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Review of the exploitation of marine resources of the Australian Indian Ocean Territories: the implications of biogeographic isolation for tropical island fisheries

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Cover image: *Etelis coruscans* (flame snapper) and *Lambis lambis* (gong gong).

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Review of the exploitation of marine resources of the Australian Indian Ocean Territories and the implications of biogeographic isolation for tropical island fisheries

Mathew Hourston

Executive Summary

The small islands of the Indian Ocean Territories are isolated reefs in an expanse of open ocean of abyssal depth. The majority of marine species that live on their reefs and lagoons have settled there from remote locations. Colonising individuals are presumed to have come to the island as the result of unusual weather and current conditions and form populations that are, necessarily, largely self-sustaining. The isolated populations that make up many of the fish and invertebrate stocks at the Cocos (Keeling) and Christmas Islands rely almost exclusively on larvae returning to their home reef to settle, grow and ultimately reproduce to maintain their numbers. This insularity is, in many cases, a direct implication of the constraints imposed on species by their own biology and reproductive strategy. In the event that a species is lost from either of the islands, recolonisation is dependent on reoccurrence of the unusual colonisation events. The vulnerability of these stocks is further exacerbated by the tiny size of the islands. The small reefs and lagoon only have the capacity to sustain small stocks of fish and invertebrates, ones that are very much at risk to chance events such as localised overfishing, anoxia events or over predation.

Many of the island's stocks of fish and invertebrates are highly vulnerable and isolated; they have very little resilience to overfishing, and once depleted have almost no capacity to recover. Evidence for the fragility of the stocks is demonstrated by the regional extinctions at the Cocos (Keeling) Islands of barramundi (*Lates calcarifer*) and threadfin salmon (*Polynemus indicus*) within the past 50 years or so, and the drastic depletions or extinctions of species such as giant clams (*Tridacna gigas*), square-tail coronation trout (*Plectropomus areolatus*) and lagoon Lutjanids within only the last 10 years. At Christmas Island the stocks of deep slope fish such as *Etelis* spp are also reputedly depleted in localised accessible areas of the coastline, and the resident stocks of dog-tooth tuna (*Gymnosarda unicolor*) are at extremely low numbers.
Given the geographical constraints and implications for the fish stock in those areas, this review examines each of the fisheries individually to identify specific research or management gaps and issues. This includes the two existing DoF managed commercial fisheries; the CKIMAFF (Cocos Keeling Island Marine Aquarium Fish Fishery) and the CILF (Christmas Island Line Fishery), potential commercial fisheries (*e.g.* bêche-de-mer and crystal crabs) as well as the harvest of various popular recreational species (*e.g.* finfish, gong gong and giant clams). These are presented as follows:

CKIMAFF

An assessment of the CKIMAFF seems to be prudent given that the current quota is underutilized and the actual catch is much smaller than the total allowable quota. This action would help to ensure long-term viability of the stocks of the endemic Cocos Pygmy Angelfish and is not expected to affect the economic viability of the fishery nor the day-to-day operations of its licensed fisher.

Finfish and CILF

Stock size and connectivity of demersal scalefish on Christmas and Cocos (Keeling) Islands has been identified as a research priority by the DoF. Studies are currently underway to assess these critical parameters of the commercially and recreationally targeted fish species. Commercial fisher activity in CILF has been determined to have only a small effect on the finfish stocks of the IOTs and as such is not a high priority for management review.

Recreational fisher activity has been identified as both a research gap and a management priority, particularly in the case of the Cocos (Keeling) Islands. Stock size and diversity of catches of demersal and pelagic fish have been notably depleted and possibly irreversible changes to the fish and invertebrate stocks are already thought to have occurred. IOT's Island-specific recreational fisheries management arrangements are currently being finalised for legislation, rather than enforcing the current mainland fishing regulations. This approach is hoped to be better suited to the IOT fish stocks as well as more likely to be accepted by the local population.

Deep-Sea Crystal Crabs

Stocks of deep-sea crystal crabs in the IOTs are considered unlikely to provide the basis of a commercially viable fishery largely because of the rarity and fragmentation of their preferred depth range in the Australian EEZ around the IOTs. That being said, strictly controlled exploratory fishing for the development of this potential fishery may be appropriate given the paucity of relevant information on these stocks. It is recommended that any exploratory activities operate under a very strong precautionary principle since existing fisheries managed by DoF for this species are yet to show long-term stock trends, even in mainland waters.

Gong Gong

Department of Fisheries research into the stocks of gong gong at Cocos (Keeling) Islands was instigated in 2007 and remains ongoing. Habitat associations and estimates of stock size are relatively well understood, however relevant aspects of this species' biology remain to be researched. Recreational harvesting of gong gong is a very popular and regular pastime of the Cocos-Malay population, to the point where concerns for the sustainability of the stocks have been expressed. The inclusion of gong gong in the present review of recreational fishing regulations is recommended.

