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Evidence for overfishing on pristine coral reefs: reconstructing coastal catches in the Australian Indian Ocean Territories

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The fisheries statistics systems of many countries are performing poorly, often failing to report on small-scale catches, particularly from subsistence and recreational fisheries. These deficiencies, which lead to the underestimation of catches, are particularly evident in overseas territories of developed countries. This study is an attempt to remedy this for the years 1950–2010 for the Australia Indian Ocean Territories, an area from which little reporting is done. The results suggest that the Cocos (Keeling) Islands had a catch of approximately 80 t·year⁻¹ in the 1950s (essentially subsistence based), which increased, starting in the mid-1980s to reach 250 t·year⁻¹ in recent years, mainly due to the introduction of recreational and later commercial fishing, with signs of overexploitation since 2000. The coastal catch from Christmas Island was tentatively assessed as being higher (40–70 t·year⁻¹) in the 1950s and 1960s than in the 2000s (<30 t·year⁻¹). Fisheries managers in these areas should focus on determining primary target species and their vulnerability to overfishing, as well as developing island specific recreational fishing management plans.

Keywords: Cocos (Keeling) Islands; Christmas Island; subsistence fishing; recreational fishing; overfishing; coral reefs

Introduction

Overexploitation of marine resources continues worldwide despite growing appreciation for the need to maintain marine ecosystem health and biodiversity (Pauly et al., 2002). Fisheries management has traditionally focused on large-scale commercial operations, mainly because of their economic importance and potential for overexploitation. Consequently, fisheries managers have typically ignored a significant portion of the world's catches – those derived from artisanal, subsistence and recreational fishing (e.g., Jacquet, Fox, Motta, Ngusaru, & Zeller, 2010; Le Manach et al., 2012; Zeller, Booth, Davis, & Pauly, 2006; Zeller, Booth, & Pauly, 2007).

Historically, the importance of subsistence and artisanal fishing operations occurring along much of the world's coasts has gone unrecognized and subsequently unreported, or at least substantially under-reported (Zeller et al., 2007). In places where reporting has occurred, catch statistics are often too vague to be useful for ecosystem analyses (Watson, Kitchingman, Glechu, & Pauly, 2004). The high prevalence of unreported subsistence, artisanal and recreational fisheries catches represents a critical knowledge gap in fisheries management, and subsequent data users often interpret non-reported or missing data as 'zero' catches (Zeller et al., 2006). Despite the general notion that they are data poor,

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small-scale fisheries have recently been demonstrated to play important roles in economics, food security, culture, society and recreation (e.g., Boistol, Harper, Booth, & Zeller, 2011; Chuenpagdee, Liguori, Palomares, & Pauly, 2006; Le Manach et al., 2012; Lingard, Harper, Ota, & Zeller, 2011; Sadovy, 2005; Zeller et al., 2007). It is thus both necessary and justifiable to retroactively estimate catches using subjective inferences and interpolation methods in order to gain insight into historical catch trends based on the premise that the alternative assumption of zero catch is less desirable (Pauly, 2007; Watson, Rashid Sumaila, & Zeller, 2011; Zeller et al., 2007).

Many small islands, where substantial subsistence fishing occurs, are associated with larger developed countries, for example, Cocos (Keeling) Islands and Christmas Island, which are both Indian Ocean Territories of Australia. Despite this association, these small islands retain much of their traditional way of life, including being heavily dependent on marine resources (Alder, Hillard, & Pobar, 2000). Currently, the small-scale fisheries occurring in these islands are excluded from the reporting of Australian national fisheries statistics. The remote nature of these islands and low urban development often result in them being described as pristine ecosystems (Australia, 2005). However, there have been recent reports of local extinctions and significant decreases in density of highly sought after marine species, especially in the Cocos (Keeling) Islands (Hender, McDonald, & Gilligan, 2001). As such, it is the aim of the present study to apply a 'reconstruction approach' (Zeller et al., 2006) to derive historic catch time series for the Australian Indian Ocean Territories (AIOT): Cocos (Keeling) Islands (CKI) and Christmas Island (CI). Note that the catch data presented here pertain only to coastal catches, i.e., they exclude large pelagic fishes (mainly tuna).

Geographical, environmental and historical review of the island areas

Cocos (Keeling) Island (12°12'S, 96°54'E) is situated in the eastern Indian Ocean, lying approximately 2,950 km northwest of Perth, Australia and about 1000 km southwest of Java, Indonesia (Figure 1). The CKI consist of 27 low lying islands, which comprise two atolls: North Keeling Atoll and South Keeling Atoll. North Keeling Island remains uninhabited and in 1995 was established as Pulu Keeling National Park, where access is by permit only. The population is concentrated on the South Keeling Atoll.

