Fisheries Centre

The University of British Columbia

Working Paper Series

Working Paper #2015 - 02

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Year: 2015

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Australia: reconstructing estimates of total fisheries removals 1950-2010

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Abstract

Australia's commercial fisheries are of significant value to the Australian economy, with the twenty Commonwealth fisheries alone worth around AUD$320 million in production value. The fisheries statistics reported by the Australian government to the Food and Agriculture Organization of the United Nations (FAO) typically consist of commercial landings from the national Commonwealth fisheries and the state fisheries. While reporting from this sector is generally robust in terms of accuracy and taxonomic precision, these statistics do not include landings from the recreational or indigenous fisheries. Recreational fishing is a popular pastime for Australians with the most recent National Recreational and Indigenous Fishing Survey (NRIFS) estimating a national participation rate of 19.5% in 2000. Within the coastal areas of Northern Australia, the indigenous communities comprise a significant proportion of the total population. Within these Northern states, a high participation rate in fishing activities was recorded by the NRIFS. Similarly, the indigenous communities of the Torres Strait Islands land a significant quantity of catch. Discards from state and Commonwealth commercial fisheries, which may in some cases be alive, are often in poor condition. Although Australia has relatively strong monitoring of discards and in some cases estimates discard rates, discards are not reported to the FAO. This is due to the fact that FAO data are presented as 'production' figures, i.e., landings. However, given the global trend towards ecosystem-based fisheries considerations, total catches (i.e., total removals) should be considered for reporting. This study reconstructs total marine fisheries removals from 1950 to 2010 for the Commonwealth and for each of the state fisheries as well as the territorial islands (Norfolk Island and Heard and MacDonald Islands) and the state islands (Lord Howe Island, Macquarie Island, and the Torres Strait Islands). We find that reported commercial landings match quite closely to the finer scale landings data provided to us by the Commonwealth and the state fisheries departments. However, when we consider total landings from all sectors plus discards, we find that the total removals are 15 million tonnes, which is nearly double the 8.1 million tonnes reported from the commercial sector to the FAO from 1950 to 2010. The most significant source of this difference comes from discards, which were estimated to be 4 million tonnes over this period, with an unestimated fraction that possibly survives after being caught. Total estimated indigenous and recreational catches amount to 2.3 million tonnes (16% of total catches) over this period. Overall, we highlight the need to estimate landings and discards from all fisheries sectors to better quantify total removals from the system to more accurately establish the multiple pressures on marine ecosystems, and thus manage fish sustainably.

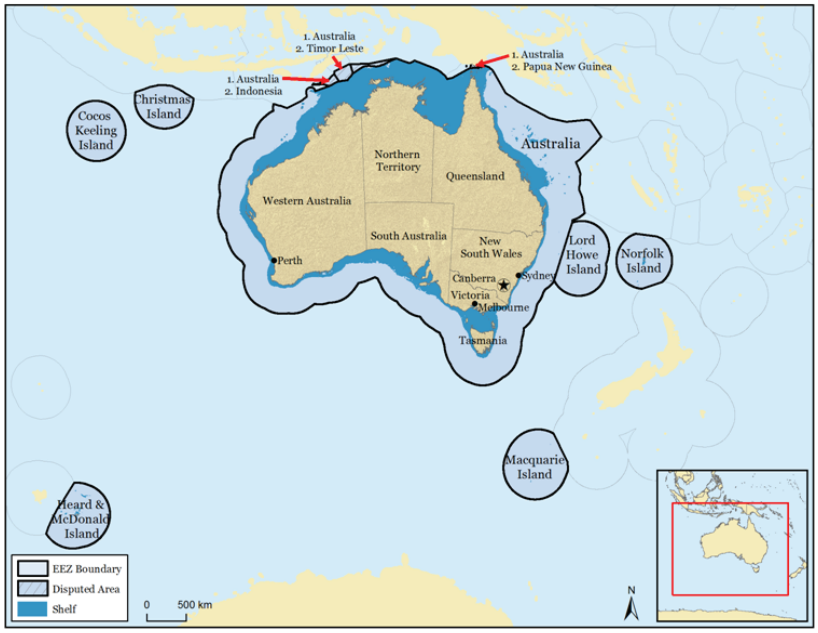

Figure 1. Australian Exclusive Economic Zones (EEZs). Note that Christmas Island and Cocos Keeling Island are not considered in the present study.

Introduction

Australia has the third largest Exclusive Economic Zone (EEZ) in the world (Figure 1), encompassing approximately 9 million km² (Kailola *et al.* 1993). There are six maritime states: New South Wales (NSW), Queensland (QLD), Western Australia (WA), South Australia (SA), Victoria (VIC), and Tasmania (TAS). Australia also has a mainland Commonwealth 'territory', the Northern Territory (NT), and four main island territories: Norfolk Island, the Heard and Macdonald Islands, Cocos (Keeling) Islands, and the Christmas Islands, all of which lack the independent data systems that states have. Additionally there are three islands, which are not considered island territories, but fall under the jurisdiction of the states: Lord Howe Island (NSW), Macquarie Island (TAS), and the Torres Strait Islands (QLD). In this report we do not present any statistics for either the Cocos (Keeling) Islands or the Christmas Islands for which catch reconstructions are already available (see Greer *et al.* 2012). Rather, in addition to data for Australia proper, we present catch data for the three state islands and the island territories of Heard and MacDonald and Norfolk Island. Macquarie Island and the Heard and MacDonald Islands have commercial fisheries, which are managed by the Australian Fisheries Management Authority (AFMA) and the Commission on the Conservation of Antarctic Marine Living Resources (CCAMLR), while Lord Howe Island and the Torres Strait Islands have significant indigenous fisheries as well as commercial prawn trawl fisheries. The island territory of Norfolk Island had an exploratory commercial fishery between 2000 and 2003 and long-term artisanal commercial and indigenous fisheries. Because Norfolk Island is reported separately in the FAO statistics, here we also present the reconstruction of the catch from this island separately from the main Australian statistics.

The waters of Australia encompass many different habitats, ranging from shallow coastal bays, to coastal and offshore coral reefs and continental shelf habitats, with temperatures varying from sub-Antarctic for the southern islands to temperate to tropical in the north. Due to this wide range of temperatures, Australia's marine fauna comprise more than 3,600 species of fish and tens of thousands of mollusc species, many of which are endemic to Australia (Kailola *et al.* 1993); (see also www.fishbase.org and www.sealifebase.org), with new species continuing to be discovered (Parsons 2011). Throughout Australia's history, these marine resources have been utilised to varying degrees by subsistence, recreational and commercial fishers. Because of the importance of the extractive uses of these resources, there is an acute recognition of the need for conservation of Australia's marine resources (Parsons 2011) and to maintain biodiversity. To this end, many marine protected areas (MPAs) have been established for biodiversity conservation since the declaration of the first Commonwealth marine reserve in 1982.

The Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) reports the Australian commercial fisheries landings to the Food and Agriculture Organization of the United Nations (FAO) annually using statistics provided by each state, the Northern Territory, and from the Commonwealth. These statistics are important for gauging landings from Australian waters relative to global landings. However, commercial landings alone cannot give a complete picture of the total removals from the system. To accurately gauge total removals, it is necessary to quantify removals from other sectors like recreational and indigenous fisheries and the amount of nonliving discards. However, while the landings from the commercial fisheries are recorded in relatively high detail with commercial logbooks and other recording measures, landings from other sectors typically do not have the same level of monitoring. Additionally, in some cases discards are only monitored in some fisheries with surveys. Therefore, here we use the best available information (e.g., surveys, reports, etc.) and some basic assumptions to estimate the total removals from Australian waters from 1950 to 2010. Accurately gauging total removals over time can inform fisheries management, policy makers, and the general public, the ultimate 'owners' of the resources. Certainly, having a more complete picture of total removals may help guide efforts to inform for the sustainable extraction of resources and the development of methods to preserve marine biodiversity.

Fishing sectors

Commercial

Australia's commercial fisheries can be split into two categories: artisanal (small-scale) and industrial (large-scale) fishing. Commercial fisheries started with the British settlement in the 1700s, with marine mammals, turtles, oysters, prawns and lobsters targeted initially. The introduction of new fishing methods in the early 20th century expanded the number and type of species caught. For example, steam trawlers owned by the New South Wales (NSW) government began operating in 1915. Hook lining of school sharks began off South Australia in the 1920s and Danish seiners were introduced in 1936 to fish for Australian salmon (*Arripis* spp.) and southern bluefin tuna (*Thunnus maccoyii*) in the southeast (Kailola *et al.* 1993). Up to the end of World War II, sea mullet (*Mugil cephalus*) and barracouta (*Thyrsites atun*) were amongst the most commonly caught species. In the 1960s, many of the prawn, abalone (Haliotidae), and saucer scallop (*Amusium* spp.) fisheries developed. Trawling for gemfish (*Rexea solandri*) and purse seining for southern bluefin tuna (*Thunnus maccoyii*) began in the 1970s. Between 1980 and 1990 landings tripled, and many deepwater fisheries began targeting species such as orange roughy (*Hoplostethus atlanticus*), blue grenadier (*Macruronus novaezelandiae*), and oreos (*Pseudocyttus* spp.). By the 1990s, many fishery resources were fully developed with at least 200 fish species and 60 species of crustaceans commonly targeted by the commercial fisheries (Kailola *et al.* 1993).

Despite the large size of its EEZ, Australia ranks 52nd in the world in terms of the weight of fish landed annually. Australia's fisheries and aquaculture focuses on high value export species such as lobsters, prawns, tuna, and abalone, with the commercial fisheries and the aquaculture industry worth over AUD$2 billion annually. The marine fishing industry ranks fourth amongst the country's food-based industries, employing an estimated 14,000 people (Anon. 2011a).

Australian fisheries are defined as those conducted within the Australian EEZ, which extends 200 nm from the coastline (or to the midline between neighbouring country claims). Prior to World War II, responsibility for commercial fisheries belonged exclusively to state governments. However in 1946, the present Commonwealth fisheries were established (MacInnes 1950), which simplified jurisdiction by implementing boundaries to dictate management responsibility to the state, territory and/or Commonwealth governments. Each state or territory has responsibility for fisheries that operate predominantly within three nm from the coastline. The Commonwealth has jurisdiction for fisheries that lie between three and 200 nm from the coastline. When a particular fishery falls within a Commonwealth and a state jurisdiction, an Offshore Constitutional Settlement (OCS) arrangement is generally developed and responsibility is passed to one jurisdiction (www.daff.gov.au). State and Commonwealth commercial fisheries operate in FAO statistical (or 'fishing') areas 71 (Pacific Western Central); 57 (Eastern Indian Ocean); 81 (Pacific Southwest); and 58 (Antarctic and Southern Indian Ocean).

Recreational

Recreational fishing is a popular pastime for Australians. The most recent National Recreational and Indigenous Fishing Survey (NRIFS) estimated a national participation rate of 19.5% in 2000, with recreational fishing from marine waters accounting for 80% of all recreational fishing effort (Henry and Lyle 2003). Additionally, the recreational sector generates employment to a variety of businesses (Anon. 2011b). Here, it was assumed that recreational fishing effort in marine waters likely varied over the 1950-2010 period, mainly due to the growth in coastal population and evolving recreational preferences.

Historically, there has been a paucity of recreational fishing surveys in Australia, thus there is little documentation of recreational fishing effort and catch prior to the 1970s. Moreover, as available surveys were conducted by state fishery agencies, there was rarely a common approach with respect to the spatial and chronological scales of these reports and thus, national catch and effort are difficult to assess by reviewing these surveys alone (Henry and Lyle 2003). The first national recreational survey (Anon. 1984), estimated the national participation rate to be 34% in 1984. However, this survey had a rather low sample size, and the resultant participation rate should be viewed with caution.

Historically, fisheries managers assumed that catches from recreational fisheries were much lower than from commercial fisheries (Gartside *et al.* 1999). However, with an increase in the number of fishers from 1970 to 1990, and the resulting establishment of more frequent state-wide recreational surveys, it became apparent that recreational catches were higher than previously thought. For example, Steffe and Chapman (2003) determined that recreational catches from the coastal lagoon Lake Macquarie were about 295 t over the survey period, while the declared commercial catches over the same period were about 274 t.

Current management of Australia's recreational fisheries is the prevue of individual state and territory governments, and is considered to represent a well-managed and enforced sector. Management is generally through input controls, but sometimes combines input and output controls, depending on the species targeted. Fishers are often required to adhere to daily bag and possession limits, minimum and/or maximum fish size limits, restrictions on the type, size, and quantity of fishing gear, and seasonal or area fishing closures (Henry and Lyle 2003). The states and territories also regulate fishing licences and provisions.

The NRIFS (Henry and Lyle 2003), conducted in 2000-2001 in response to the substantial increase in recreational fishers over the last few decades, was the first comprehensive national survey to examine recreational fishing in Australia. As such, it is the foundation on which our estimates of recreational catches from 1950 to 2010 are based. Amongst its many objectives, the survey was to assess recreational fishing pressure by quantifying catch, effort, and participation rates. Also, the authors estimated the total numbers of fish caught per species or family, in addition to an estimate of the total tonnage of primary finfish species, resulting in an estimated catch of 27,000 t (Henry and Lyle 2003).