Bêche-de-mer

Bêche-de-mer stocks at the Cocos (Keeling) Islands were found to have moderate densities, but due to the small atoll size, were relatively small and predominantly comprised of the low-value species, *Holothuria atra*. On the basis of existing information regarding the fate of bêche-de-mer stocks worldwide, in conjunction with specific information for the IOT stocks, it is reasoned that bêche-de-mer stocks are of more value to the local ecosystem than to a commercial fishery, as it is unlikely to be a profitable fishery in the long term. It is recommended that a bêche-de-mer fishery not be developed in the IOTs.

Giant Clams

The recreational harvest of giant (*Tridacnia* spp.) clams at the Cocos (Keeling) Islands is currently unregulated. The apparent local extinction of *Tridacna gigas* indicates that the stocks of similarly exploited species may also be under immediate threat. An accurate and reliable estimate of the current state of the clam stocks on the Cocos (Keeling) Islands is a research priority. The initial stages of this stock assessment have been conducted, however formal reporting has not yet been completed. It is recommended that the precautionary principle be followed when these clams are included in the review of recreational fishing regulations.

Inshore Decapods

Rock lobsters and mudcrabs are not considered to have potential to be commercially fished. Rock lobsters are not heavily exploited recreationally, however mud crabs are to a greater degree. Furthermore, their long pelagic larval duration makes them robust to fishing on a small scale. Hermit crabs, ghost crabs and sand crabs are all proposed to be totally protected at Cocos in the fisheries management strategy, in-line with the current Parks Australia legislation. No recommendations are made regarding further management of these stocks other than to include them in the upcoming review of recreational fishing regulations.

Sharks

Sharks are currently not exploited commercially or recreationally at either of the islands in the IOTs. A commercial fishery for sharks was suggested in the early 1990's but was never developed as a result of concerns for the welfare of the stock given the history of similar fisheries worldwide. These concerns remain valid, and as such the development of a shark fishery in the IOTs is not recommended.

The current level of commercial harvesting of marine resources is considered to be a very minor influence on the ecology of the IOTs due to the small scale of activity. In contrast, the influences of the recreational/artisanal sector are thought to have resulted in considerable ecological changes, particularly at the Cocos (Keeling) Islands. Following extensive community consultation and consideration of preliminary research surveys, the Department developed the IOT's Island-specific recreational fisheries management arrangements. DoF are currently working on the legislation for these management arrangements. It is recognised that any fisheries legislation requires implementation of ongoing fisheries compliance enforcement and community education on-Island.

The biggest perceived hurdles to the effective management of all recreational fishing on the IOTs is the current lack of regulations and enforcement, particularly in the case of the Cocos (Keeling) Islands. The regulatory mechanisms being developed for the fish stocks of the IOTs needs to be enforced before they will have any effect. Unfortunately the artisanal use of the fish resources by the locals typically does not align with the actions needed to maintain a healthy ecosystem, which is likely to cause conflict when management tools are enforced. Management of this sociological and cross-cultural disparity is seen to be as considerable a task as actually managing the fish stocks (Alder *et al.*, 2000). Addressing these sociological and enforcement issues are considered a management priority.

2.0 Background information in the Indian Ocean Territories

2.1 Geography and Oceanography

Christmas Island is located 2600 km northwest of Perth and 290km south of the Indonesian island of Java (Bunce, 1988). The Cocos (Keeling) Islands are located a further 1000km west-southwest of Christmas Island (1300 km from Indonesia) (Figure 1). Both island groups are the emergent tops of seamounts, and are part of the 2000km long Vening-Meinesz seamount chain, which is oriented approximately east-west. Aside from the seamounts, the water is typically between 5000m and 6000m deep over the surrounding abyssal plain. An exhaustive examination of the macroscale geomorphology of the islands and the surrounding geological features is contained in Brewer *et al.* (2009).