The South Keeling islands were first settled by John Clunies-Ross and Alexander Hare in 1827, who brought with them workers from Java and Sumatra (Gibson-Hill, 1946), prior to this the islands were uninhabited. The Clunies-Ross family became known as the 'King of Cocos', reigning over the island for more than 150 years (Woodroffe & Berry, 1994) and operated a feudal-style government whereby the Malay population (descendants of the original workforce brought in 1827) worked on the family's coconut oil plantation in exchange for housing and food until the 1950s. During this period, the islands were annexed by Britain, however, Queen Victoria granted full control to the Clunies-Ross family of the islands 'in perpetuity' (Kerr, 2009; Woodroffe & Berry, 1994). In 1955, the islands became a territory of Australia and in 1978, unsatisfied with the Clunies-Ross rule of the island, Australia purchased all the lands except for the family home (Woodroffe & Berry, 1994). However, it was not until 1984, that the Malay population still residing in CKI became citizens of Australia (Kerr, 2009).

Since the 1950s, the population on the CKI has fluctuated between 600–700 people, with a slight decreasing trend in the late 1970s (Figure 2). The vast majority of the current population are 'Cocos-Malay' people who have maintained a largely traditional way of

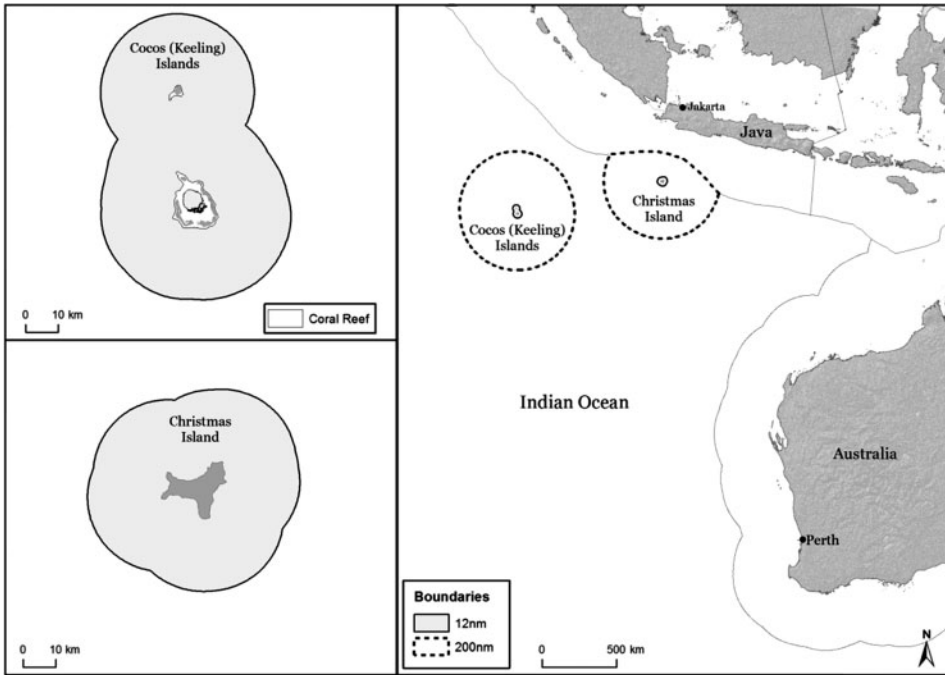


Figure 1. Map of the eastern Indian Ocean showing the locations of Cocos (Keeling) Islands and Christmas Island in relation to major landmasses in the region. The boundaries shown are the 12 nautical mile limit of the Australian Fisheries Management Authority excepted waters and the 200 nautical mile Australian Exclusive Economic Zone.

life rooted in Islam. They are heavily reliant on local marine resources for protein, although this may have decreased slightly with mainland Australia’s increasing presence. However, shipped products are expensive and employment opportunities on the island are few. Thus, many locals remain rooted in traditional cuisine and resource use. Culturally important species are the giant clam (*Tridacna* spp.), spider conch shell (*Lambis lambis*)

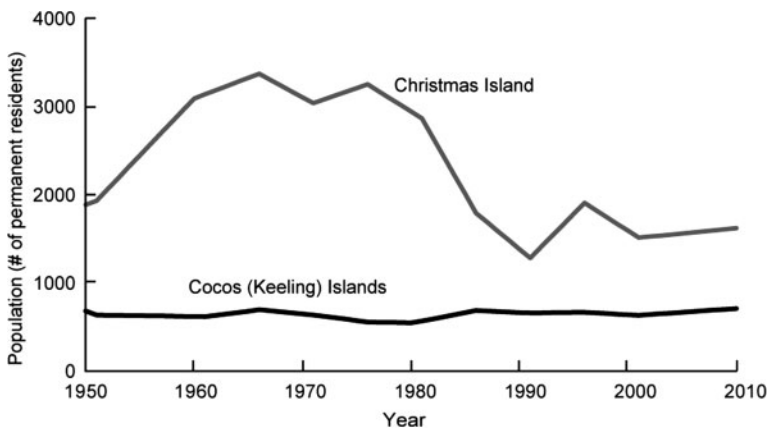


Figure 2. Population estimates for Cocos (Keeling) Islands and Christmas Island from 1950–2010.