Indigenous catches

The indigenous people of Australia were the first settlers of the continent prior to the arrival of Europeans in the 18th century. They were hunter-gatherers who adapted particularly well to the diversity of Australian habitats, which range from tropical forests to coastal and riverine environments to deserts (Gracey 2000). Those aboriginals inhabiting coastal areas were the first to exploit marine resources, which provided a significant component of their diet (Hobson and Collier 1984; Gracey 2000; Gerritsen 2001; Roberts and Schilling 2010). Indeed, the profound connection of Aboriginal people to both the sea and land is reflected in the managed use of these resources throughout time (Benzaken *et al.* 1997) and often it is difficult to disentangle, when examining their fishing practice, what can be considered a cultural expression from its subsistence purpose (Roberts and Schilling 2010).

To date, the indigenous fishing survey of Northern Australia (Coleman *et al.* 2003) featured within the NRIFS, is the most comprehensive study of indigenous fishing effort in Australia. Therefore, we rely heavily on this survey as a foundation for our estimates of indigenous catches from 1950 to 2010. The survey focuses on indigenous communities within Queensland, Western Australia and the Northern Territories and their fishing practices from June 2000 to November 2001. The survey indicates that approximately 37,300 persons aged five or over fished in the surveyed states, representing a 91.7% participation rate. Line fishing was the most popular method of fishing, while hand collection, spear and net methods were also popular (Coleman *et al.* 2003).

Consumption rates of seafood and fishing effort may vary regionally and through time, depending on the size of the population living close to the coast and the hunting traditions of particular tribes. However, consumption rates have only been estimated in different regions at different time periods. For example, Coleman *et al.* (2003) reported substantial differences in the patterns of fishing effort between regions, with the proportion of saltwater-based fishing effort ranging from 45% in Western Australia to 90% in Queensland. Meehan (1982) and Henry and Lyle (2003) estimated seafood consumption in the Northern Territories contributed between 30 and 40% of caloric intake by coastal communities. Tasmanian historical data provides little reference to patterns in indigenous seafood consumption Hiatt (1967). However, we assume that it may have been (and continues to be) relatively low due to the small indigenous population that resides in the coastal regions of Tasmania. Consumption rates of marine resources in NSW have not been estimated. However, some studies have shown that the Murray/Darling river basin was an important resource for freshwater fish (O'Dea *et al.* 1991). Consumption rates in Victoria and South Australia were assumed to be low.

Indigenous fishing is a recognized sector alongside commercial and recreational fishing in Australia (Schnierer 2011). Therefore, each state and territory has special provisions for indigenous fishing. However, in some cases, indigenous fishers, are required to adhere to general state and territory fishing rules (Coleman *et al.* 2003); (www.alrc.gov.au).

Regional sectors

The Torres Strait Islands

Part of the Australian state of Queensland, the Torres Strait is a shallow continental shelf sandwiched between the northern end of Australia and Papua New Guinea, with average depths of 30-50 m in the east and 10-15 m in the west, and covering an area of around 60,000 km^2. The archipelago consists of approximately one hundred islands, many of which are uninhabited. While the Torres Strait Islanders are distinct from the Aboriginals of the mainland, migration of Torres Strait Islanders to and from the mainland is common (Busilacchi 2008) and the island population can fluctuate over short time periods. The 2012 population of the Torres Strait was approximately 6,000 people (www.abs.gov.au).

In the Torres Strait region, indigenous fishing rights have been recognised as part of the native title rights of Aboriginal and Torres Strait Islander peoples (*Native Title Act 1993*). Additionally, the Torres Strait Treaty, ratified in 1985, has a similar aim to "acknowledge and protect the traditional way of life and livelihood including traditional fishing" (*Torres Strait Treaty 1984*). Notably, the Torres Strait Treaty of 1984 also ensures that indigenous inhabitants take measures to protect the marine environment (Article 13) and to identify and protect flora and fauna that may otherwise be threatened with extinction (Article 14).

The Torres Strait Islanders depend heavily on the surrounding marine resources and consumption rates of marine species are considered to be among the highest in the world (Johannes and MacFarlane 1991). For many generations, turtles (*Eretmochelys imbricata* and *Chelonia mydas*) and dugong (*Dugong dugong*) have been hunted, and still represent a substantial part of the diet, especially during celebratory feasts (Johannes and MacFarlane 1991). This resulted in dwindling numbers of dugong, particularly throughout the 1970s and 1980s when the hunt intensified (Johannes and MacFarlane 1991). However, management of dugong and turtle populations has improved, with greater enforcement and control strategies, such as the Torres Strait Regional Authority (TSRA) dugong and marine turtle management project.

Consumption rates of seafood vary among the Islands of the archipelago. Poiner and Harris (1991) report a daily consumption rate of 191-214 g·person^{-1}·day^{-1} (i.e., 69-78 kg·person^{-1}·year^{-1}, including fish, turtle and dugong) on Yorke Island, while consumption rates on Mabuig Island can be as high as 450 g·person^{-1}·day^{-1}, i.e., 164 kg·person^{-1}·year^{-1} (Nietschmann 1982), one of the highest in the world, and much higher than indigenous seafood consumption on the Australian mainland.

Although there is a paucity of information regarding changes in consumption rates and fishing effort over time on the Torres Strait Islands, it has been estimated that over the last decade, with increased access to modern fishing techniques and the ability to freeze and transport fish to the mainland (a common practice among residents), there has been an increase in fishing effort and landings (Busilacchi 2008). Without information on commercial sales of fish species, we assume here that all of the catch from the Torres Strait Islands can be considered under a generalised 'subsistence' heading, but may include local or regional sale or barter/trade.

Lord Howe Island

The island of Lord Howe lies 700 km northeast of Sydney, in the Northwest of FAO area 81 (Southwestern Pacific). In 1982, the island was listed as a UNESCO World Heritage Area due to the high biodiversity of tropical and sub-tropical fauna. Additionally, in 2000, the Commonwealth waters between 2 and 12 nm were proclaimed a marine park under the *National Parks and Wildlife Conservation Act* 1975 (Anon. 2002a). Because landings from Lord Howe Island are not presented together with the state landings from NSW, we discuss the catches from this small island separately. There are no Commonwealth fisheries within the waters of Lord Howe. However, commercial fisheries

for tuna and billfish and the southern squid jig fishery are found in adjacent waters. Additionally, some of the island residents partake in subsistence and recreational fishing, though it is estimated that no more than 20t a year is taken from the waters by the islanders (Anon. 2002a). Hand lining methods are used to target yellowtail amberjack (*Seriola lalandi*) and yellowfin tuna (*Thunnus albacares*). Other species targeted by the island community include crimson jobfish (*Pristopomoides filamentosus*), redfish (*Centroberyx affinis*) and white trevally (*Pseudocaranx dentex*).

Sometimes excess catches from subsistence or recreational fishing may be sold. This is likely a very small proportion of overall catch. This particular situation is more common when there is a large tourist industry, such as on Lord Howe Island and thus we estimate this proportion and assigned it to a category called 'unreported artisanal'.

Discards in Australia's main industrial trawl fisheries

There are five major industrial trawl fisheries in Australia: Torres Strait prawn, northern prawn, Commonwealth trawl, NSW ocean trawl, and the Queensland trawl fisheries, and they jointly generate the highest amounts of discarded bycatch (Koopman *et al.* 2009). In response, the Commonwealth and state fisheries have made substantial efforts to reduce bycatch and manage discards. In an assessment of Australia's fisheries, Kelleher (2005) estimated annual discards of 123,000 t from the state and Commonwealth fisheries, with the majority of discards originating from the prawn trawl fisheries. There are significant numbers of juveniles and sub-adults of commercially important species among the discards (Kennelly *et al.* 1998; Broadhurst 2000) and a high mortality rate among discarded species, which may affect the recruitment and biomass of stocks of other fisheries (Broadhurst 2000). However, over the last decade, all fisheries have issued bycatch reduction plans (Tonks *et al.* 2008). It is important to note that we assume here that all discards are released dead, but there is likely a proportion that survives release and our estimate of fisheries-specific discards may be overestimated in these cases. On the other hand, as we do not estimate discards for all fisheries and gears in Australia, our overall estimates of discards in Australia may still be an underestimate.

Torres Strait prawn fishery

The Torres Strait prawn fishery (TSPF) operates within FAO area 71 (Western Central Pacific) and is the most important commercial fishery in the Torres Strait region, with about 70 actively operating vessels (Gillet 2008). The main target species is the brown tiger prawn (*Penaeus esculentus*) with secondary catches of blue endeavour prawn (*Metapenaeus edneadvouri*) and red spot king prawn (*Melicertus longistylus*), which are caught with otter trawl (Woodhams *et al.* 2010). On average, annual catches are approximately 1,000 to 1,500 t·year^{-1} (Harris and Poiner 1990; Woodhams *et al.* 2010) with a value of AUD$19.2 million for the 2002/2003 season (Gillet 2008). Management of the fishery is through a series of input controls such as limited entry, gear restrictions, pro rata allocation of effort to operators, and seasonal and permanent area closures (Woodhams *et al.* 2010).

Harris and Poiner (1990) estimated discards of approximately 7,000 t·year^{-1} in 1985 and 5000 t in 1986, while Kelleher (2005) estimated discards from the TSPF to be nearly 6000 t·year^{-1}. As there are many endemic and rare species associated with the tropical seabed habitats in which this fishery operates (Pitcher *et al.* 2007), assessing the impact of trawling is essential. To reduce discarding and control some of the discards, bycatch reduction devices (BRDs) have become mandatory from 2004 onwards (Woodhams *et al.* 2010).

Northern prawn fishery

The Commonwealth northern prawn fishery (NPF) operates in FAO area 71 and 57 (Eastern Indian Ocean), and has been in operation since the late 1960s. It is the most economically valuable fishery managed by the federal government, yielding an ex-vessel value of AUD$74 million in 2003 (Gillet 2008). It is a multispecies fishery, which utilizes otter trawls to target prawns. The primary target species include white banana prawn (*Fenneropenaeus merguiensis*), grooved prawn (*Penaeus semisulcatus*), and brown tiger prawn (*P. esculentus*). The banana prawn fishery operates in the eastern waters of the Gulf of Carpentaria and within the Joseph Bonaparte Gulf, while the tiger prawn fishery operates in the southern and western Gulf of Carpentaria and along the Arnhem coast (Larcombe and Perks 2010).

Current management of the fishery is through input controls such as seasonal and area closures, gear restrictions, and a limited entry regime (Larcombe and Perks 2010). The management restrictions are implemented under the 1995 Northern Prawn Fisheries Management Plan, which in turn derives its authority from the Fisheries Management Act (1991); (Gillet 2008). Previous estimates of total discards from the NPF are large. Pender *et al.* (1992) estimated 47,000 t of discards in 1988, while Kelleher (2005) estimated 42,750 t annually.

The NPF has conducted research on the environmental impacts of the fishery including bycatch issues (Larcombe and Perks 2010). In 2001, the mandatory use of BRDs was required in order to enable small bycatch species to escape. Additionally, the fishery was the first to develop a plan to mitigate bycatch, the Northern Prawn Fishery bycatch action plan (Anon. 1998b), updated in 2009.

Commonwealth trawl fishery

The commonwealth trawl sector is a component of the Southern and Eastern Scalefish and Shark Fishery (SESSF) operating in FAO area 81 and 57. Primary target species include blue-eye trevalla (*Hyperoglyphe antarctica*), blue grenadier (*Macruronus novaezelandiae*), blue warehou (*Seriolella brama*), school whiting (*Sillago flindersi*), and flathead (Platycephalidae). Fishing ranges from Sydney to southern Tasmania and west towards Cape Jervis in South Australia. The trawl sector was valued at AUD$54 million (gross value of product, GVP) in 2006.

As a Commonwealth fishery, the trawl sector of the SESSF is managed by AFMA. Current management measures range from Individual Transferable Quotas (ITQs) and mesh size limits to effort controls implemented through limits on the number of vessels permitted to operate (Koopman *et al.* 2009). The fishery catches over 350 species. However, only about 100 are of sufficient commercial value to be landed (Knuckey 2006). In 2004, it was estimated that 2,859 t (12%) of quota species were discarded out of a total quota catch of 24,181 t (Koopman *et al.* 2005). Furthermore, from a total non-quota catch of 18,426 t, 12,863 t (i.e., 70%) were discarded (Koopman *et al.* 2005). Substantial amounts of the discarded fish are small, generally discarded in poor condition, and therefore unlikely to survive (Koopman *et al.* 2009). Kelleher (2005) presents an annual discard estimate of 17,000 t. Mandatory gear requirements were implemented in 2006 to reduce bycatch and hence discards.