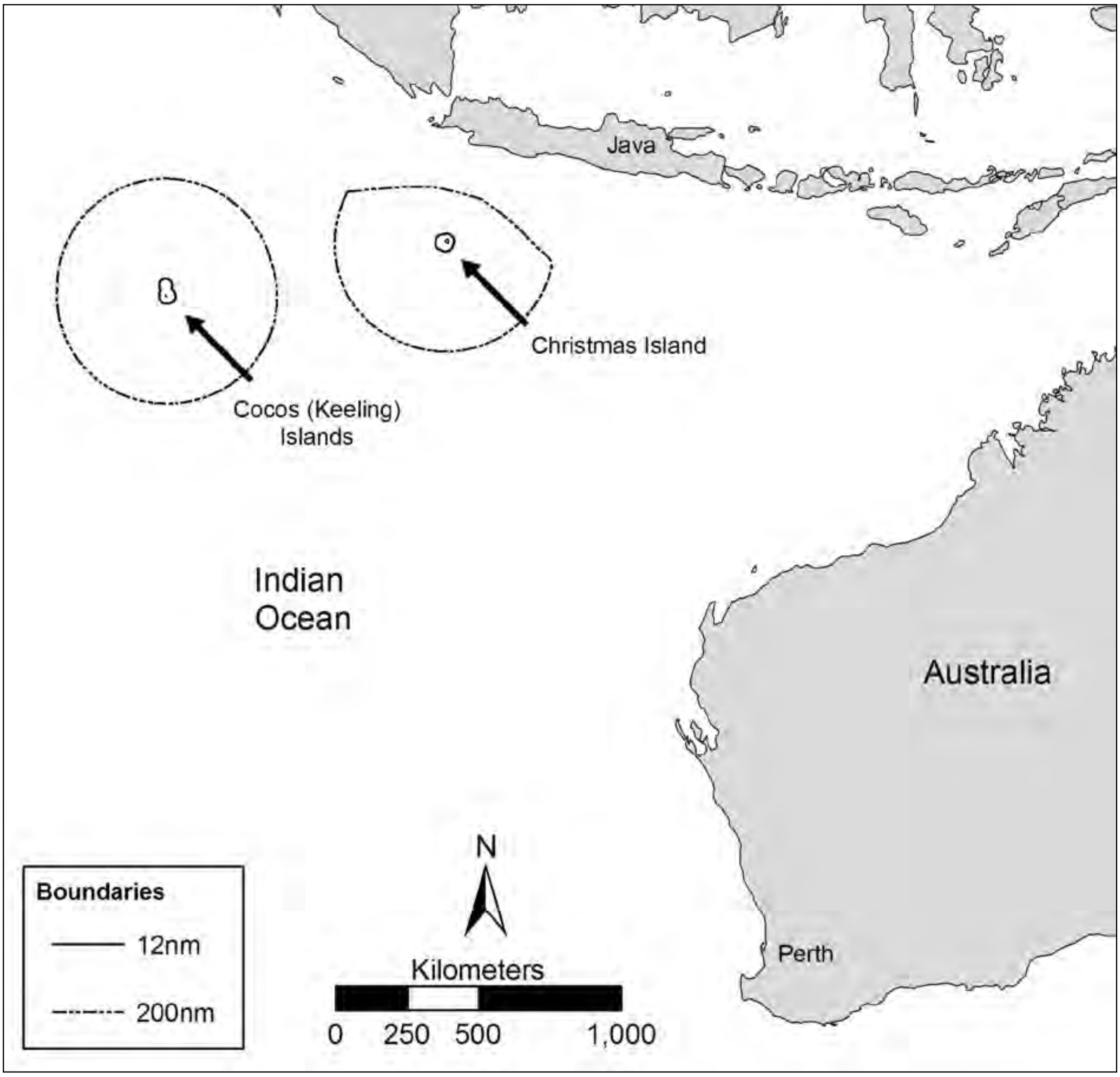

Figure 1. Map of the eastern Indian Ocean showing the location of Christmas Island and the Cocos (Keeling) Islands in relation to the major landmasses of the region. Also shown are pertinent boundaries at 12nm (limit of AFMA excepted waters) and 200nm (Australian exclusive economic zone) around the islands.

The currents that influence the oceanography of the IOTs are complex and include depth stratification as well as seasonal changes due to monsoonal weather patterns. However, for the majority of the year the dominant oceanographic influence on the surface waters is the South Equatorial Current, which flows westward as an extension of the Indonesian Through Flow. This system of currents is thought to be the dominant source of pelagic larval recruitment from distant sources (Brewer *et al.*, 2009). During September/October, the strength of this current system decreases and moves southward such that upwelling of abyssal waters occurs around the IOTs, decreasing surface water temperatures, increasing nutrient availability and increasing planktonic productivity in local waters (Davies, 2006).

Astronomical tides are mixed but predominantly semi-diurnal. Tidal range is typically between 0.4 and 1.2 m with the height between lowest and highest astronomical tide being ca 1.65m (Bunce, 1988). The relatively small tidal fluctuations, along with the very limited shallow areas bordered by very deep oceanic waters, means that the tidal regime has relatively little impact on the hydrology of Christmas Island. The Cocos (Keeling) Islands are more affected by tidal fluctuations, having a much lower overall profile as well as a shallow lagoon. The swell season typically coincides with the monsoon, and is characterised by large swell waves from the northwest occurring between December and March.

The narrow subtidal platform present on Christmas Island allows for almost complete flushing and homogeneity between coastal and oceanic water bodies. In contrast, the Cocos (Keeling) Island lagoon is poorly flushed in sections, reputedly resulting in anoxia and fish kill events.

2.2 Subtidal habitat

Although geographically grouped together, Christmas Island and the Cocos (Keeling) Islands are geologically very different, which has influenced the ecology of local areas. Christmas Island is a relatively high mountainous island with naturally occurring plateaus and cliffs, giving the island a stepped appearance. The coastline of the island predominantly comprises cliffs > 5m high and then a narrow intertidal/subtidal platform (10-200m wide; Brewer *et al.*, 2009). There is often another subtidal step at approximately 35-40m depth. The bathymetry then descends to more than 1500m within a few hundred metres of the coast, and to more than 5000m within a few kilometres. Since there is only a very narrow strip of shallow water around Christmas Island, there are relatively few shallow water habitats and by extension, lower diversity of shallow water species. By far the most common shallow water habitat at Christmas Island is the fringing reef, which often has a substantial cover of live coral (<50%) as well as other lesser contributing substrates such as bare rock, coral rubble, natural pavement and coarse sand. Soft sediment habitats such as fine sand are almost absent from Christmas Island, only being found in among coral reef patches and on isolated beaches (*e.g.* Dolly Beach). Mud substrates are all but absent on this island (Brewer *et al.*, 2009).