and coral trout (*Plectropomus leopardus*) (Gibson-Hill, 1946; Hender et al., 2001). The locals do not consume sharks but, if sharks are captured their fins may be dried and sold informally to passing international vessels heading to Indonesia (Gibson-Hill, 1946). This occasional source of income is likely to have decreased with increasing Australian presence on the islands and it is extremely unlikely that a prominent shark export trade exists today. Fresh water and land suitable for agriculture are scarce on the islands.

A small proportion of the CKI resident population is comprised of Australian expatriates and government workers. It is thought that this portion of the population, relative to the Cocos-Malay people, relies more on resources brought in from mainland Australia, but contributes substantially to a recreational fishing sector. There is a relatively small tourism industry, which has been increasing, with currently approximately 150 beds available for tourism and flights occurring 1–2 times a week from Perth, Australia. The main attractions to tourists are fishing and diving.

Christmas Island (10°30'S, 105°40'E) is located 2600 km northwest of Perth and 290 km south of Java, Indonesia (Figure 1). Geologically, although part of the same Vening-Meinesz seamount chain, CI differs drastically from CKI. CI is mountainous, surrounded by a fringing reef which quickly drops off to deep, oceanic water (Hourston, 2010). Although less remote than CKI, CI remained uninhabited until the late 1800s when the Clunies-Ross family established a permanent settlement to provide lumber for use on CKI (Hourston, 2010). Soon after, the settlement expanded to provide workers for phosphate mining. At this time, the island was annexed by Britain and was later co-managed with Singapore. In 1957, the island was transferred to Australia. The majority of the island has since been designated a national park (Christmas Island National Park).

The population of CI has fluctuated since the 1950s, likely a result of its boom and bust economy (Roughan, Casement, Simpson, & Stovell, 2011), and its current size is approximately 1600 permanent residents (Figure 2). In addition to phosphate mining, a large casino and resort was opened on the island in 1993, aimed primarily at a rich Asian clientele. However, the resort began losing money and was shut down in 1998, causing job losses. The resort has since re-opened without the casino in an attempt to bring jobs and money to the island but without the potential dire consequences of a casino in a small community. The resort is now one of four, forming the backbone of a small tourism industry. Like the CKI, most tourists come to the island for either fishing or diving.

Much like those of the CKI, the local residents of CI are the descendants of mainly Chinese and Malaysian workers. Resources are brought in from mainland Australia. However, they are expensive, and mainly consumed by the small Australian expatriate population. Less is known about the traditional and subsistence needs of the local people on CI than the CKI; however, it is thought that they also rely heavily on local marine resources. The bulk of the research about local biodiversity has focused on the (terrestrial) red crab (*Gecarcoidae natalis*) and bird populations. There has been little study on local marine resources, and their level of exploitation and vulnerability remains unknown.

For a detailed description of the Australian acquisition of the CKI and CI, see *A Federation of these Seas* by Allan Kerr (2009).

Methods

The coastal catches of the AIOT have gone unreported. Therefore, marine coastal catches had to be entirely reconstructed. The methods used in this study were based on the methodology of Zeller et al. (2006). Estimates of marine catches were based on a

literature review that utilized single year anchor points of catch data, *per capita* catch rates, human population data, interpolation techniques and anecdotal information. The available coverage in terms of fisheries sectors, targeted species, and culturally important information differed between island areas. Consequently the development of data anchor points also differed between the CKI and CI. The following sections outline, in detail, the methods used for each island territory.

Cocos (Keeling) Islands

Small-scale Fishing

Small-scale fishing on the CKI consists of both subsistence and artisanal fishing. For the purposes of this study, subsistence fishing was defined as any fishing activity that does not generate an income above that needed to live at the most basic subsistence level. In contrast, artisanal fishing is defined as that carried out by individuals or households involving low investment in technology and gear whose catch is usually sold locally. The literature search uncovered two anchor points described as subsistence fishing for the years 1992 (Alder et al., 2000) and 1993 (Hender et al., 2001). In order to derive a complete time series of catch estimates we converted these anchor points to an average *per capita* consumption rate.