New South Wales oceanic trawl fishery

The ocean trawl fishery in FAO area 81 is one of the primary state fisheries in NSW (valued at AUD$20.6 million (GVP) in 2010) and consists of both prawn and fish trawling fleets. Both sectors use demersal otter trawl nets, and many of the fishers hold dual licenses for both the fish as well as prawn trawl sector of the fishery (Anon. 2007). The ocean prawn trawl fishery dates back to 1926. Trawling occurs off the north coast of NSW where the primary target species are school prawn (*Metapenaeus macleayi*), eastern king prawn (*Penaeus plebejus*), and greasyback prawn (*M. bennettae*).

The NSW Department of Primary Industries (DPI) manages the ocean trawl fishery under the Fisheries Management Act. The fishery is mainly regulated by input controls including limited entry and fishing gear restrictions and requirements. A range of output controls also exists including size limits, restrictions on catching certain species, and daily catch limits.

Kelleher (2005) estimated discard rates from the ocean prawn trawl fishery to be 88.7%, producing total discards of around 16,000 t (depending on the annual catch). Similarly, Kennelly *et al.* (1998) estimated that for a catch of 1,500 t, 16,400 t of bycatch was produced, with 81.8% or 13,500 t being discarded.

BRDs were introduced in 1999 for prawn trawl nets, which led to a decline of incidental catches (Anon. 2004).

Queensland trawl

Queensland's trawl fisheries operate in FAO Area 71, combined they are the largest of Australia's trawl fisheries with approximately 424 vessels and annual landings valued at AUS$100–150 million (average GVP). There are three main trawl fisheries, which operate within Queensland jurisdiction: the East Coast Otter Trawl Fishery, the River and Inshore Beam Trawl Fishery and the Finfish (Stout Whiting) Trawl Fishery. All three fisheries are state controlled and managed by the Queensland Department of Agriculture, Fisheries and Forestry.

The fishery covers a large geographic area, which includes areas of the continental shelf, shallow-water embayments, and parts of the Great Barrier Reef Marine Park and primarily targets tiger prawns (*Penaeus esculentus*, *P. semisulcatus* or *P. monodon*), endeavour prawns (*Metapenaeus endeavouri* and *M. ensis*), red spot king prawn (*Penaeus longistylus*), banana prawn (*Penaeus merguiensis*), greasyback prawns (*M. bennettae*), school prawns (*M. macleayi*), eastern king prawn (*Penaeus plebejus*), scallops (*Amusium balloti* and *A. pleuronectes*), stout whiting (*Sillago robusta*), and Moreton Bay bugs (*Thenus orientalis and T. indicus*).

Kelleher (2005) estimates annual discards of 35,565 t from the Queensland trawl fisheries, which represents a discard rate of 80%. It is estimated that between 500 and 1000 species are taken as bycatch in the East Coast Otter Trawl Fishery, of which about 30% are regarded as common. The remaining 70% are rare species, caught in low numbers, which presents difficulties from a monitoring perspective because such species generally occur too infrequently to detect changes in abundance at a statistically significant level (Huber 2003).

The Queensland government has recognised the necessity for a reduction in discards from the trawl fisheries and undertaken many research initiatives related to the ecological sustainability of bycatch to address the issue; by 2002 both TEDs and BRDs were mandatory in all otter trawls throughout the state (Courtney *et al.* 2007).

Methods

Quantifying landings by sector

Commercial

Commonwealth data was provided by ABARES. The responsible agencies (e.g., DPI) for each state provided landings data. The only exception was Western Australia, where data were unavailable for this study. The data varied in terms of the spatial and taxonomic resolution by state.

Data provided by the Commonwealth consisted of annual landings by species for 1990-2010 by calendar year with total catches in tonnes per species rounded to the nearest whole tonne. We used this dataset to tally the total Commonwealth catch for 1990-2010. In addition to these data, annual landings per species by gear type (line, net, trap, trawl, dive/manual collecting, and dredge) for each species with catches over 500 kg were available for 1999-2010. In order to maintain confidentiality of fisher information, no records were provided where less than five vessels contributed to the total catch value.

NSW provided annual landings and price for each species for the entirety of the state waters from 1945 to 2010 by calendar year. Data were provided by both common and scientific name per species. Catch data (t) for eastern rock lobster (1885-2010) and blacklip abalone (1960-2010) were provided separately, as these stocks are recorded on a separate database.

Queensland provided annual landings by species for 1990-2009 by 30 nautical mile grid cells by gear. Catch data for bêche-de-mer were provided in numbers per species per year, which were converted to weight using average weight data available in Kinch *et al.* (2008). Catch data for 2010 were taken from the 2011 stock status reports (Anon. 2011c).

The Northern Territory provided annual landings and quantity per species caught both inside and outside the Gulf of Carpentaria from 1983-2010 by calendar year.

South Australia provided fisheries landings data for fiscal year 1984/5 to 2009/10. For the marine scale fish fishery, weights ($kg \cdot year^{-1}$) were available by gear category and species. For reasons of confidentiality, when there were less than five licences for a particular species, the landings were aggregated. For the abalone fishery, the shell weight for blacklip and greenlip abalone was provided for western, central, and southern zones. For the rock lobster fishery, total landings ($kg \cdot year^{-1}$) for the northern and southern zones were provided. The western king prawn landings ($t \cdot year^{-1}$) were available for four regions: Investigator Strait, the Gulf of St. Vincent, Spencer Gulf, and the west coast region. Annual landings ($t \cdot year^{-1}$) from the sardine fishery were available for the entirety of the state waters for fiscal year 1991/92 through 2009/10. South Australian blue crab fishery landings ($t \cdot year^{-1}$) were available from fiscal year 1997/98 through 2009/10 for the entirety of the state waters. For South Australia, giant crab data were obtained from Currie and Ward (2009), consisting of monthly catches for fiscal years 1992/93 to 2007/08.

Victoria provided annual landings, value, and effort (number of fishers) data for all species from fiscal year 1978/79 to 2009/10 for bays and inlets and the Bass Strait (oceanic) fisheries. In addition, rock lobster and abalone landings were provided separately over the same time period. Annual abalone landings, values, and effort (diver days, diver hours, and number of fishers) were available for western, central, and eastern zones. Rock lobster landings, value, and effort (soak days and numbers of fishers) from lobster pots were available for the eastern and western zones. In addition, a category called 'other' for fiscal years 1978-2009/10 was provided with total catch per year available. A list of species was presented for each year which constituted the 'other' category. As there was no reference to the fraction each taxon represented in the 'other' category for each year, the total list of species reported for 1978-2010 in the 'other' category was divided into fractions according to their contribution to the total catch over the full time series (1979-2010). This estimated percentage was used through 1979-2010 as the best available estimate.

Catch data provided by Tasmania constituted landings for all species managed by the state jurisdiction. Data were provided per species. Temporal coverage varied, with southern rock lobster data available from 1945-2010, while for the majority of other species, data were available from 1970-2010.

Data for Western Australia was obtained from published reports. Annual landings by species from fiscal years 1997/98 to 2009/10 were obtained from the State of Fisheries and Aquatic Resources reports on the Western Australian Department of Fisheries website. As there was no information for fiscal year 2010/2011, the data for 2009 were assumed to also represent 2010.

When required, state and Commonwealth data that were provide in fiscal year increments were allocated to calendar year by dividing the fiscal year equally in half and apportioning half to the earlier year and half to the later year (i.e., fiscal year 2008/2009 was split evenly between 2008 and 2009). In cases where state data were unavailable for certain time periods, catch data were taken from the ABARES '25 Years of Australian Statistics' report (Stewart *et al.* 1991), which summarized commercial catch per species per state from 1964 to 1999. Where a species was caught by both state and commonwealth fisheries, ABARES data were not used to provide state data for these species in order to prevent double counting, and a linear interpolation was performed instead. Wherever possible, historic information for each fishery was obtained including estimates of the first year of operation and catch, trends, such as to determine whether a species was avoided for a particular time period, and thus did not require an interpolation of its catch.

The following gears were identified as defining artisanal fisheries: trap and line, hand diving and gillnet; gear defined as industrial included: all trawling and dredging methods, and large-scale trap and longline. State and Commonwealth commercial data were designated artisanal or industrial, depending on the gear type used or the scale of the fishery.

The 2010 annual status report for Macquarie Island (Patterson and Skirtun 2011) presents the Patagonian toothfish catch for 1994-2010 (fishing off Macquarie Island only began in 1994) and the total weight of finfish bycatch for 2010, which we assumed was representative of the total landings within the Macquarie Island waters. The ratio of catch to total finfish bycatch (28:1) was calculated for 2010 and used to estimate annual finfish bycatch from 1994 to 2009. The primary bycatch species are ridge-scaled rattail (*Macrourus carinatus*) and blue antimora (*Antimora rostrata*), and, since no information is available regarding other finfish bycatch, it was split equally between these two species. No bycatch ratio was applied to years 1999-2003 as commercial fishing was closed for research.

Heard and MacDonald Island landings data for fiscal years 1999/00 to 2009/10 were taken from the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) statistical bulletin volumes 23 and 24, and converted to calendar year. Landings data for the years 1996-1999 were obtained from the FAO.

Recreational fisheries

Using all of the species listed as fished in marine waters in the NRIFS, total catch weight and weight per species or family caught were estimated using weights provided in Henry and Lyle (2003) or by FishBase (www.fishbase.org) for species lacking this information. This provided an estimate of total catch by species for the year 2000. In the absence of a better alternative, the relative contribution (in percentage weight) of taxa listed by the NRIFS was maintained from 1950 to 2010. A category of 'other fishes' was included in the NRIFS, along with total numbers of fish caught. To eliminate the 'other fish' category and partition these catches to specific taxa, the weight of 'other fish' caught was divided amongst the list of known species caught according to the proportion of each of these species in the total recreational catch.

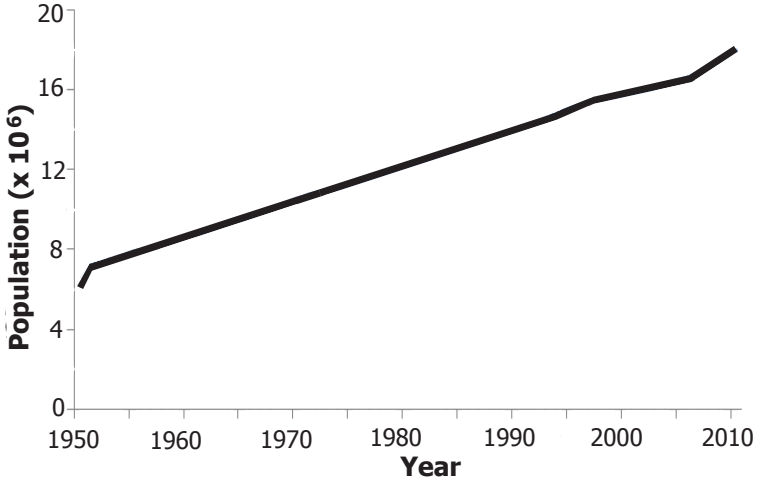

Figure 2. Estimated coastal population of Australia, 1950-2010

Human population statistics per state and territory were extracted from the Australian Bureau of Statistics database (ABS; www.abs.gov.au) for census years. The estimated percentage of the population living near coastal areas according to the ABS is 84%, therefore this proportion of the total populations was used in order to determine a more conservative estimate of recreational fishing effort from marine waters. A linear interpolation was performed between census years to provide a complete time series of population numbers (Figure 2).

The national participation rate in recreational fisheries was estimated to be 19.5% in the NRIFS (Henry and Lyle 2003). Additionally, PA Management Consultants estimated a national participation rate of 34% in a separate survey (Anon. 1984), which due to small sample size may have over-estimated participation rate. A per capita recreational catch of 12.6 kg·person^{-1}·year^{-1} was established by dividing the estimated total catch calculated from NRIFS by the number of participants listed in the survey.

The estimated coastal populations, participation rates and per capita recreational catch rates (kg·person^{-1}·year^{-1}) were used to represent fluctuations in recreational fishing effort over 1950-2000 using the following equation:

$$A = (B*C*D)/100$$

where A is the total annual recreational catch (t); B is the coastal population (number); C is the participation rate (%); and D is the annual recreational catch per person (t·person^{-1}·year^{-1}).

Annual recreational catches from 1950 to 1970 were determined using a participation rate of 19.5% and an estimated recreational catch of 12.6 kg·person^{-1}·year^{-1}, the latter assumed constant until 2000. From 1970 to 1980, the national participation rate of 19.5% (for 1970) was linearly interpolated to a 34% participation rate in 1980 in order to account for the estimated increased promotion and participation in recreational fishing at the time. We realize these rates and their interpolation may be speculative and uncertain. This rate was assumed to remain constant until 1990. We recognise this may have contributed to potential over-estimation of catches due to an uncertain but high estimate of participation rate. However, we feel that our use of a conservative catch rate may ameliorate any potential over-estimation of participation rate. Finally, from 1990-2000, the participation rate was linearly interpolated from 34% in 1990 to 19.5% in 2000 to account for possible declines in recreational fishing effort.