The Cocos (Keeling) Islands form a typical oceanic coral atoll, with the landmass being very flat and close to sea level (<8m above sea level; DEH, 2004). The 27 islands of the main atoll form a semi-continuous ring, surrounding a relatively shallow and largely protected lagoon (Figure 2). The outer reefs and slope habitats present at Christmas Island are also found at Cocos, however, the habitats present within the lagoon are the main point of difference between these two islands. The sheltered lagoon allows biogenic sands to gather to create substantial soft bottom areas and sand flats. In some areas water movement is low enough that muds are able to form. Seagrass habitats are also present in the Cocos lagoon, and are predominantly comprised of *Thallasia hemprichi.* Algal dominated areas are also present, which are the favoured habitat of the gong gong (Bellchambers *et al.*, 2009). Small amounts of small leafed mangrove (*Pemphis acidula*) also occur in intertidal areas. The reef within the lagoon is relatively shallow and sheltered. There are several morphologically different areas including deeper bombies, shallow reefs and blue holes, each creating distinct habitats (Woodroffe, 1994) and preferred by various faunal assemblages.

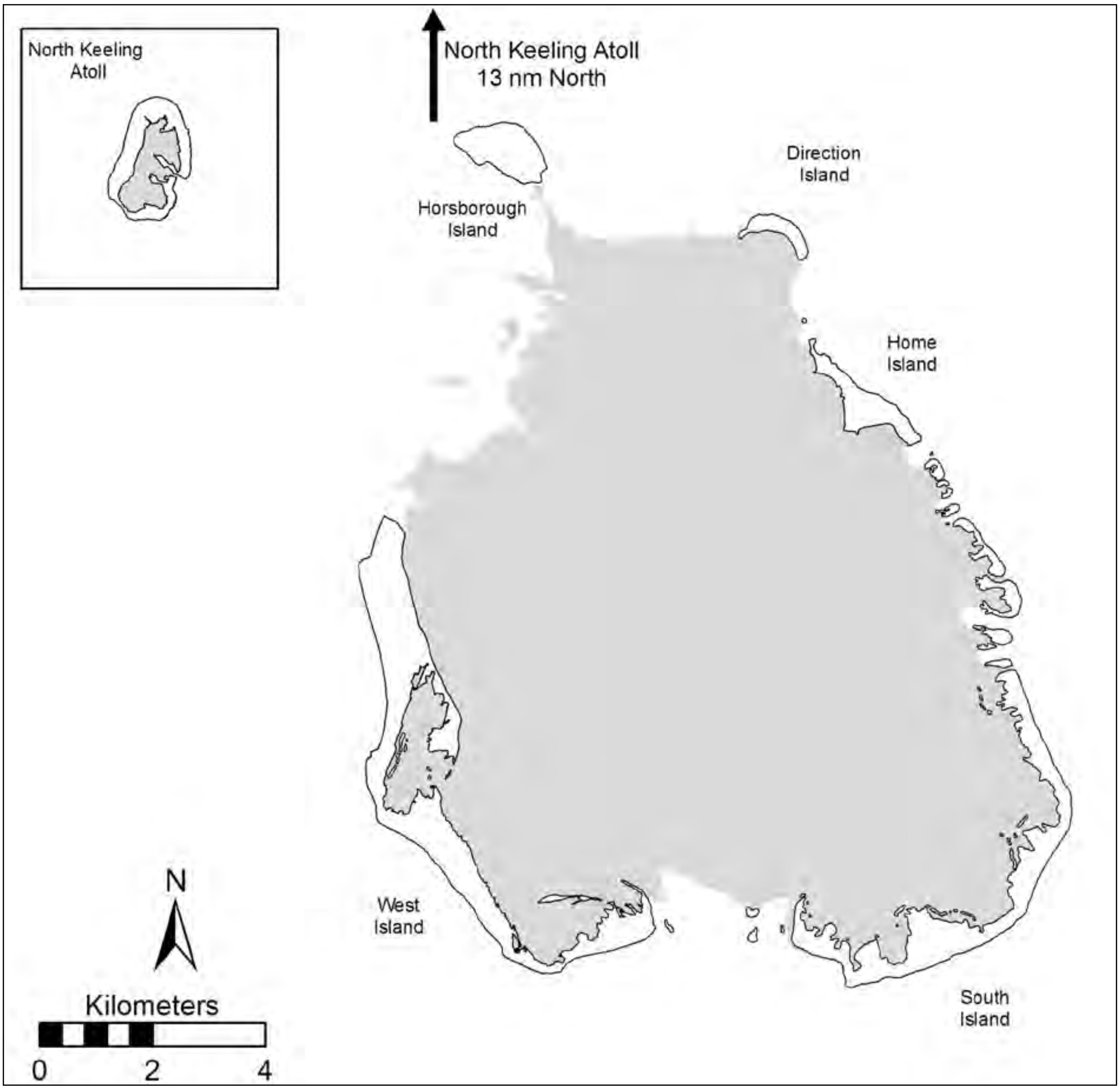

Figure 2. Map of the southern (main map) and northern (inset) atolls in the Cocos (Keeling) Islands group showing main islands, settlements, and the extent of lagoonal waters (shaded) as defined by Woodroffe (1994).