In order to estimate an average catch rate *per capita* it was necessary to first estimate the annual human population of the CKI since 1950. The Australian Bureau of Statistics (ABS) has been collecting census data every 5 years since 1986 for the CKI. Prior to 1986, population estimates were found on Populstat (www.populstat.info) for the following years: 1940, 1951, 1961, 1966, 1971, 1976 and 1981. In order to obtain a complete population time series since 1950, a linear interpolation between years of known data was used to estimate the population for unknown years.

The 1992 and 1993 subsistence catch estimates given by Alder et al. (2000) and Hender et al. (2001) were given as ranges. The median for each range was used to calculate an average between the two years. Also calculated was the average population for those two years. Therefore, the average catch rate in kilograms per person was calculated by dividing the average catch of 1992 and 1993 by the average population in those years. The average catch rate was found to be $115.11 \text{ kg}\cdot\text{person}^{-1}\cdot\text{year}^{-1}$. We assume that the *per capita* catch rate in 1950 was the same as for the 1992–93 period. Thus, we multiplied this average *per capita* catch rate by the total population size for each year since 1950 to estimate the subsistence catch per year.

In small communities, it is often difficult to distinguish between fish used strictly for subsistence needs (i.e., self- and family-consumption, and local barter and exchange) and fish that are sold to generate income for the household. In order to account for artisanal catch, we assumed no market economy existed prior to 1985. The arrival of Australian expatriates and government employees in the mid-1980s, together with a budding tourism industry, stimulated the economy, and hence stimulated the growth of an artisanal (i.e., small-scale commercial) sector. As such, it was assumed that 10% of the estimated total subsistence catch turned into artisanal fishing from 1985 onwards. The artisanal catch remained constant at 10%, because resources brought in from mainland Australia are expensive, consequently it is likely that Cocos-Malay people continued to fish for themselves as opposed to transitioning over time to purchasing all their food.

Recreational fishing

Recreational catch can be defined as fishing where the main motivation is not consumption, trade or sale of the catch, but rather enjoyment. It is unlikely that prior to 1985 there was much recreational fishing occurring due to the absence of non-Cocos-Malay people in the CKI. As such, it was assumed that prior to 1985 the recreational catch was zero. For the remaining time period, two anchor points were found; one in 1993 and another in 2001 (Hender et al., 2001). A linear interpolation between a catch of zero tonnes in 1984 and an average recreational catch of 22.5 tonnes in 1992 (Hender et al., 2001) was done to estimate annual recreational catches for the missing years. Similarly, an interpolation was used between the 1992 recreational catch estimate and a 2001 average recreational estimate of 106.2 tonnes (Hender et al., 2001). The observed increase in recreational catches between these two anchor points is large. It is likely erroneous to assume that recreational catches continued to increase at such a rate past 2001, especially when tourism trends are considered.

The tourism industry in the CKI remains relatively small, with regular flights initiated in the early 1990s. In addition, there have been no major developments to increase the tourist capacity on the island within the last decade. As a result, the recreational catch from 2002 to 2010 was estimated using a per tourist catch rate. Available on the ABS website are hotel occupancy rates for each state since 2001. In order to estimate the occupancy rate for hotels in the CKI, the state of Western Australia's (WA) statistics were used as this is the governing state body of the AIOT. We were able to estimate the number of beds available for tourists on the island (approximately 150) and use the annual average occupancy rate supplied by WA to determine the likely number of tourists on the island per year. It was then possible to take the recreational catch known in 2001, divide it by the number of tourists for 2001 to yield a per tourist catch rate of 25 kg assuming that each tourist stays one week. The recreational catch rate from 2002 to 2010 was calculated by multiplying the number of tourists visiting the CKI per year based on a 1 week stay using an average occupancy rate as collected by the WA government. Although the estimated catch of 25 kg per tourist may be high and not all tourists are going to fish, our estimate of recreational catch was considered conservative as the recreational catch of local residents was not estimated in addition to this.

Commercial fishing

Currently, there appears to be five commercial fishing licences on issue, only one of which is considered active and it is a permit for the capture of live aquarium fish (beginning in 1993). Our study does not include fish taken for the aquarium trade, thus these data were excluded. Two more permits (out of the five) were issued beginning in 2002 by the Australian Fisheries Management Authority (AFMA) for exploratory purposes (AFMA, 2002). At this time, the total allowable catch (TAC) was set at 20 tonnes per permit annually. It is unknown to the authors whether or not this exploratory fishing continues to occur; the permits are renewed each year but the fishery may be inactive. When contacted, the AFMA maintained its policy that prohibits the release of catch data to researchers. Thus, we assumed that since the licences are issued annually, the fishery remains active and catches its total TAC of 20 tonnes. The final two of the five permits issued allow Australian boats to fish for tuna in the CKI and CI

offshore longline fisheries. However, these catches were not included here as large pelagic fishes (i.e., tunas) were not considered in this analysis.