To obtain estimates of total recreational catch per year for 2000-2010, state surveys for this period were examined (McInnes 2008; Jones 2009; Lyle *et al.* 2009). The catch for primary target species available in these reports were compared to the catches for the same species by state recorded in the NRIFS for the year 2000 to establish an estimated rate of increase or decrease in catch per species over time. An average of these percentages was calculated

giving an estimated 35% decrease in total catch (in weight) of all primary species available for comparison. The assumption was made that this decline would apply to all other secondary species. Therefore, the 2010 total recreational catch was estimated to be 35% of the total catch calculated in 2000 (NRIFS) and a linear interpolation was performed between the 2000 and 2010 estimates in order to obtain total catch by year. Any potential change in preference from primary to secondary species may have resulted in a slight overestimate of this rate of decline.

The percentage per taxon out of the total catch previously calculated was then applied to the estimated annual catch to give a complete annual recreational catch per taxon from 1950 to 2010.

Indigenous fishing

Mainland

Population numbers for indigenous communities of Australia were obtained from ABS (Anon. 1998a, 2002b) for 1950, 1956, 1966, 1971, 1976, 1981, 1986, 1991, 1996, 2001, 2006 and 2010. For years when data were unavailable, population numbers were derived by interpolating linearly between these estimates. Using information available from ABS, the proportion of indigenous people living in each state was used to assign population numbers per state and territory. As no other estimates of this proportion were available, these numbers were kept constant from 1950 to 2010. Furthermore, using information on the distribution and location of these populations per state, the percentage of the population living near the coast was estimated in order to determine the number of indigenous people that would likely utilise marine resources. These estimated coastal population numbers for each state and territory were used for the following calculations.

For the northern states (Queensland, Western Australia, and the Northern Territory), all of the species listed as fished in marine waters in NRIFS were used to estimate the total weight caught and the catch weight per species or higher taxon groups. We used the numbers per taxon fished for the survey year (2000) and weights (kg) available in the NRIFS or from FishBase (www.fishbase.org) when weights were not available, which provided an estimate of total catch by taxa in 2000. Using this estimate, a per capita consumption rate of 40 $kg \cdot person^{-1} \cdot year^{-1}$ was derived using the numbers of fishers estimated in the NRIFS. This estimate, assumed stable over time, was multiplied by the population numbers described above to calculate total indigenous catch per year. Also, we used the taxonomic breakdown in the NRIFS surveys for 2000/2001 to disaggregate indigenous catches for all other years.

For the southern states (Victoria, South Australia, New South Wales, and Tasmania), which were not part of the indigenous survey within the NRIFS (Coleman *et al.* 2003), the consumption rate was assumed to be half the rate calculated for the northern states (McNiven 2003). Thus, a rate of 20 $kg \cdot person^{-1} \cdot year^{-1}$ was multiplied by the coastal indigenous populations of the southern states to derive an estimated total annual indigenous catch per state. As for the northern states, the consumption rate was kept constant from 1950 to 2010. Furthermore, as the species caught in the northern states would generally differ from those in the southern states due to the geographical difference, and also because of lack of information on the species composition of the indigenous catches in the southern states of Australia, the category 'Marine fishes not identified' was assigned to the catches in the south.

Regional sectors

Torres Strait Islands

Population figures for the Torres Strait Islands were obtained from Cornish and Thompson (1989) as well as several web-sources[1,2,3]. There were no population estimates available for 1960-1986. For this period and others where data were unavailable, population numbers were linearly interpolated. Thus, a sharp linear decline is noted between 1960-1986 (Figure 3), which may not represent the true pattern over time.

A daily consumption rate estimate was obtained by calculating the average consumption rate for the Yorke, Mabuig, and Boigu islands from data gathered from 1980 to 1990 (Nietschmann 1982; Poiner and Harris 1991; Harris *et al.* 1994). These reports provided estimated daily consumption rates of seafood including dugong and turtle. The calculated average daily consumption rate of 109 $g \cdot person^{-1} \cdot day^{-1}$ (39.8 $kg \cdot person^{-1} \cdot year^{-1}$), was used for 1950-1990 as the best available estimate, and excluded the consumption values of dugong and turtle, two taxa not considered in this reconstruction.

Figure 3. Indigenous population of the Torres Strait Islands 1950 to 2010

[1] www.abs.gov.au
[2] www.trsa.gov.au
[3] www.aiatsis.gov.au

Busilacchi (2008) estimated the marine indigenous catch by 1020 persons (in 2005 and 2006) to be 169 t, which would corresponds to a catch rate of 452 g·person^{-1}·day^{-1} (i.e., 165 kg·person^{-1}·year^{-1}). This high value does not reflect individual seafood consumption rates, but also includes a component of seafood, which, as modern amenities improved, is frozen and transported to the mainland to be shared with relatives. As there is a paucity of information reflecting more recent consumption rates of seafood on the Torres Strait Islands, the high 'consumption' rate of 165 kg·person^{-1}·year^{-1} was kept constant from 2006 to 2010, and we linearly interpolated from the rate of 39.8 kg·person^{-1}·year^{-1} in 1990 to the rate in 2006. The population trend and per capita consumption rates for each time period were used to estimate the total annual indigenous catches by Torres Street islanders from 1950 to 2010.

The species composition of the total indigenous catch for the Torres Strait Islands was determined using the primary target species presented in Busilacchi (2008), Harris and Poiner (1990) and Harris *et al.* (1994), and assumed constant through time.

Lord Howe Island

The population of Lord Howe Island was 264 people in 1966 and 347 in 2007 (www.abs.gov.au). A report by Environment Australia (Anon. 2002a) suggests that only 20 t of fish are caught annually. Therefore, using this estimate in conjunction with the population in 2007, a catch *per capita* of 57 kg·person^{-1}·year^{-1} was derived. Using the population estimate from 1966 and this catch rate, we estimated the 1966 annual catch to be 15.05 t, and annual island catches between 1996 and 2007 were estimated by linearly interpolating between these years. As there has been very little population fluctuation in the population from 1966 to 2007, we carried the 1966 estimate back to 1950 unaltered, and the 2007 estimate forward to 2010 unaltered.

According to Anon. (2002a), the primary species targeted by Lord Howe islanders are yellowtail amberjack (*Seriola lalandi*) and yellowfin tuna (*Thunnus albacares*). As these two species were clearly dominant, 60% of the catch was split evenly between yellowtail amberjack and yellowfin tuna, with the remainder assigned evenly to crimson jobfish (*Pristopomoides filamentosus*), redfish (*Centroberyx affinis*), white trevally (*Pseudocaranx dentex*) and 'marine fishes nei'.

Unreported artisanal fishing on Lord Howe

Here, we define the 'artisanal' catch as the fraction of the total catch (dominated by indigenous and recreational catches) that is sold. Tourist numbers on Lord Howe were reported to be 12,900 in 1999/2000 and have been estimated to have doubled since 1984/85 (Anon. 2002a). Therefore, we estimated the tourist population in 1984 to be 6,450 people. As the Island was only assigned as a UNESCO World Heritage area in 1982, it was estimated that the tourist numbers prior to 1982 were lower, i.e., that in 1980 it was half of the value in 1984, or 3,225. It is estimated that after the introduction of a flying boat system for tourist transport in 1947, there was an estimated 300 beds available for tourists around this time (www.lhimuseum.com) and this value was used as an anchor point for 1950 tourist numbers. A linear interpolation was performed between these values to determine the tourist population from 1950 to 2010.

Using the tourist population numbers, we estimated the catch that was sold for tourists dining on the island. We assumed that tourists may stay on the island for an average of four nights and dine twice on locally caught seafood, i.e., consuming an average serving of 250 g per meal. Multiplying this figure by annual tourist numbers results, for example in an estimated total artisanal catch of 6.5 t·year^{-1} in 2000, i.e., 0.5 kg·tourist^{-1}·year^{-1}. This per tourist rate, assumed constant, was applied to the annual tourist numbers to obtain the annual artisanal catch sold to local restaurants and lodgings for consumption by tourists; the annual estimates were then split among the same taxa as for subsistence catches (see above).

Discards in Australia's main industrial trawl fisheries

Torres Strait prawn fishery

Estimates of annual catch from the Torres Strait prawn fishery (TSPF) were taken from Commonwealth data provided by AFMA, and from Watson *et al.* (1990) and Woodhams *et al.* (2010). The discard rate of 79.2% (Kelleher 2005) was applied from the beginning of the fishery in 1970 until 2004. From 2005-2010, we assumed that the discard rate was half (i.e., 39.6%) so as to account for the introduction of bycatch reduction devices (BRDs) in 2004. Harris and Poiner (1990) provided the species composition of the discarded catch, based on seven trawl surveys conducted over two years (1985 and 1986). The percentage contribution of the primary species in these two years was used to disaggregate the discard taxonomically from 1970 to 2010.

Northern prawn fishery

Commonwealth catch data for the Northern prawn fishery (NPF) were provided by AFMA. The discard rate of 77.3% (Kelleher 2005) was used to estimate annual discards from the beginning of the expanded fishery in 1970 until 2001. While discard rates between different species can vary (e.g., tiger prawns generate high levels of bycatch while banana prawns generate low levels of bycatch), we assume here that the discard rate estimated by Kelleher

(2005) accounts for differences in discard rate between different species. From 2002-2010, we assumed that the discard rate was half (i.e., 38.65%) so as to account for the introduction of BRD's in 2001. Tonks *et al.* (2008) and Stobutzki *et al.* (2001) provided the species composition of the discarded catch, and the average of their percentage compositions were used for the entire time period, from 1966 to 2010. As 20% of the banana prawn catch is taken from the Joseph Bonaparte Gulf (Tonks *et al.* 2008), 20% of the discards were assigned to FAO area 57, with the remaining 80% discarded in the primary FAO area of the NPF, FAO area 71.

Commonwealth trawl sector of Southern and Eastern scalefish and shark fishery

Catch data for the trawl sector were obtained from the Commonwealth for 1950 to 2000, and complemented with information from Stobutzki *et al.* (2010) and Koopman *et al.* (2006). An estimated 85% of the annual catch is taken from fishing area 57 and 15% from area 81; thus, discards were also split between FAO areas using a 85:15 ratio.

Quota discards of the Commonwealth trawl sector

Quota species discarded by the south east commonwealth trawl sector, are the target species of this fishery including: blue grenadier (*Macruronus novaezelandiae*), blue eye trevalla (*Hyperoglyphe Antarctica*) and Jackass morwong (*Nemadactylus macropterus*). The two main reasons for discarding target species are: 1) size-based discarding of small and unmarketable fish, referred to as high-grading, and 2) quota-related discarding where landings are constrained by available quota holdings or reduced market interest.

An average discard rate of 11.5% for quota species in 2004 and 2005 (Koopman *et al.* 2006) was applied to annual catches to estimate total quota discard weight per year. This rate was held constant from 1950-2006. However, from 2007-2010, we assumed that the discard rate was half (i.e., 5.75%) so as to account for the introduction of BRDs in 2006. The discarded quota species recorded by observers onboard trawl vessels (Koopman *et al.* 2006) were assumed to be representative of discard quota species from the SETF. The percentage of each taxon in the total discard weight presented in (Koopman *et al.* 2006) was estimated and the resulting catch composition was assumed constant through time, i.e., was applied every year to the estimated quota discard weight. We note that the trading of excess quota catches between vessels significantly increased in 2010, which led to a large reduction in the discards of many species since 2010 (pers. comm. Caleb Gardner, August 2013).

Non-quota species discards of the Commonwealth trawl sector

A quota discard-to-non-quota discard ratio is presented in Koopman *et al.* (2006). Average discarded catch for 2004 (1,882 t quota discards versus 12,863 t non-quota discards) and 2005 (2,859 t versus 13,948 t) were calculated, yielding a mean ratio of 1:5.8. This ratio was applied to the above estimated annual quota discard weights to estimate annual non-quota species discards. Recent management changes will likely contribute to reductions in discarding going forward.

Knuckey (2006) and Wayte *et al.* (2007) present details of the species composition of non-quota discard. The taxa listed in these reports and the estimated weight per taxon out of total non-quota discards were assumed constant, and used to disaggregate the non-quota discard.

New South Wales ocean trawl fishery

Catch data for the Prawn Trawl sector was obtained from state fisheries data. The prawn catch to bycatch ratio (1:10.4) presented by Kennelly *et al.* (1998) was used to estimate total bycatch per year. An estimated 81.8% of total bycatch is discarded (Kennelly *et al.* 1998); thus, 81.8% of the estimated annual bycatch was taken to represent the estimated discards. Due to the introduction of BRD's in 1999, we assumed that the discard rate was half (i.e., 41.9%) from 2000-2010.

The species composition of the discarded catch was estimated using the numbers of discarded fish and the species composition in Kennelly *et al.* (1998). Estimated weights per taxon were obtained from FishBase (www.fishbase.org) to calculate the weight discarded per taxon. The percentage composition of each species out of the estimated total discards was calculated and the resulting taxonomic composition was assumed constant from 1950 to 2010.