2.3 Climate

The climate is typical of monsoonal areas, with a wet and dry season. The wet season typically lasts from December to April, with some substantial rainfall continuing through into June. During this time winds are variable in direction and strength. The doldrums typically occur between February and April, and tropical cyclones, although relatively rare, also occur during the wet. The wind regime during the wet is then periods of very little wind, interspersed with storms and the occasional cyclone. The remainder of the year is less rainy, and experiences relatively consistent southeast trade winds up to 20km/hr (BoM, 2010a). Christmas Island has historically been relatively free of cyclone activity with cyclones causing damaging winds occurring once every five years. This is in contrast to the north west coast of the Australian mainland, which receives one cyclone every year on average, and the nearby Cocos Islands, which receive one every two years (BOM, 2010b). The minimal cyclonic activity at Christmas Island compared to the Cocos (Keeling) Islands is a product of its more northerly location at the northern edge of the cyclone belt (Brewer *et al.*, 2009). Temperature is extremely stable at both Christmas and Cocos Islands, with temperatures remaining between 21 and 28ºC day and night, year round

2.4 History and Government

Captain William Keeling and the East India Company discovered the Cocos (Keeling) Islands in 1609 (Bunce, 1988) but the Islands were not settled until 1826 by Alexander Hare who brought with him an entourage of Malay, Chinese, Papuan and Indian settlers to establish a settlement and agricultural crops. This attempt was not successful and the Clunies-Ross family later settled the Islands. The Islands were handed from the Dutch to the British in 1857 and this precipitated a rapid development of plantations for the production of coconuts (Bunce, 1988). In the early 20th century the Islands became a communication link and underwater telegraph cables were laid south-west to South Africa, north to Singapore and South East to Perth in Western Australia. Bungalows, offices and a European settlement were also established. The Cocos –Keeling Island group was the site of military activity in both the first and second world wars (Bunce, 1988). In 1951 the Cocos (Keeling) Islands were transferred from Britain to Australia and this was formalised in 1955. By 1951 there were only 350 Cocos Malay people left, who demanded improved living conditions. In 1978 the Australian government negotiated the purchase of the Islands from the Clunies-Ross family. Government initiatives in the 1980's saw compulsory education, a safe freshwater supply, sewage and free elections (Bunce 1988). In 1987 the copra (coconut) industry was declared unprofitable and the islanders looked to diversify their limited economic base. The employment opportunities on the islands remain scarce more than 20 years later.

Christmas Island was named on Christmas day 1643 by William Mynors of the East India Company. However, the first concerted effort of exploration was in 1857 since the rugged coastline and sheer cliffs had previously discouraged exploration of the island. The British annexed the island in 1888 following the discovery of valuable phosphate deposits. The first permanent settlement was established by the Clunies-Ross family in the late 1800s to provide lumber for use on the Cocos (Keeling) Islands, and the settlement expanded soon after to accommodate the workers on the phosphate mine. As for Cocos, the islands were a strategic military point during World War II, being briefly occupied by Japanese troops. The British recovered the island, and in 1957 (two years later than the Cocos Islands) it was transferred to the Australian government.

Christmas Island and the Cocos (Keeling) Islands collectively comprise the Australian Indian Ocean Territories. As a Commonwealth territory, they operate under federal level and local level governments only, without state-level bodies or governance. Various community services typically provided by the State governments are serviced either from the Commonwealth (e.g. Police) while others are provided by W.A. state agencies under Service Delivery Agreements on behalf of the Commonwealth (e.g. Department of Health and Water Corporation). DoF supply fisheries management services under such a Service Delivery Agreement."

2.5 Flora

The principal vegetation on the Cocos (Keeling) Islands is coconut palms (*Cocos nucifera*), reflecting the Island's recent history as a copra (coconut) plantation. Little is known about the structure and composition of the original vegetation (Bunce, 1988). North Keeling is the only Island with a natural forest of tall trees. Grand Devil's Claw (*Pisonia grandis*) trees and coconut palms form stands of varying densities and the understorey consist of coarse grasses and/or dense thickets of shrubs.

Christmas Island is covered largely by dense rainforest, with a much more diverse range of species than found on Cocos. 213 species of plants have been recorded from the island, with 17 of those species being endemic. Aside from the areas where mining or residential areas have been cleared, the islands flora is considered relatively unmodified largely as a result of its relatively recent human habitation. Additionally, almost 70% of the island is national park. In areas where the terrestrial national park abuts the coastline, the national park boundary extends 50m out into the ocean to account for terrestrial/marine adjacencies and ecological connectivity (Figure 3).