The total annual catch from 1950 to 2010 was derived by adding the annual catches from subsistence, artisanal, recreational and commercial fishing sectors.

Taxonomic breakdown of the catch

The baseline for determining what species comprise the catch came from an anthropological study completed in the mid-1940s, which outlined the catch supplied to European workers of the Cocos Cable Station over a 4-month period by local Cocos-Malay fishers (Gibson-Hill, 1946). The lowest taxonomic unit that could be distinguished was the family level with fish from the following families Serranidae, Latidae, Lethrinidae, Lutjanidae, Gerridae, Labridae and Carangidae all contributing to the catch. The average proportion of each family over the 4-month period was calculated. When comparing the above list of families with other sources describing fisheries targets, it was found that it was a reasonable representation of reef fish, but failed to incorporate some culturally important species that would have likely been kept and consumed by Cocos-Malay fishers and not given to the European workers (i.e., spider conch shell, giant clam and sea cucumbers). Thus, the proportions were adjusted such that 90% of the catch is comprised of the aforementioned seven reef fish families, with the remaining 10% allocated to spider conch (*Lambis*; 5%), sea cucumber (Holothurians; 2.5%) and *Tridacna* spp. (2.5%).

The above proportions were assumed to be constant from 1950 to 1992. In 1993 and again in 2001, there were studies conducted on the densities of fish on the CKI (Hender et al., 2001). In particular, it was noted that the density of groupers (Serranidae), which made up the highest proportion of the catch in the 1940s, had declined from 136 individuals·hectare⁻¹ to 36 individuals·hectare⁻¹ (a decrease of about 75%). It is thus unlikely that the high proportion of Serranidae observed earlier in the catch continued throughout the 1990s. Therefore, we decreased the proportion of Serranidae in the catch in equal increments between the years 1993 and 2002, and increased the contribution of the other reef fish families accordingly. From 2003 onwards, the proportions of the reef fish families were assumed to remain constant.

Similarly, it was found that the giant clam may now be extinct from the near shore waters of the CKI. According to a study conducted in 2001, there were only two individuals of *Tridacna gigas* known from the atoll at the time (Hender et al., 2001). In order to account for the change in density of *Tridacna* spp., the proportion of the total catch decreased from 2.5% to 0.005% from 1993 to 2002. In order to account for this change, the proportion of spider conch shells increased to make up the difference. The increase in spider conch is justified, because prior to contact with mainland Australia, its collection was largely restricted to exposed reefs during low tide, whereby women and children would collect them by hand. However, increased access to equipment such as masks and snorkels has made it possible to now access spider conchs in deeper waters (J. Hender, pers. comm., Australian Department of Climate Change and Energy Efficiency).

Christmas Island

Small-scale fishing

Our literature search yielded no quantitative data on subsistence or artisanal fishing on CI. In order to estimate catches for these sectors, a seafood consumption estimate was used.

The first step in this approach was to estimate annual resident population since 1950. This was done in the same manner as for Cocos (Keeling) Island, first using ABS and Populstat to provide anchor points, followed by linear interpolations between census population estimates.

The next step was to determine an estimate of *per capita* consumption of seafood on CI. The World Health Organization (WHO) suggests that in 1997 the global average was ~16 kg of fish *per capita*, with island countries having substantially higher dependence on protein derived from fish (www.who.in/en). A study conducted by Bell et al. (2009) found that fish consumption in the Pacific Islands and territories to be much higher than what was indicated by the WHO. On average, Pacific Island countries and territories consume 50.7 kg *per capita* per year (Bell et al., 2009). It is likely that CI has fishing habits similar to other Pacific countries, but to remain conservative, a *per capita* consumption rate of 35.5 kg was used for the 1950–1989 time period. A key difference to note between CI and CKI, is that CKI is a coral atoll environment with easy access to reef resources, which may explain the very high *per capita* consumption rate calculated, whereas CI is a volcanic island with a limited coral reef and a unique coastline, which limits access to what marine resources are present (recall: *Geographical, environmental and historical review of the island areas* in the introduction section). Furthermore, an increasing presence from mainland Australia not yet experienced in CKI would likely have decreased fish consumption rates on CI due to increased availability of alternative protein sources shipped from the mainland. Therefore, beginning in 1990, we assumed *per capita* consumption started to decrease so that by the year 2000, it had declined by 30%. For the remaining years it was assumed that the *per capita* consumption rate remained constant and the rate for 2000 was thus carried forward, unaltered to 2010. To further remain conservative, only 60% of the population was considered to partake in small-scale fishing throughout the entire time period.

For the purpose of this study, it was necessary to allocate proportions of the total small-scale catch to either subsistence or artisanal sectors. CI has had a stronger presence from mainland Australia than the CKI due to phosphate mining, resort development, asylum seekers and the development of a large immigration detention centre. Consequently, there has been greater potential for market growth over a longer period of time. Subsistence fishing was considered responsible for 75% of the total small-scale catch and artisanal fishing comprised the remaining 25%. These proportions remained unchanged from 1950–2010.