Queensland trawl fishery

Catch data from all trawl sectors were obtained from the Queensland Department of Agriculture, Fisheries and Forestry. An 80% discard rate (Kelleher 2005) was applied to these data from 1950-2001 to provide estimates of discards, but this discard rate was halved for 2002-2010 due to evidence that with the introduction of BRD's in 2001, the discard rate dropped by 40-50% (Courtney *et al.* 2007). The species composition of the discarded catch was estimated using primary discarded species listed in (Courtney *et al.* 2007); (Chapter 5: Eastern king prawn fishery; Chapter 6: Tiger/endeavour prawn fishery). The average taxonomic composition per taxon was used and kept constant through time.

Results

The reconstructed total catch from 1950 to 2010 amounted to over 15.1 million t for all sectors combined (Figure 4a, Appendix Table 1), representing over 400 taxa. Of this total reconstructed catch, there are 10 major taxa, which represent almost 30% of the total reconstructed catch (Figure 4b), with the cumulative catch of these taxa ranging 290,000 to 700,000 t (Appendix Table 2).

Commercial

Total industrial and artisanal commercial catches from both state/territory and Commonwealth fisheries cumulatively amounted to an estimated 12.6 million t from 1950 to 2010 (Figure 4a, Appendix Table 1). These catches include the commercial landings from Heard and McDonald Island and Macquarie Island. These total commercial catches (excluding discards) as estimated here are not much higher than the Australian landings reported to the FAO for the same period (i.e., 8.0 million t, Figure 4a).

Recreational

From 1950 to 2010, we estimate total recreational catches to be slightly over 2.2 million t (Figure 4a, Appendix Table 1). Catches gradually increased from 1950 (around 15,600 t) to a peak in 1990 (just under 60,000 t) before declining thereafter to just under 30,000 t by 2010 (Figure 4a). We recognize that these estimates may be highly uncertain, but resemble a comprehensive (country-wide) time series estimate as a first-order approximation in line with the rationale of catch reconstruction as described in Zeller *et al.* (2007). Sharks and rays make up 12% of the total recreational catch, while other species and families of significant composition include snappers (Sparidae; 8.1%); flatheads (Platycephalidae; 6.1%); smelt whitings (Sillaginidae; 5.5%); Spanish mackerels (*Scomberomorus* spp.; 4.7%); redfish (*Centroberyx affinis*; 3.9%); mackerels/tunas/bonitos (Scombridae; 3.5%) and Australian salmon (*Arripis trutta*; 2.9%; Appendix Table 3).

Over the entire time period (1950-2010), almost 50% (i.e., 1.1 million t) of the total recreational catch was landed in FAO area 57 (Eastern Indian Ocean). Approximately 28% (645,000 t) came from FAO area 71 (Western Central Pacific), while 22% (482,000 t) came from FAO area 81 (Southwestern Pacific; Appendix Table 3).

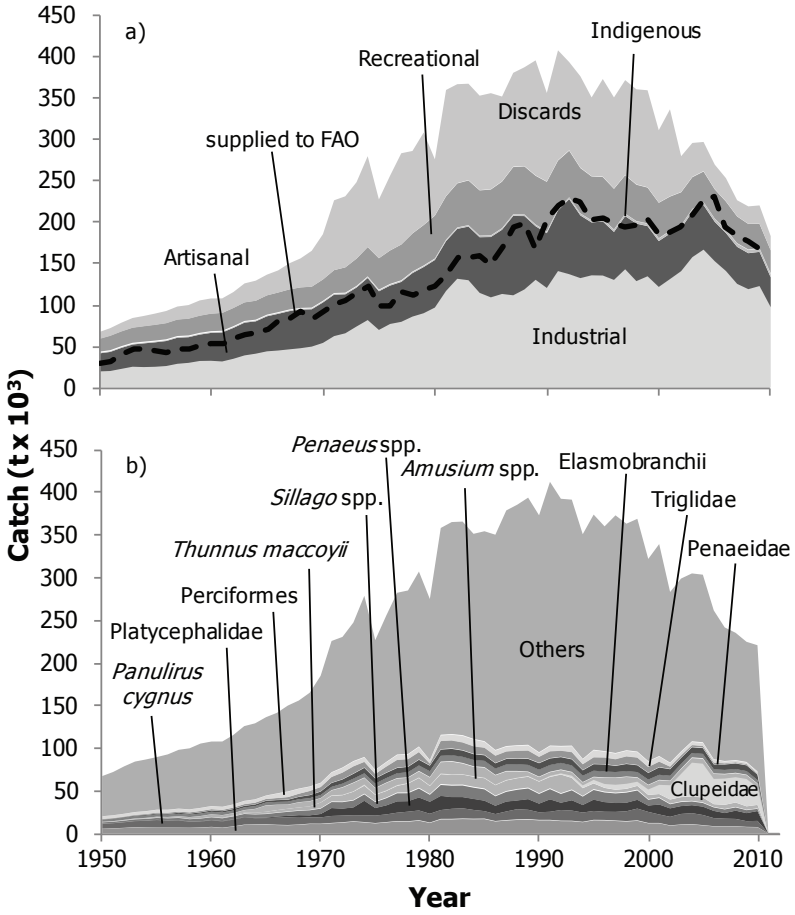

Figure 4. Reconstructed total catch for Australia during the period 1950 to 2010; a) by fisheries sector, plus discards for Australia, with officially reported landings as presented by the FAO overlaid as line graph, b) by major taxa. 'Others' category consists of an additional 442 individual taxa.

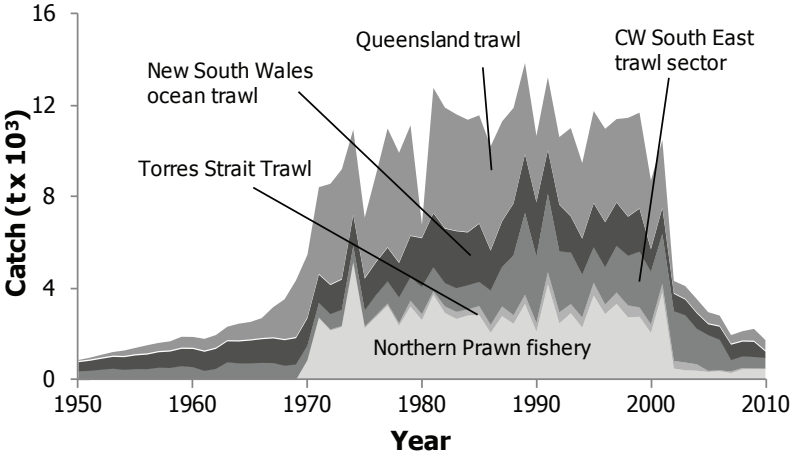

Figure 5. Total discards (t) from the primary state and commonwealth trawl fisheries 1950-2010

Indigenous catches

Total indigenous catches include landings by indigenous fishers on the Australian mainland and in the Torres Strait region. Overall, this yielded a total indigenous catch of around 99,000t from 1950 to 2010, with an increasing trend noted (Appendix Table 1). Approximately 60% of the total indigenous catches (around 65,000 t) originated from FAO area 71, 32% (around 28,000 t) from FAO area 57, while 6,000 t came from FAO fishing area 81. Overall, 6 taxa represented 50% of the total indigenous catch, which included sharks and rays, trevally (Carangidae), rabbitfishes (Siganidae), mullet (Mugilidae), threadfins (Polynemidae) and mud crab (Scylla spp.) (Appendix Table 4).

Unreported artisanal

Cumulated unreported artisanal catches of 180 t from 1950 to 2010 were estimated for Lord Howe Island, representing the excess indigenous or recreational catch sold by islanders to local restaurants and hotels to provide seafood for tourists.

Discards in Australia's main industrial trawl fisheries

Discards from the major Australian fisheries represent a significant component of the reconstructed total catch (Figure 4a). From 1950 to 2010, slightly over 4 million t were discarded (Figure 5), with the bulk of the discards originating from FAO area 71 (around 2.4 million t), followed by FAO fishing area 81 (around 890,000 t), and FAO fishing area 71 (around 820,000 t). Here we assume that the compulsory introduction of BRDs in the late 1990s and early 2000s has contributed to reductions in wasteful discarding (Figure 5).

Discussion

FAO reported landings, which often account only for commercial or even only large-scale or export-oriented fisheries in a country, serve a useful purpose in quantifying the removals of landed species by the commercial sector. However they do not track total removals from a system, which would provide a better understanding of the ecosystem effects of fishing. To quantify the later, one needs to capture, in addition to commercial landings, levels of discarding and catch from other sectors. Furthermore, the FAO data are the only publically available, global dataset of fisheries catches, and thus a valuable, but underutilised resource.

The fisheries landings estimated for the industrial and artisanal commercial sectors in this catch reconstruction are, as expected, relatively close to the FAO reported landings statistics (8.6 million t vs. 8.1 million t, respectively). This is not surprising, since FAO does not collect independent data, but rather depends entirely on data reported to it by member countries. Thus, any discrepancies between FAO data and national data reflect more on national-international data transfer mechanisms and national prioritization then on data quality. Australia has robust fisheries management in place, which includes relatively strong accounting of landings statistics from commercial fisheries. However, unlike for many small island or developing countries, where artisanal small-scale and subsistence catches may form the bulk of the landings and therefore contribute to the data reported to or by FAO, Australia only reports their commercial fisheries landings.

Here, we attempt to estimate and add removals by the recreational and indigenous sectors, as well as discards to the publically reported commercial landings as reported by FAO on behalf of Australia. The inclusion of these components illustrates that there are substantial removals in excess of those from the commercial fisheries and that quantifying total removals is of importance in understanding the effects of fishing on the ecosystem, and to properly and comprehensively account for all extractive use of marine resources. We find that total removals from 1950 to 2010 are just under 15 million t versus the nearly 8.1 million t in commercial landings that were reported to FAO over this period.

The slightly higher commercial landings estimated in this reconstruction (a difference of 521,000 t) is primarily due to higher estimates of landings prior to 1990 and also because ABARES, the agency that reports the national catch statistics to FAO, does not include landings (e.g., taxa) with very low tonnages (i.e., 100 t) in its report to FAO (P. Sahlqvist, ABARES, pers. comm., April, 2011). Here, however, we were able to acquire landings statistics from the Commonwealth and state agencies directly and these tonnages, while small, contribute to some of this difference. The differences prior to 1990 are not unexpected, as it has been noted that inaccuracies in the recording of landings data by the fisheries agencies were more prevalent in the early years of the industrial fishing sector (Stewart *et al.* 1991). Some of these issues include data entry errors, confusion over jointly managed fisheries (e.g., logbook requirements differ between the states and the Commonwealth often resulting in duplicate reporting of catches), problems with conversions from numbers to live weight, and failure to verify logbook entries (i.e., lack of enforcement leading to mis-reporting). Additionally, each state and territory had different methods of recording data and often changed data collection methods, resulting in inconsistencies between the data collected and stored (Stewart *et al.* 1991). As a result, many of the earlier state records are unavailable or incomplete. In addition to this, many Commonwealth fisheries do not have complete records prior to the late 1980s (i.e., consistent Commonwealth reported landings for all fisheries begin only in the late 1980s).

To estimate the landings prior to the years when consistent reporting began, we used linear extrapolation of data. When using ABARES state data (Stewart *et al.* 1991) to fill in gaps where state data were unavailable, the best effort was made to exclude data for species that are caught by both state and commonwealth fisheries, in order to prevent double counting.

Non-commercial catch is minor relative to commercial but not trivial and ideally should also be reported to track the contribution of fisheries to food security. Together, the recreational and indigenous sectors represent on average 16% of the reconstructed data over the time series, a proportion that has remained relatively constant over time. Data on recreational fishing prior to the 1970s are scarce, and so we assumed that the participation rate was constant from 1950 to 1970 and that increases in coastal populations were the main contributor to increasing recreational landings. From 1970 to 1990, it was estimated that participation in recreational fishing increased, resulting in catches more than double the average annual recreational catches estimated for the 1950 to 1970 period. We assumed that this was mainly due to the fact that the coastal population of Australia doubled from 1950 to 1980 (Lyle and Smith 1998), and that recreational fishing divisions within the Department of Fisheries as well as fisherman associations (Coleman 1998) were created to promote recreational fishing. Also, in Queensland, permits were available to the public until the 1990's (Fishing Industry Organization and marketing act 1982), which allowed the sale of recreational catch and thus added to the popularity of the sport (W.Sawynock, Infofish Australia, pers. comm., October, 2012; and R.Thurston, University of Queensland, pers. comm, August, 2012). Overall, the average catch estimated for the 1990s (51,000 $t \cdot year^{-1}$) is quite close to a previous estimate for 1994, when the participants of an Australian Society for Fish Biology workshop estimated the total recreational catch for Australia to be 54,300 $t \cdot year^{-1}$ (Hancock 1995), based on population data, participation rates, and estimated average catch per person. However, we recognize the preliminary and potentially highly uncertain nature of our estimation of recreational catches over time, and suggest these numbers be viewed with caution.

