7,779	5,625	6,975	95,610
2009	6,750	21,510	24,150	8,730	-	8,587	5,988	7,616	85,510
2010	6,690	24,190	22,890	9,230	-	8,385	6,671	8,786	85,060

Appendix Table A5. Breakdown of miscellaneous small fish (trash fish). SourceMatsushita and Ali (1997).

FAO fish category	% of catch
Cardinal fishes nei	12
Stolephorus anchovies nei	12
Marine crustaceans nei	12
Marine crabs nei	11
Lizardfishes nei	10
Ponyfishes	8
Largehead hairtail	6
Threadfin breams nei	2
Grunts, sweetlips nei	3
Indian mackerels nei	3
Terapon perches nei	3
Flatfishes nei	2
Puffers nei	2
Various squids nei	2
Bigeyes nei	2
Gobies nei	1
Elongate ilisha	1
Spinefeet nei	1
Cuttlefish, bobtail squids nei	1
River eels nei	1
Others	7