Commercial fishing

There exists one commercial fishery operating out of CI; the Christmas Island Line Fishery (CILF). It is not known exactly when the fishery opened, but there were six commercial fishing permits issued as early as 1992 (Anon., 1997). However, by 2007, there were only three commercial fishing permits available and only one operating in 2008 (Fletcher & Santoro, 2008). In keeping with Western Australia's privacy policy, reported catches were not available. As such, catch was estimated since 1992, gradually decreasing the number of boats (assumed to be less than 10 m) fishing for 100 days of the year with a starting catch rate of 30 kg·day⁻¹. This catch rate was assumed to remain constant for the rest of the study period.

Recreational fishing

Information on recreational fishing for CI was unavailable. As such it was calculated by taking a proportion of the artisanal catch (see above for artisanal methods). In 1950, 5% of the artisanal catch was assigned as recreational fishing and using linear interpolation, the recreational catch increased to account for 55% of what was calculated as artisanal catch. The change in the amount of recreational catch over time increased because it is thought that the amount of leisure time and number of travellers visiting the island are likely to have increased throughout the study period. However, it is likely that recreational fishing occurs to a lesser extent than on CKI due to the substantially more difficult accessibility of coast and coastal waters on Christmas Island.

Taxonomic breakdown of catch

There are no studies that investigated the species caught from either small-scale or commercial fishing on CI. Thus, we used the catch composition established for the CKI due to similarities between the reef species composition on the two islands, with some small adjustments. Thus, we assume again that seven reef fish families (Serranidae, Latidae, Lethrinidae, Lutjanidae, Gerridae, Labridae and Carangidae) comprise 60% of the total catch from 1950–2010, with the remaining 40% being divided between crustaceans (25%) and an ‘other invertebrates’ category (15%).

Results

Cocos (Keeling) Islands

The total reconstructed estimate of coastal catches for the CKI over the 1950–2010 time period was 6453 tonnes. Estimated catches have risen from approximately 70 t·year⁻¹ in the 1950s to 250 t·year⁻¹ in the late 2000s (Figure 3). This has occurred despite the population remaining quite stable (Figure 2). Prior to the early 2000s, the bulk of the catch was taken by local subsistence fishers. However, beginning in the early 1990s, fishing by other sectors (recreational and commercial) began increasing. Presently, it is

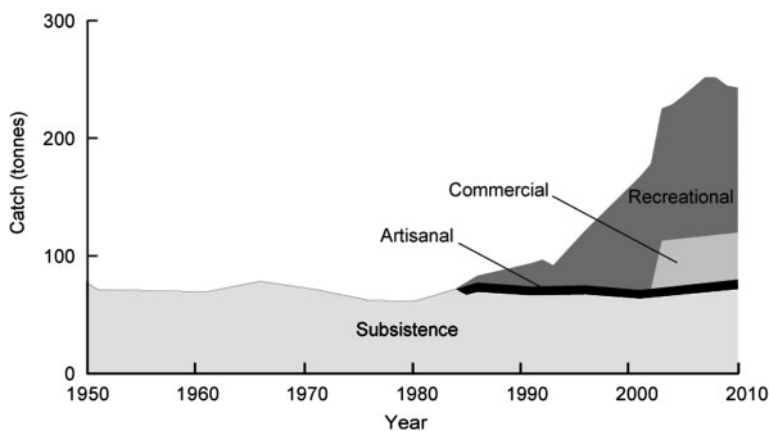


Figure 3. Estimated total catch for Cocos (Keeling) Island, a remote Australian Indian Ocean territory, from 1950–2010 indicating individual fishing sector contributions.

estimated that the commercial and recreational fishing sectors extract over three times as much as small-scale fishing (subsistence and artisanal) in any given year (Figure 3).

The analysis regarding species landed from the CKI revealed that the majority of fish caught are likely to be groupers (Family Serranidae) especially prior to the early 1990s (Figure 4). Prior to their decrease in the 1990s, serranids comprised 63% of the total catch and more recently comprise 15% of the total annual catch.

Christmas Island

The total reconstructed estimate for coastal catches of CI over the 1950–2010 time period was 3089 tonnes. The total catch on CI peaked at 70 t·year⁻¹ in the mid-1960s and is presently estimated to be about 30 t·year⁻¹ (Figure 5). The catch almost doubled from 1989 to the mid-1990s (resulting in a secondary peak) which can be explained by the introduction of a commercial fishing sector in 1992. After a short-lived increase, catches again declined. This was both a product of decreased consumption and decreased effort in the commercial sector. This led to a decline in catches to approximately 30 t·year⁻¹ by the late 2000s.