The decline in recreational catches from 1990-2010 is probably due to several factors. First, the cessation of permits allowing the sale of recreational catch in Queensland, which began in 1990, may have reduced the incentive to participate in recreational fishing and thus reduced the total recreational catch by reducing fishing effort (Allen *et al.* 2006). Also, Sutton *et al.* (2009) reported that from 1996-2002, the participation rate of recreational fishing in Queensland decreased from 28.1% to 20.6%, mainly due to a reduction in leisure time needed to partake in the sport and increasing costs associated with the pastime. Similarly, recent state-wide surveys have shown a decline in participation rate and effort over the last decade. Notably, there was a decrease from 23.3% to 16.4% from 2000 to 2007 in South Australia, with an overall decrease of 42% in fishing days over this same period (Jones 2009). Additionally, Coleman (2003) presents details of a decline in fishing effort in the Northern Territory with 100,000 days less fishing effort in 2000 than in 1995.

The recreational catches reported here are the best available estimate, but may still contain inaccuracies in some cases. Firstly, there is little information available regarding the actual decline in total landings by taxon (per state and territory) for the last decade (2000-2010) or whether this decline applies to recreational fishing for all species. Therefore, the method we used to calculate the average decline in catch from 2000-2010 may not be accurate. Secondly, it must be noted that game fish landings from charter vessels were not included in this estimate of recreational catches. 'Game species' such as marlin, tuna and some shark species are most frequently caught on charter vessels. However, recreational boats, especially with the increased affordability of technology such as Global Positioning Systems (GPS) and sounders, are commonly used to fish for large pelagic species. On charter boats, billfish are mainly returned to sea, but only about 10-25% of tuna are released. Here we assumed that all game fishing was catch and release, thus we likely underestimate this component of retained catch. However, in some instances this assumption may be violated if trophy species are kept in accordance with fishing club rules. Our estimates of recreational catches may therefore be an underestimate for some taxa if these game species were landed. Finally, the numbers fished per species/family presented in the NRIFS were extrapolated upwards from the survey size to represent the whole country and this extrapolation in numbers fished may have been an over estimate for some species (W. Figueira, University of Sydney, pers. comm., December, 2012), therefore, using the numbers fished per taxon to calculate total catch weight may have resulted in over-estimates.

There was a paucity of information regarding consumption rates of indigenous people and fishing effort prior to the 1980s. Additionally, there was no recording of the indigenous population in the Australian census prior to 1971 (www.abs.gov.au). Therefore, total catches estimated using consumption rates based on estimated population figures may have inaccuracies, which may be compounded by the fact that the coastal proportion of the indigenous population was not measured directly, but was inferred from published percentages of populations of indigenous people living in outlying areas. Displacement of indigenous communities from inland areas to coastal regions was frequently performed by the Australian government to free fertile land for agricultural use (Roberts and Schilling 2010). The effect of this displacement on fishing and fish consumption rates is not known. In the 1960s, particularly in the southern states, there was a rapid change in the living conditions and food sources for many displaced communities, with government agencies providing more western-style foods. This likely reduced their participation in traditional hunting of both terrestrial and marine resources (Gracey 2000). On the other hand, as general coastal development increased, interference with traditional fishing practices of coastal indigenous communities may have occurred (Roberts and Schilling 2010), resulting in reduced catch rates. However, these factors are difficult to quantify and thus changes in indigenous fishing will remain uncertain.

Fishing on the Torres Strait Islands may have increased due to the modernisation of fishing techniques and improved living standards (Busilacchi 2008). Recent factors that are particularly important are the greater ease of transport between islands allowing landings to be sent to the mainland and the use of freezers on the islands permitting storage of catch (Busilacchi 2008). Therefore, an increase in catches is likely to have occurred over the last 30 years, also due to improved fishing techniques. The likelihood of overexploitation of marine resources as a result of technological improvements emphasizes the need for the assessment of subsistence fishing effort and catch, especially because traditional knowledge previously passed down through generations may not be sufficient to promote the conservation of endangered marine resources (Dews *et al.* 1993).

The estimates presented here of catches by indigenous communities do not include species such as turtle and dugong. Turtles and dugongs are an important part of the diet of the Torres Strait islanders. Nietschmann (1982) reported that both dugongs and turtles accounted for 89% of the total seafood consumption on Mabuiag Island (Torres Strait) in the 1970s. Additionally, Coleman (2003) reported that indigenous communities in WA, QLD and NT hunted up to 6,455 marine turtles, 1,619 dugongs, and 388 crocodiles in one year.

Our results suggest that a wide range of taxa occur in the catch of indigenous fishers in all three FAO areas included here (Appendix Table 4). This may suggest that the ecosystem impacts of fishing are dispersed in this sector. FAO fishing area 71 had the largest indigenous catches over time due to the large population numbers and consumption rate in that area. Although NSW (FAO area 81) has one of the largest indigenous populations, the estimated population in coastal areas is low. Also, it is estimated that the main indigenous fishing of marine resources occurs in the northernmost tropical states of Australia (McNiven 2003).

Discards are a significant component of the reconstructed catches. Five of the primary state and Commonwealth trawl fisheries were selected to represent the major components of discarding in Australia's waters. The low selectivity of trawl fishing gear often results in a large bycatch component, the majority of which may often be discarded (Stobutzki *et al.* 2001). However, according to the estimates we present here, bycatch and discarding was a more serious problem (i.e., a larger component of total removals) from 1980 to 2000. Since the early 2000s, discards have decreased substantially to approximately 10% of the estimated levels 20 years ago and continue to decline. This is a notable change and can be viewed as a step in the right direction for Ecologically Sustainable Development (ESD), which is an important goal for Australia's Department of Agriculture, Fisheries and Forestry (DAFF). DAFF has a statutory requirement under section 516A of the Environmental Protection and Biodiversity Conservation Act 1999 (the EPBC Act) to promote ESD and the long-term viability of fisheries is key to this objective.

As a result of the vast geographical spread of some of the Australian trawl fisheries, the fact that vessels can fish both on- and off-shelf and in various habitats and for a multitude of species, it is difficult to ascertain uniform bycatch profiles (Huber 2003). Additionally, as some of the discarded species are taken from summaries for the fisheries as a whole, the species composition of discards may vary in different regions (Knuckey 2006). Thus, the species composition of the discards presented here are approximate. In some fisheries, such as the Queensland trawl and the Commonwealth southeast trawl fishery, there may be up to 1,000 and 250 species, respectively, discarded annually. However, many of these taxa may not be regularly caught as bycatch (Huber 2003). Similarly, it is suggested that Northern prawn fishery discards comprise over 350 species of teleost and 43 species of elasmobranchs (Stobutzki *et al.* 2001). Therefore, it is difficult to accurately establish the proportion of each taxon, and only the primary taxa (Stobutzki *et al.* 2001; Tonks *et al.* 2008) were selected to represent the discarded species of the Northern prawn fishery. A key point is that the taxa of catches from these trawl fisheries are mixed with no dominant group, suggesting that ecosystem impacts of fishing may be dispersed. However, among the discards estimated here, many are commercially important species such as silver sea bream and red spot whiting (Kennelly *et al.* 1998), which highlights the need to assess the quantity of discards from trawl fisheries and potential impacts on particular fish stocks. Fortunately, in Australia, management has been proactive in researching and addressing the fisheries impact on the environment with a particular focus on the reduction of bycatch and consequent discards (Koopman *et al.* 2009). As a result, state/territory and Commonwealth governments have made some changes to fisheries management with an emphasis on sustainable fishing practices (Anon. 2007). These changes required the development of fishery management strategies and associated environmental assessments for some of the fisheries and the mandatory introduction of BRDs. We assume here that these types of changes may have reduced discard rates in recent years.

Overall, this catch reconstruction highlights that there have been major changes in Australian fisheries catches over the last 20 years, with a reduction in landings and removals, particularly in regard to improved methods to address discards. The declining catch may not be due to unsustainable fishing, as Australia has developed effective management and stocks are generally in good condition and deemed to not be overfished (Anon. 2011a). Therefore, the recent reductions in domestic catches may be driven by increased imports (Anon. 2012) and managed reductions as part of a national trend towards targeting Maximum Economic Yield (MEY).

Estimating and quantifying total removals from all fishing sectors, as well as discards and illegal fishing will provide us and the general public with a more complete picture of the effects that fishing had and may have on the ecosystem. Having a more comprehensive tally of removals provides us with one key piece of the puzzle, which should be complemented with similar comprehensive time series data on fishing effort, including accounting and adjusting for technology creep and efficiency increases etc. Ideally, this will then be interpreted in the context of management changes, and permit embedding fisheries in an ecosystem context (Pikitch *et al.* 2004). Such a conceptual shift in perspective requires far more comprehensive, and publically transparent, accounting of all catches taken from the ocean, including those not utilised and hence discarded.

Norfolk Island

Introduction

Norfolk Island, one of Australia's external territories, is located in the South Pacific Ocean (29°S, 168°E) approximately 1,500 km east of Brisbane in FAO fishing area 81. Norfolk Island is represented separately from Australia in the FAO database, and therefore we present the catch reconstruction for this island independently. The fishing activity on the Island consists of an inshore artisanal, recreational and subsistence fishery and an exploratory offshore demersal finfish fishery, which had been in operation from 2000 to 2003 (Leatherbarrow *et al.* 2010).

Offshore demersal fishing began in the 1950s when Japanese vessels undertook long lining. Effort was sporadic and annual catches amounted to less than 100 t (Leatherbarrow *et al.* 2010). In 2000, AFMA issued two trawl and five demersal line exploratory permits for alfonsino (*Beryx splendens*) and orange roughy (*Hoplostethus atlanticus*). These were to be the primary species of the offshore demersal fishery, as it had been assessed that these stocks would be able to sustain commercial fishing effort (Anon. 2010). However, these taxa were caught in low numbers and higher landings of bass groper (*Poyprion americanus*), hapuku (*P. oxygeneois*) and blue-eye trevalla (*Hyperoglyphe antarctica*) were reported over the trial period, 2001-2003 (Leatherbarrow *et al.* 2010). Due to the failure to land the target species in high enough numbers, the fishery has not operated since 2003.

The inshore fishery on Norfolk Island consists of a small-scale recreational and subsistence shore- and boat-based fishery, which is operated by locals. Data from this inshore fishery are not reported to the FAO, and consist of recreational and subsistence fishing with the likelihood of some unreported artisanal components when subsistence or recreational catches are sold. Land-based fishing from rocks and jetties (Anon. 2010) targets species such as yellowfin tuna (*Thunnus albacares*), yellowtail kingfish (*Seriola lalandi*) and ophie (silver trevally; *Pseudocaranx dentex*) whereas boat-based fishing targets trumpeter (redthroat emperor; *Lethrinus miniatus*).

Methods

Offshore commercial fishery

In total, it is reported by AFMA that 96 t were caught by the demersal fishery from 2001 to 2003 (Leatherbarrow *et al.* 2010) and this was split evenly amongst the three years. As there is no reference to the catch composition, it was assumed that the catch consisted of the primary species mentioned by Leatherbarrow *et al.* (2010) as dominating the catch; thus 90% of the catch was divided evenly amongst these species (bass Groper, hapuku, and blue-eye trevalla), while the remaining 10% was applied evenly to orange roughy and splendid alfonsino.

Inshore fishery

The total catches of the inshore fishery were available for 2007 and 2008 (Anon. 2010). The average of the 2007 and 2008 catches was 6.34 t. Population figures were obtained from several websites[4] and linear interpolation was used to estimate a complete population time series for 1950 through 2010. Using the estimated population for 2007/2008 and the average catch for 2007 and 2008 (6.34 t), an average per capita catch rate of 3 kg·person^{-1}·year^{-1} was derived, which was combined with the population figures to estimate total catch from 1980 to 2010. For 1950, we assumed that the per capita catch rate was three times the 1980 per capita catch rate, i.e. 9 kg·person^{-1}·year^{-1} owing to anecdotal reporting of larger catches prior to 1959 (Anon. 2010), we linearly interpolated annual catches between 1950 and 1980. Using the species composition of the landings in 2007 and 2008 (Anon. 2010), the average proportion of landings per taxon was calculated and this proportion per taxon was applied to each of the annual catch estimates.