2.6 Fauna

The terrestrial fauna on The Cocos (Keeling) Islands, much like the original vegetation is highly modified and quite depauperate. Remnant populations tend to be restricted to North Keeling Island, which is set aside as a national park.

The larger landmass of Christmas Island has somewhat preserved the integrity of the local ecosystem, allowing refuge for the native species in the denser part of the rainforest, including the endemic red land crabs and the globally threatened robber crabs (*Birgus latro*). Christmas Island is also a critical habitat for several species of seabirds such as the Abbotts Booby, Christmas Island Frigatebird and Golden Bosunbirds. Several terrestrial pest species pose significant threats to the native fauna, with the most destructive species being the Yellow Crazy Ant (*Anoplolepis gracilipes*) and its symbiotic scale insect, which form very high density "super-colonies" and denude areas of the forest of all other fauna (Abbott, 2005).

The islands of the IOTs have attracted the attention of researchers studying hybridisation in fish species. The waters around the Cocos and Christmas Islands house the largest number of naturally occurring hybrid fish in the world (11 hybrids). This hybrid hot-spot is thought to be the product of the location of the islands at the suture zone between the Indian and Western Pacific biogeographical regions. The fish fauna is typically described as of Western Pacific origin but there is a presence of certain Indian Ocean species, albeit in relatively low numbers (Marie, *et al.*, 2007; Hobbs *et al.*, 2009).

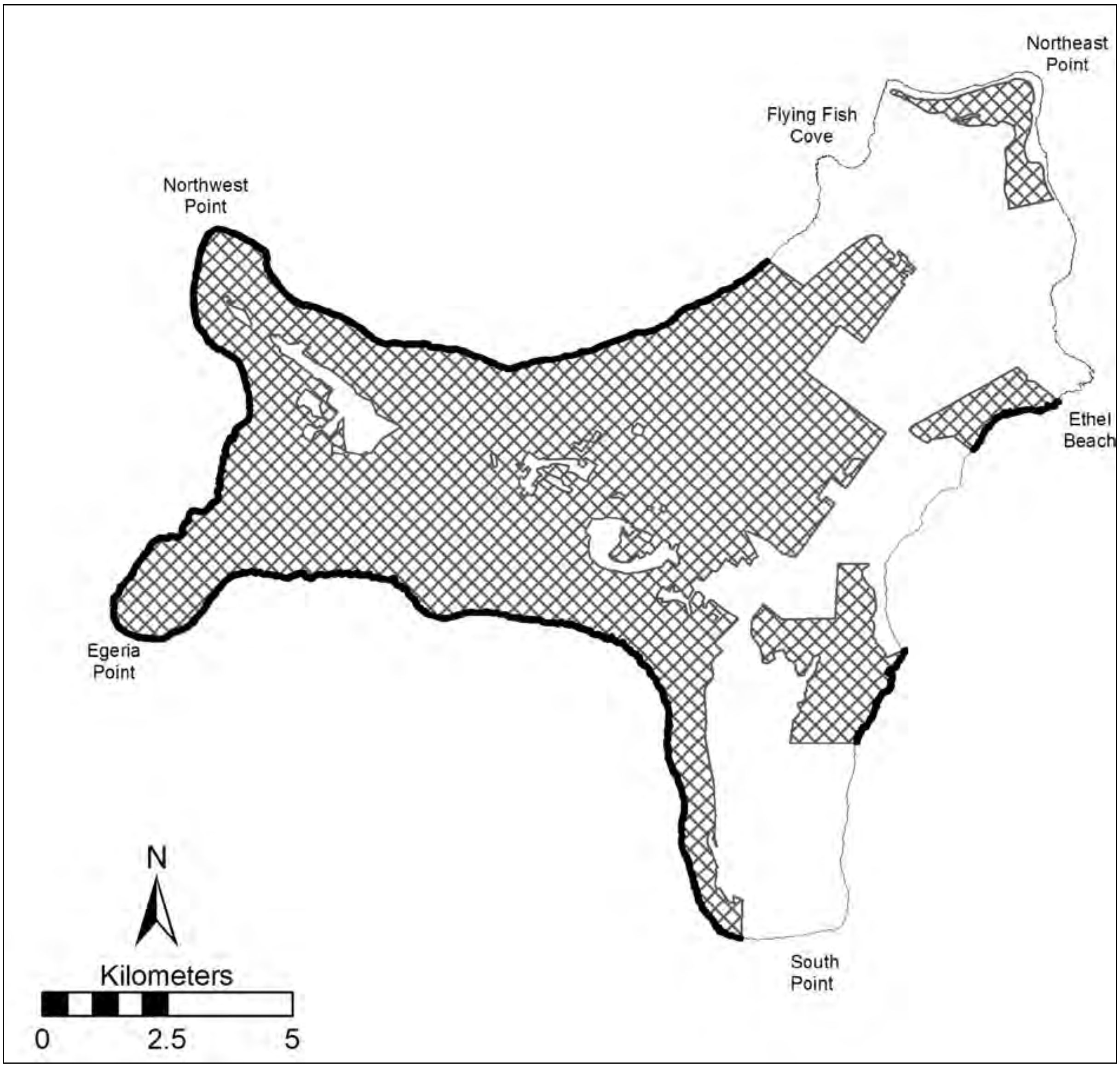

Figure 3. Map of Christmas Island showing national park reserves (hatched) including marine adjacencies (bold coastline). Boat ramp access is via Flying Fish Cove and Ethel Beach.