As a result of our assumption, the taxonomic breakdown of the catch is dominated by reef fish families, each of which comprise approximately 8% of the total annual catch from 1950–2010 (Figure 6). Crustaceans are likely to comprise a significant proportion of annual catches estimated to be about 25% in this study. The ‘other’ category accounts for the exploitation of other invertebrates such as squid and bivalves.

Discussion

The present study used a reconstruction approach (Zeller et al., 2006) to retrospectively calculate the total catch, as well as the contributions of individual fishing sectors and the taxonomic breakdown of the catch for 1950–2010 for the Australian Indian Ocean

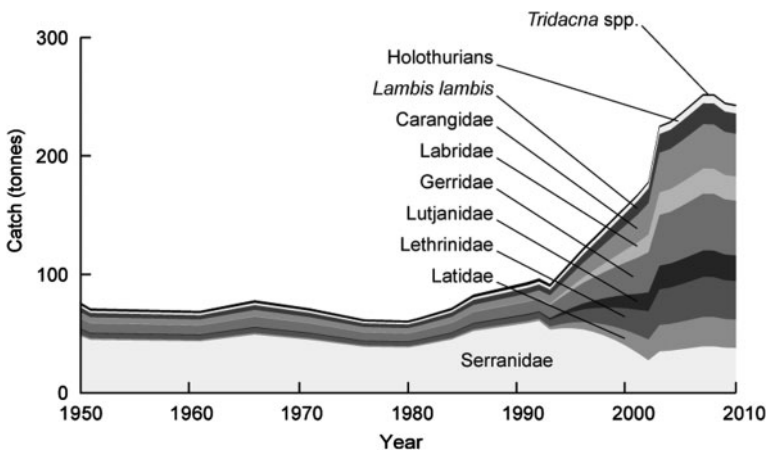


Figure 4. Taxonomic breakdown of Cocos (Keeling) Islands total catch from 1950–2010; *Tridacna* spp. (Giant Clams), Holothurians (Sea Cucumbers), *Lambis lambis* (Spider Conch Shell), Carangidae (Jacks and Mackerels), Labridae (Wrasses), Gerridae (Mojarres), Lutjanidae (Snappers), Lethrinidae (Emperors), Latidae (Perches) and Serranidae (Groupers).

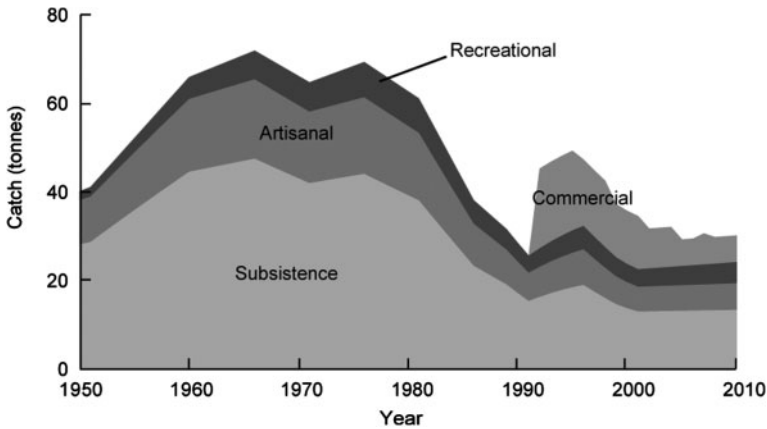


Figure 5. Estimated total catch for Christmas Island, an Australian Indian Ocean territory, from 1950–2010 indicating different fishing sector contributions.

Territories. There has been no formal collection of data for these territories and therefore this is the first attempt to provide a historical total fisheries catch time series for these islands. The results suggest that fishing is far from negligible, with the CKI landing approximately 250 tonnes and CI landing approximately 30 tonnes in 2010.

What remains to be determined is the level of fishing that can be sustained. One such estimate was generated in 1999, based on standing stock biomass collected in 1993 leading to an estimated sustainable catch rate of 160–320 tonnes per year (Hender et al., 2001). Thus, our results suggest that overfishing may have been occurring in the waters of the CKI for about a decade. These results are further supported by anecdotal evidence describing local depletions of less resilient species such as coral trout (*Plectropomus* spp.) and other serranids (groupers; as mentioned above), and humphead wrasse (*Cheilinus undulatus*) (Hender et al., 2001; Hourston, 2010). For both islands, recreational fishing