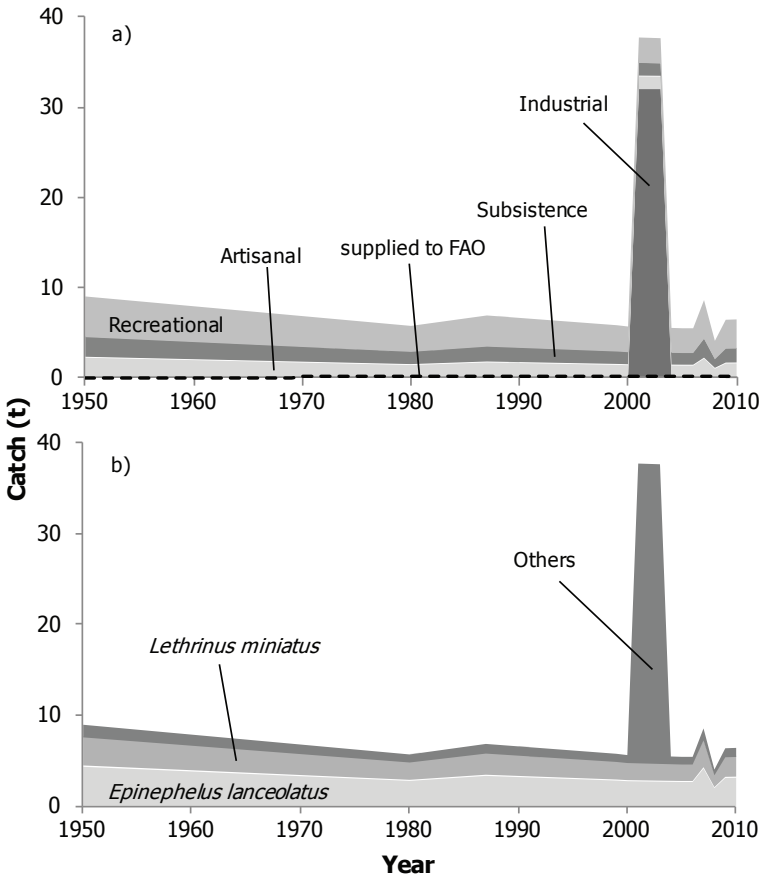

Figure 6. Reconstructed total catch for Norfolk Island, 1950-2010 a) by fisheries sectors, with reported landings as presented by the FAO, b) by major taxa. 'Others' represent 12 additional taxonomic categories.

[4] www.abs.gov.au; www.indexmundi.com; www.popustatinfo.com

Leatherbarrow *et al.* (2010) mention that the Norfolk Island inshore fishery consists of subsistence, artisanal, and recreational sectors and therefore a ratio of 25:25:50 was used to assign proportions of the estimated total catch to each sector, respectively, under the assumption that recreational fishing is likely the primary sector, and that local demand for seafood is primarily met by imported frozen fish.

Results

A total of 96 t was caught by the Norfolk Island demersal fishery over the short trial period (2001 to 2003) during which it operated (Figure 6a). An estimated 400 t was caught from 1950 to 2010 by the inshore fishery, giving a total reconstructed catch of just over 500 t for Norfolk Island (Appendix Table 5). FAO data reports a total of 10.25 t for the same period (i.e., 498.5 t potential unreported to the FAO). Two taxa represented over 60% of the total reconstructed catch (Figure 6b).

Discussion

The difference between the reconstructed catches for Norfolk Island and the data reported for Norfolk Island by FAO is due to the presence of the small-scale inshore fishery on Norfolk Island, which is a combination of recreational, subsistence and artisanal fishing. These components seem unreported to FAO. It is likely that that there are more species caught on Norfolk Island; however, due to the lack of information on these fisheries, we conservatively relied on the primary species represented in Anon (2010).

Overall conclusion

While we find that the Australian industrial landings reconstructed here and those reported to FAO are largely comparable, there is a substantial gap between FAO reported data and the estimated annual catches from all fishing sectors and components (including discards). Discards are responsible for the majority of this difference. Australian State and Commonwealth fisheries have made great efforts to reduce bycatch, and discards have been declining in recent years. Overall, while there remain significant knowledge gaps regarding the national scale of the subsistence and recreational fishing sectors and levels of discards over time, this reconstructed dataset provides a clearer baseline picture of trends in total catches and the contribution of fisheries to food production from all sectors, not only the commercial channel. Additionally, better estimates of catches by all sectors are needed to more accurately establish the multiple pressures on marine ecosystems, and and thus promote the ecologically sustainable development of fisheries.

Acknowledgements

We acknowledge *Sea Around Us*, a scientific collaboration between The University of British Columbia and The Pew Charitable Trusts. Many people provided data or insights into this work, and we especially would like to thank J. Adams, M. Apostoles, C. Ashby, P. Baker, G. Begg, S. Buckley, S. Connelly, C. Dichmont, M. Dunning, N. Engstrom, W. Figueira, A. Fowler, C. Gardner, S. Griffiths, M. Grubert, A. Handley, J. Higgs, P. Hone, M. Ives, A. Jones, K. Jones, M. Knight, J. Lyle, M. MacDonald, D. Makin, J. Meeuwig, M. O'Neill, W. Sawynock, A. Steffe, R. Stevens, J. Stewart, R. Thurston, T. Ward, and H. Webb.

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Appendix Table A1. FAO landings vs. reconstructed total catch (in tonnes), and catch by sector with discards shown separately for Australia, 1950-2010.

Year	FAO landings	Reconstructed total catch	Industrial	Artisanal	Indigenous*	Recreational	Discard
1950	29,102	67,400	21,100	21,600	686	15,600	8,390
1951	32,802	72,200	21,500	23,000	696	17,600	9,400
1952	40,801	78,800	24,100	25,300	705	18,000	10,660
1953	46,302	84,500	26,700	26,700	715	18,400	11,870
1954	47,102	86,900	26,300	28,500	724	18,800	12,550
1955	45,701	89,800	26,600	29,400	739	19,200	13,720
1956	43,701	92,900	27,500	30,100	752	19,700	14,850
1957	48,002	98,300	30,200	31,300	774	20,100	15,870
1958	46,701	100,000	31,400	30,900	776	20,500	16,560
1959	50,602	105,600	33,600	31,700	822	20,900	18,550
1960	53,502	108,000	33,900	33,500	825	21,300	18,490
1961	53,902	108,000	33,000	34,800	828	21,700	17,650
1962	60,101	115,700	36,300	37,100	831	22,100	19,310
1963	63,702	126,100	40,300	39,400	834	22,500	22,970
1964	65,802	129,400	42,400	38,900	837	23,000	24,300
1965	71,802	136,600	45,200	42,100	840	23,400	25,040
1966	81,201	141,800	46,200	44,100	843	23,800	26,720
1967	84,002	150,300	47,600	46,000	867	24,300	31,510
1968	93,102	156,200	49,000	46,500	890	24,800	34,990
1969	83,202	165,400	50,900	44,900	914	25,300	43,300
1970	92,512	185,300	55,400	48,600	938	25,800	54,560
1971	100,612	226,200	63,600	49,800	962	27,700	84,110
1972	106,312	231,000	67,000	46,800	985	30,600	85,580
1973	114,812	247,900	75,100	46,900	1,009	33,000	91,950
1974	123,803	279,200	82,900	50,600	1,032	35,400	109,320
1975	98,544	227,200	71,000	46,400	1,056	37,900	70,780
1976	98,899	255,800	78,200	46,100	1,079	40,400	89,960
1977	116,662	282,800	80,700	48,000	1,085	43,200	109,820
1978	112,160	285,500	87,100	52,300	1,090	45,900	99,180
1979	118,442	307,700	91,100	55,500	1,095	48,800	111,220
1980	122,183	275,500	97,900	57,200	1,101	51,700	67,600
1981	136,686	359,000	117,900	59,900	1,106	52,500	127,600
1982	158,573	365,900	132,600	60,000	1,169	53,200	119,020
1983	157,719	366,500	130,800	64,500	1,232	53,900	116,040
1984	159,028	352,100	115,600	66,900	1,294	54,700	113,650
1985	149,399	355,100	110,200	72,600	1,357	55,400	115,590
1986	169,564	351,100	114,300	77,200	1,420	56,100	102,020
1987	194,654	379,600	112,700	95,500	1,477	57,000	112,900
1988	199,526	386,300	119,700	88,300	1,533	57,900	118,850
1989	168,391	394,600	131,300	64,400	1,589	58,800	138,510
1990	205,897	355,400	121,500	65,900	1,647	59,700	106,580
1991	221,147	406,700	141,800	72,900	1,754	58,100	132,240
1992	229,108	392,500	138,100	90,300	1,886	56,200	106,070
1993	225,521	375,400	133,400	75,300	2,027	54,700	110,010
1994	201,899	350,700	136,700	63,500	2,169	52,900	94,680
1995	204,108	372,900	136,500	65,100	2,311	50,800	117,480
1996	199,709	350,500	131,200	57,700	2,463	49,000	109,680
1997	193,938	373,800	144,000	63,900	2,558	46,400	113,960
1998	195,415	364,000	129,700	69,100	2,651	43,800	114,470
1999	203,374	362,300	135,600	60,300	2,742	43,300	116,760
2000	186,286	314,200	122,700	55,100	2,832	42,700	87,050
2001	187,060	339,600	132,200	54,600	2,936	41,200	104,700
2002	193,402	283,800	141,700	51,700	3,071	39,700	43,040
2003	209,567	299,500	158,600	54,400	3,207	38,200	40,770
2004	227,250	300,500	167,600	53,600	3,346	36,700	35,110
2005	231,192	273,300	153,700	47,400	3,486	35,300	29,350
2006	193,503	256,000	141,900	45,600	3,673	33,800	27,860
2007	184,340	229,100	126,400	44,500	3,722	32,300	19,300
2008	177,577	221,900	120,100	43,300	3,769	30,800	21,000
2009	167,287	223,300	123,800	41,100	3,817	29,300	22,020
2010	167,491	186,200	98,400	35,900	3,858	27,800	17,110

* For global database use by *Sea Around Us*, indigenous will be treated as 'subsistence' as defined by *Sea Around Us*.

Appendix Table A2. Reconstructed total catch (in tonnes) by major taxa for Australia, 1950-2010. 'Others' contain 40 additional taxonomic categories.