3.0 Biogeography of Isolated Islands

3.1 Island Biogeography concept

Island biogeography is the term usually given to the concept that states that isolated islands (or habitats) will usually support a lower species richness than mainlands, and that the smaller and more isolated those islands are, the more depressed the diversity will be (MacArthur & Wilson, 2001). Although a generalisation, this concept is applicable to the isolated islands of the Indian Ocean Territories (IOTs). Christmas and Cocos (Keeling) Islands are reported to have fewer species than their nearest mainland neighbour (Indonesia), particularly in the case of organisms such as molluscs, reef-building corals and crinoids (Berry & Wells, 2000) and fewer even than the islands and reefs closer to mainland Australia (*e.g.* Scott, Ashmore and Abrolhos). While the inherent species richness of an island may have little direct bearing on the viability of its potential fisheries, the underlying reasons for this paucity, *i.e.* those at the core of the Island Biogeography Concept, are highly relevant.

With the increasing isolation of an island, the harder it is for any shallow water species to traverse the open ocean and establish a viable colony. By extension, the further the distance to travel, the fewer the number of species that are capable of making such a long and perilous journey. The difficulties relating to colonisation and more importantly ongoing recruitment have considerable implications for the viability of commercial and recreational extractive activities. On a nearshore island or mainland, fisheries-scale recruitment may come from either local sources (autochthonous) where larvae are retained near their natal reef, or external sources (allochthonous) comprising migratory larvae from distant populations. In extreme cases of isolation, allochthonous recruitment is effectively nil, meaning that autochthonous recruitment is the only possible way to maintain the population. For this reason, the breeding stock of fisheries on isolated islands must be maintained, since depleted stocks have little means of external recruitment.

The size of islands will also affect the fisheries they may support, with smaller islands often offering less area and lower habitat diversity than larger ones. This lack of suitable habitats will decrease the size of the fish stocks, adding a further reason for caution when exploiting these fisheries. The Island Biogeography Concept also asserts that smaller isolated islands have less resilience to acute stressors than mainland ones, e.g. the rapid depletion of a species, since they do not have the diversity of habitats to act as refugeum for populations of species under pressure.

3.2 Biogeographic isolation of the Indian Ocean Territories

The isolated location of Australia's Indian Ocean Territories is considered to have had a considerable influence on the composition of the marine biota, particularly for the Cocos (Keeling) Islands, which are more than 1000km from the nearest sizeable landmass. The marine species that have colonised these islands must have at some point traversed the open ocean from the closest landmasses to form viable colonies at this remote location. Aside from those species that are pelagic as adults, such as tuna, it is helpful to determine if a species' pelagic stage has a long duration or short duration. The difference between the two has relevance for management of any extractive activity since colonisation events occur over very different time scales (Sponaugle *et al.*, 2002).

A few species present on the IOT islands have long larval stages, for example the local species of spiny lobsters (*Panulirus* spp.) all have planktonic larval development times of up to 10 months (Matsuda *et al.*, 2006) and the larval stages of mud crabs (*Scylla* spp.) are protracted and have potential to travel great distances (Gopurenko *et al.*, 2003). It is likely then that the adult stocks of these species were recruited to the islands from distant populations such as Indonesia or as far as the Australian mainland (Morgan, 1994). Conversely, many of the larvae that originate on the islands are likely to be lost to the open ocean or even transported to distant populations due to flushing of the outer reef and lagoon waters.

The majority of species on the island that have planktonic larvae, have only a short larval period, typically in the order of 30 days or less. A few examples of species with short larval durations and which are the present (or are a close relative of those that are) on the reefs of the IOTs include:

- Coral trout, *Plectropomus areolatus* - 29 days (similar to *P. leopardus*) (Samoilys, 1997)
- Gong gong, *Lambis lambis* - 19-40 days (Queen conch *Strombus gigas* used as a surrogate; see Sub-section 5.7) (Stoner *et al.*, 1992)
- Giant clams, *Tridacna derasa* and *T. maxima* - 8-9 days (Benzie & Williams, 1997)
- Sandfish, Bêche-de-mer, *Holothuria scabra* - 21 days (Bell *et al.*, 2008).

As an extreme example, some species of corals may have a larval duration as short as three days. In contrast to the species with long duration larvae, populations of species with short larval durations need to be self-sustaining in an isolated location. Recruitment from external landmasses are unlikely, whereas the faster a larva settles, the more likely it is to be retained on or near its natal reef.