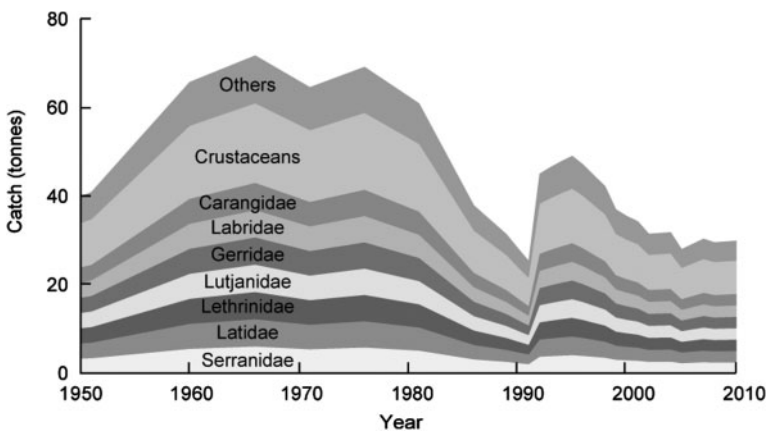


Figure 6. Taxonomic breakdown estimated for Christmas Island catch, 1950–2010; Others (Squid, Molluscs & other invertebrates), Crustaceans (Crabs, Prawns, etc), Carangidae (Jacks and Mackerels), Labridae (Wrasses), Gerridae (Mojarres), Lutjanidae (Snappers), Lethrinidae (Emperors), Latidae (Perches) and Serranidae (Groupers).

presents a problem. The CKI's small-scale fishery, apart from a few culturally important species, likely remains below the estimated sustainable annual stock yield (Hender et al., 2001). The recreational fishing industry has grown substantially in the last two decades, placing unprecedented pressure on the marine populations of the atoll.

We have no evidence suggesting any overfishing around CI. However, the lack of information on CI is alarming. The present study recovered no information regarding recreational catches or cultural practices catches for the recreational sector on CI, which for CKI, was a substantial component of the total catch since the mid-1990s. The recreational catch calculated in this study should be regarded with caution and an emphasis on better data collection for this sector should be a priority, especially given the significant impacts of recreational fishing found for the CKI. The need for management of the marine resources of the Australian Indian Ocean Territories is not lost on the Australian Government: 'Island specific recreational fisheries management arrangements for the Indian Ocean Territories are currently being progressed to legislation' (Anon., 2011).

In addition, the consumption rate used for CI in this study was a conservative *per capita* estimate of 35.5 kg at the start of the time series, and 24.85 kg at the end of the study period. Comparable island entities have been found to have much higher *per capita* consumption rates (Bell et al., 2009; Gillett, 2009; Trujillo, Harper, & Zeller, 2011). Therefore, it is important to find out what the habits of Christmas islanders are. Currently, there is little information regarding their dietary or cultural habits and this represents a critical limiting factor for the methods used to determine catches in this study. Research tactics such as a household surveys every couple of years would provide a greater understanding of the needs of these islanders (Zeller et al., 2007).

Near-shore, commercial fishing in both territories appears to be minimal. However, the study was hindered by inaccessibility to officially collected catch data. A report for the CKI evaluated the viability of commercial fishing for some species, such as sea cucumbers, and spider conch shell. However, it also found that the majority of 'potential' fisheries candidates were not actually viable (Hourston, 2010). The commercial catch for the CKI estimated here assumed that exploratory fishing continues to occur in the absence of a CKI-specific fisheries management plan. In contrast, the commercial fishing which takes place at CI does have some form of management in place.

Another problem in the EEZ of CI is illegal foreign fishing (Anon., 1997). The EEZ claimed by Australia for CI and by Indonesia for Java overlap, which has created disputes over fishing rights and management of resources. Australia reported that in the 1990s, 40–60 illegal foreign fishing vessels were apprehended per year in the EEZ of CI (Anon., 1997). Although illegal fishing was not included in this analysis, it should be addressed by resource managers.

It should also be noted that large-scale commercial fishing for large pelagic species such as tuna and billfish do occur in the EEZ of both CKI and CI. These data were not included in this report as the fishery is part of the Western Australia Tuna and Billfish fishery, which also fishes off the west coast of Australia. These data are difficult to disaggregate spatially and are likely accounted for in the statistics of responsible Regional Fisheries Management Organizations (Indian Ocean Tuna Commission) and by FAO reported landings for Australia. The interaction between this commercial fishery and the small-scale fishing sector is not well understood and research of this interaction would be crucial to any fisheries management plan.

Overall, this study found the extraction of fisheries resources from the Australian Indian Ocean Territories to be significant, and thus requires implementation and enforcement of a fisheries management plan specific to each island area. The time series presented here are an attempt to provide managers with an estimation of historic catches in areas where fishing is occurring but reporting is not. It is hoped that fishing on what are considered some of the last pristine reefs of the world does not continue to go unnoticed and unmanaged because of the notion that impacts resulting from small-scale fishing are negligible.

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