Year	Platycephalidae	*Panulirus cygnus*	*Penaeus* spp.	*Sillago* spp.	*Amusium* spp.	Clupeidae	*Thunnus maccoyii*	Elasmobranchii	Penaeidae	Triglidae	Perciformes	Others
1950	5,690	6,000	216	1,500	4	54	382	2,150	459	710	3,070	47,200
1951	6,200	6,000	244	1,670	7	58	417	2,400	569	698	3,140	50,800
1952	6,740	6,600	272	1,830	11	62	551	2,470	671	749	3,190	55,600
1953	7,620	7,100	299	1,950	14	65	684	2,530	773	903	3,230	59,300
1954	7,170	7,900	327	2,130	22	69	817	2,590	877	1,040	3,290	60,700
1955	7,050	9,000	355	2,300	125	73	950	2,660	979	1,115	3,340	61,800
1956	7,010	8,300	382	2,510	132	77	1,082	2,720	1,084	1,239	3,400	65,000
1957	6,980	8,600	410	2,680	232	82	1,471	2,780	1,182	1,335	3,420	69,100
1958	6,860	7,000	438	2,870	135	86	1,973	2,840	1,284	1,384	3,460	71,700
1959	7,230	7,000	465	3,200	143	91	2,527	2,900	1,389	1,561	3,540	75,600
1960	7,910	7,700	493	3,340	243	95	2,915	2,970	1,487	1,533	3,550	75,800
1961	7,020	7,400	521	3,290	547	99	2,834	3,030	1,589	1,481	3,560	76,700
1962	8,510	8,000	548	3,480	951	102	2,475	3,090	1,691	1,648	3,610	81,500
1963	10,580	8,600	576	3,690	1,355	106	2,777	3,160	1,793	1,932	3,700	87,800
1964	10,860	7,400	604	4,030	1,769	110	4,369	3,220	1,902	2,076	3,790	89,300
1965	11,020	7,400	624	4,300	2,272	294	7,415	3,290	2,007	2,143	3,840	92,000
1966	10,450	8,380	1,506	4,460	2,783	333	6,107	3,350	2,113	2,331	5,270	94,700
1967	10,130	9,240	1,787	4,880	3,124	324	4,741	3,430	2,242	3,029	6,460	100,900
1968	10,750	8,970	2,220	5,300	3,463	332	5,965	3,500	2,773	3,606	5,870	103,400
1969	11,780	7,500	2,461	6,140	4,130	281	5,936	3,580	3,527	4,850	5,040	110,100
1970	11,730	7,470	4,152	6,540	6,554	534	4,892	3,680	4,024	5,256	4,810	125,700
1971	12,630	8,320	9,516	7,380	6,550	1,232	5,619	3,960	4,537	6,988	5,260	154,200
1972	13,440	7,940	8,422	7,900	7,405	1,069	8,586	4,290	4,878	8,007	5,600	153,400
1973	14,600	7,250	9,425	8,370	9,642	1,129	9,825	4,700	5,684	8,686	5,790	162,800
1974	13,690	8,060	17,546	7,790	9,295	2,042	7,804	5,040	6,433	6,910	5,290	189,300
1975	12,500	8,940	9,135	7,240	7,746	1,126	7,239	5,130	6,013	5,206	4,520	152,400
1976	13,630	9,150	10,906	8,690	7,670	1,349	8,738	5,440	6,072	7,276	5,110	171,700
1977	14,930	9,930	13,671	9,870	7,780	1,556	7,772	5,820	6,194	9,415	5,810	190,100
1978	14,670	11,370	12,695	9,760	10,384	1,339	6,143	6,190	6,317	8,903	5,660	192,100
1979	15,910	11,610	15,676	10,920	11,282	1,547	7,008	6,660	6,635	8,915	6,100	205,500
1980	13,090	10,480	14,492	8,530	9,466	1,283	9,407	7,030	6,477	2,292	3,760	189,200
1981	17,500	10,500	17,122	13,350	11,520	1,695	13,275	7,070	7,290	10,022	6,670	243,000
1982	17,530	11,970	14,229	13,880	11,492	1,403	15,103	7,170	7,445	9,684	6,940	249,100
1983	17,980	12,120	13,551	14,140	11,670	1,288	12,662	7,490	7,315	9,372	7,960	251,000
1984	17,690	10,450	13,362	13,690	11,848	1,394	11,044	7,670	6,751	9,094	8,160	241,000
1985	17,870	8,840	12,646	13,820	12,026	1,453	11,882	7,550	6,519	8,736	7,150	246,600
1986	14,940	8,300	10,010	11,530	12,204	1,259	11,089	7,570	6,209	8,785	6,280	252,900
1987	16,070	10,260	11,978	11,880	12,382	1,447	9,935	7,820	6,474	8,643	5,820	276,900
1988	16,890	12,170	10,562	13,040	12,560	1,357	7,355	8,110	6,607	9,134	5,920	282,600
1989	17,210	11,120	12,874	13,020	12,738	1,673	4,576	8,060	7,069	9,654	6,220	290,400
1990	16,310	9,040	10,462	11,830	13,552	1,386	4,634	8,340	7,651	7,341	4,930	278,400
1991	16,330	9,610	15,035	12,440	13,304	2,063	4,200	8,150	7,664	8,258	6,280	309,900
1992	15,380	12,680	8,828	10,740	21,895	2,227	3,919	8,020	6,718	7,432	5,070	290,400
1993	15,270	12,100	12,497	12,160	13,575	3,345	3,895	7,820	7,086	8,354	7,140	289,000
1994	14,010	11,030	9,160	10,210	9,045	3,900	3,474	7,550	6,348	7,081	5,910	263,900
1995	16,360	10,560	13,680	11,860	6,597	4,880	3,152	7,290	7,648	7,932	8,440	276,300
1996	16,200	9,760	11,654	11,800	4,363	5,255	7,281	7,090	8,284	8,059	7,030	264,100
1997	15,520	10,300	10,830	11,630	3,290	6,571	8,016	6,650	7,225	7,681	6,850	279,300
1998	14,830	11,720	10,369	12,320	3,427	6,616	8,095	6,460	8,409	8,848	6,700	266,200
1999	15,740	14,010	10,670	11,400	4,373	5,552	4,765	6,290	7,973	8,887	6,600	273,500
2000	12,600	13,200	7,699	7,100	4,871	7,010	5,139	6,210	7,837	6,860	6,550	237,500
2001	12,590	10,140	12,044	7,910	3,854	11,491	5,411	6,110	8,653	6,687	6,150	249,000
2002	9,700	10,200	10,240	5,050	4,864	17,514	4,963	5,860	7,710	2,802	4,380	200,500
2003	10,790	12,560	9,534	4,980	5,015	28,119	5,629	5,730	7,078	2,739	4,240	203,100
2004	11,180	13,110	9,637	4,630	5,008	40,929	5,458	5,520	6,639	2,301	3,880	197,300
2005	10,000	12,080	10,136	4,490	5,726	40,837	5,814	5,240	6,829	2,267	3,770	196,900
2006	8,730	9,640	8,712	4,260	3,197	30,531	5,944	5,000	5,734	1,950	3,520	174,900
2007	8,610	9,090	6,813	4,420	4,852	31,743	5,003	4,760	6,405	1,108	2,380	156,900
2008	8,780	8,600	9,967	4,020	5,149	30,630	4,633	4,560	6,555	1,168	2,190	149,500
2009	7,920	6,790	9,692	3,680	3,915	33,030	4,557	4,360	6,788	1,339	1,980	141,200
2010	7,700	7,310	11,901	2,730	4,048	21,154	4,355	4,150	6,320	1,194	2,050	148,300

Appendix Table A3. Reconstructed catches (in tonnes) for the recreational sector by FAO area and taxon 1950-2010.

Taxon	FAO area 57	FAO area 71	FAO area 81
Ariidae	1,073	6,112	2,689
Arripis georgianus	48,024	-	-
Arripis trutta	52,128	-	12,951
Bothidae	1,258	447	988
Carangidae	18,157	15,324	5,118
Centroberyx affinis	35,515	-	51,107
Cephalopoda	34,583	3,072	3,861
Clams or cockles and arkshells	508	7	158
Clupeidae	2	401	46
Donax spp.	1,934	900	980
Elasmobranchii	200,352	41,239	36,676
Girella tricuspidata	985	52	16,243
Haliotidae	5,447	-	612
Hemiramphidae	11,256	307	1,228
Kyphosidae	1,715	22	1,404
Kyphosus spp.	3,275	345	39,465
Labridae	24,952	18,905	3,049
Lates calcarifer	4,621	34,875	-
Lethrinidae	13,875	46,370	345
Lutjanidae	3,193	26,145	957
Lutjanus spp.	3,893	53,780	-
Monacanthidae	7,096	88	6,281
Mugilidae	13,357	6,122	8,348
Mullidae	2,154	10	80
Mytilidae	1,563	7	1
Nemadactylus spp.	9,030	754	8,168
Nemipteridae	3,160	395	36
Octopus	834	-	288
Osmeridae	28,309	3,644	586
Oysters	328	1,093	824
Palinuridae	45,386	1,427	761
Pectinidae	673	-	-
Penaeidae	1,705	3,221	6,519
Perciformes	33,886	-	-
Pinna bicolor	27,602	-	-
Platycephalidae	59,744	24,573	51,898
Pleuronectidae	1,258	447	988
Polynemidae	10,341	32,746	-
Pomatomus saltatrix	11,851	9,502	14,777
Portunus pelagicus	51,714	2,731	9,063
Sciaenidae	26,714	13,357	15,583
Scomber australasicus	4,641	296	14,811
Scomberomorus spp.	21,061	75,994	7,519
Scombridae	12,812	15,451	49,383
Scylla spp.	7,901	38,144	1,754
Seriola spp.	751	9,600	10,519
Serranidae	27,288	29,127	1,034
Sillaginidae	78,743	23,261	20,745
Sparidae	82,302	54,868	45,723
Sphyraenidae	26,994	3,225	1,647
Terapon spp.	7,758	5,601	105
Thyrsites atun	25,181	89	89
Trachinotus spp.	1,281	25,041	12,501
Trachurus spp.	5,080	2,933	6,798
Triglidae	977	35	1,905
Marine fishes not identified	10,443	12,603	6,126

Appendix Table A4. Reconstructed catches by the indigenous sector by FAO area and taxon 1950-2010

Taxon	FAO area 57	FAO area 71	FAO area 81
Arcidae	-	1,004	-
Ariidae	497	1,501	-
Arripis georgianus	20	-	-
Arripis trutta	11	-	-
Bivalvia	-	243	-
Carangidae	4,795	6,653	-
Cardiidae	-	46	-
Centroberyx affinis	194	283	104
Cephalopoda	-	224	-
Clams or cockles and arkshells	80	923	-
Clupeidae	117	1,559	-
Donax spp.	-	49	-
Elasmobranchii	1,558	12606	-
Girella tricuspidata	-	2	-
Haemulidae	-	140	-
Hemiramphidae	-	150	-
Labridae	491	1,165	-
Lates calcarifer	558	2,072	-
Lethrindidae	-	1,823	-
Lethrinidae	261	-	-
Lutjanidae	654	2,841	-
Lutjanus spp.	13	410	-
Monacanthidae	9	3	-
Mugilidae	210	4,562	-
Mullidae	-	7	-
Mytilidae	11	499	-
Nemipteridae	32	65	-
Oysters	278	1,052	-
Palinuridae	42	3,502	-
Penaeidae	1	54	-
Platycephalidae	4	56	-
Polynemidae	1,550	3,531	-
Pomatomus saltatrix	-	1	-
Portunidae	272	1,241	-
Portunus pelagicus	8	20	-
Pristipomoides filamentosus	-	-	104
Pseudocaranx dentex	-	-	104
Scaridae	-	145	-
Sciaenidae	-	119	-
Scomber spp.	87	770	-
Scomber australasicus	5	-	-
Scombridae	56	1,665	-
Scorpaenidae	-	7	-
Scylla spp.	365	3,691	-
Seriola lalandi	70	-	313
Serranidae	590	1,792	-
Siganidae	-	5,351	-
Sillaginidae	31	112	-
Sparidae	101	1,157	-
Sphyraenidae	5	54	-
Terapon spp.	116	84	-
Thunnus albacares	-	-	313
Trachinotus spp.	-	49	-
Tridacnidae	-	980	-
Marine fishes not identified	15,189	826	5,126

Appendix Table A5. FAO landings vs. reconstructed total catch (in tonnes), and catch by sector for Norfolk Island, 1950-2010.

Year	FAO landings	Reconstructed total catch	Industrial	Artisanal	Recreational	Indigenous
1950	-	9	-	2	5	2
1951	-	9	-	2	4	2
1952	-	9	-	2	4	2
1953	-	9	-	2	4	2
1954	-	9	-	2	4	2
1955	-	8	-	2	4	2
1956	-	8	-	2	4	2
1957	-	8	-	2	4	2
1958	-	8	-	2	4	2
1959	-	8	-	2	4	2
1960	-	8	-	2	4	2
1961	-	8	-	2	4	2
1962	-	8	-	2	4	2
1963	-	8	-	2	4	2
1964	-	7	-	2	4	2
1965	-	7	-	2	4	2
1966	-	7	-	2	4	2
1967	-	7	-	2	4	2
1968	-	7	-	2	4	2
1969	-	7	-	2	3	2
1970	0.25	7	-	2	3	2
1971	0.25	7	-	2	3	2
1972	0.25	7	-	2	3	2
1973	0.25	7	-	2	3	2
1974	0.25	6	-	2	3	2
1975	0.25	6	-	2	3	2
1976	0.25	6	-	2	3	2
1977	0.25	6	-	2	3	2
1978	0.25	6	-	1	3	1
1979	0.25	6	-	1	3	1
1980	0.25	6	-	1	3	1
1981	0.25	6	-	1	3	1
1982	0.25	6	-	2	3	2
1983	0.25	6	-	2	3	2
1984	0.25	6	-	2	3	2
1985	0.25	7	-	2	3	2
1986	0.25	7	-	2	3	2
1987	0.25	7	-	2	3	2
1988	0.25	7	-	2	3	2
1989	0.25	7	-	2	3	2
1990	0.25	7	-	2	3	2
1991	0.25	7	-	2	3	2
1992	0.25	6	-	2	3	2
1993	0.25	6	-	2	3	2
1994	0.25	6	-	2	3	2
1995	0.25	6	-	2	3	2
1996	0.25	6	-	2	3	2
1997	0.25	6	-	1	3	1
1998	0.25	6	-	1	3	1
1999	0.25	6	-	1	3	1
2000	0.25	6	-	1	3	1
2001	0.25	38	32	1	3	1
2002	0.25	38	32	1	3	1
2003	0.25	38	32	1	3	1
2004	0.25	6	-	1	3	1
2005	0.25	5	-	1	3	1
2006	0.25	5	-	1	3	1
2007	0.25	9	-	2	4	2
2008	0.25	4	-	1	2	1
2009	0.25	6	-	2	3	2
2010	0.25	6	-	2	3	2

Appendix Table A6. Reconstructed total catch (in tonnes) by major taxa for Norfolk Island, 1950-2010. 'Others' contain 12 additional taxonomic categories.

Year	*Epinephelus lanceolatus*	*Lethrinus miniatus*	Others
1950	3	4	1
1951	3	4	1
1952	3	4	1
1953	3	4	1
1954	3	4	1
1955	3	4	1
1956	3	4	1
1957	3	4	1
1958	3	4	1
1959	3	4	1
1960	3	4	1
1961	3	4	1
1962	3	4	1
1963	3	4	1
1964	3	4	1
1965	3	4	1
1966	3	4	1
1967	3	3	1
1968	3	3	1
1969	2	3	1
1970	2	3	1
1971	2	3	1
1972	2	3	1
1973	2	3	1
1974	2	3	1
1975	2	3	1
1976	2	3	1
1977	2	3	1
1978	2	3	1
1979	2	3	1
1980	2	3	1
1981	2	3	1
1982	2	3	1
1983	2	3	1
1984	2	3	1
1985	2	3	1
1986	2	3	1
1987	2	3	1
1988	2	3	1
1989	2	3	1
1990	2	3	1
1991	2	3	1
1992	2	3	1
1993	2	3	1
1994	2	3	1
1995	2	3	1
1996	2	3	1
1997	2	3	1
1998	2	3	1
1999	2	3	1
2000	2	3	1
2001	2	3	33
2002	2	3	33
2003	2	3	33
2004	2	3	1
2005	2	3	1
2006	2	3	1
2007	3	4	1
2008	1	2	1
2009	2	3	1
2010	2	3	1