Despite the fact that many marine species present on the IOTs have short duration larval phases and as such are unlikely to survive transport from external populations, their very presence on these reefs indicates that such transport is possible. At some point, colonisation event(s) occurred, perhaps due to random larval transport via unusual weather conditions or current patterns. While this episodic larval transport has resulted in colonisation of the islands, the volume and reliability of this vector is often far to small to form the basis of fishery-relevant recruitment events. Species that have colonised the IOTs via these random recruitment events must maintain their population through *autochthonous* recruitment. For this reason, stocks must be managed carefully, with consideration of their small size and isolation from external recruitment.

Aus-Connie is the Australian Connectvity Interface, which allows estimation of the degree of connectivity between marine areas around Australia through modeling ocean circulation patterns (Condie *et al.*, 2005). The Aus-ConnIe system suggests that under normal circumstances a minimum of around 80 days of passive planktonic duration is required for appreciable transfer of viable planktonic larvae to travel from the closest neighbouring source populations (Indonesia) to Christmas Island. It is recognised that many larvae cannot validly be considered passive particles, however given the considerable distances involved, a substantial portion of the transport must be attributed to passive vectors. This is particularly the case for the Cocos (Keeling) Islands, which are about three times as far from the larger landmasses of Indonesia and Australia than is Christmas Island. Although Christmas Island may be used as a stepping stone to Cocos, the probability of larvae being transported between two small islands is relatively low and not a reliable source of recruitment on a timescale relevant to fisheries management.

Allen & Smith-Vaniz (1994) mention that the majority of the fish species that are present on the Cocos (Keeling) Islands have planktonic larval stages lasting several weeks, which facilitated colonisation of the islands at some point. Furthermore, their biogeographic heritage is largely western Pacific and Indonesian rather than of the Indian Ocean reflecting the dominant source of larvae. Christmas and the Cocos (Keeling) Islands exemplify the two aspects of biogeographic isolation, physical distance and small size leading to limited habitats. Although the two island groups have 350 species of fish in common, Christmas Island has 210 species which are not found at Cocos, and Cocos has 175 not found at Christmas. The 210 species at Christmas but not Cocos largely show an affiliation with Indonesian communities, indicating that they are colonists from Indonesia to the north that have thus far been unable to reach the more distant Cocos. In contrast, the 170 present on Cocos, but not Christmas are predominantly lagoon-associated species, a habitat that is absent from Christmas Island. This pattern suggests that presence of suitable habitat for recruits also affects community composition.

The iconic Christmas Island Red Crab (*Geocarcoidea natalis*) is an excellent example of the implications of isolation for marine recruitment to the IOTs. Despite having a planktoninc larval stage of around 27 days, the red crab is only found at Christmas Island and North Keeling Island (the latter thought to be through human introduction). Even the recruitment of these crabs to their own natal island is extremely variable, with significant recruitment typically occurring in only 1-2 years out of every 10 (Brewer *et al.*, 2009).

3.3 Evidence of biogeographic isolation on the IOTs

One of the most commonly cited examples of the biogeographic isolation of the IOTs is the absence of skates and rays (excluding the pelagic manta ray) from the Cocos (Keeling) Islands, which are benthic species without a planktonic dispersal mechanism. The Cocos lagoon could be considered an extremely favourable area for the skates and rays that typically inhabit shallow waters with sandy substrates. Their conspicuous absence from the lagoon is presumably a reflection of their inability to traverse the surrounding deep oceanic waters to reach their preferred habitat. Without a planktonic larval stage it would appear that they have simply not had an opportunity to colonise the region.

The coral communities in the IOTs are also quite different from mainland Australia with 70% of the 320 species known to occur on the mainland being absent from the Islands. Of the 100 or so species known to occur at both island and mainland locations, about 30 display marked differences between the locations in terms of habitat preference, colour, and growth forms (Veron 1994).

The genetics of the fish species on the islands also offer compelling evidence for the lack of gene flow and hence larval dispersal for certain groups of fish. Preliminary studies on cod (Serranidae) and snappers (Lutjanidae) in the region suggest that many of these reef fish have very limited gene flow between the islands and the closest large landmasses. Investigation into this low genetic connectivity is the subject of ongoing research (S. Newman, pers. com.).

4.0 Indian Ocean Territory Fisheries

4.1 Governance and background

The fisheries on Christmas Island and Cocos (Keeling) Islands are the responsibility of the Commonwealth Government under the *Fisheries Management Act 1991*, however, the day-to-day management of the inshore fisheries is conducted by the WA Department of Fisheries (DoF) under a service delivery arrangement with the Commonwealth Attorney-General's Department (AGD). Provision for this arrangement is made within the federal *Fisheries Management Act 1991.* The waters within 12 nautical miles of the islands are excepted from commonwealth waters under the above Act and are now managed by DoF under the *Fish Resources Management Act 1994 (WA)(CI)(CKI)* (the 'Applied Act') on behalf of the Commonwealth. Beyond the 12nm limit the Commonwealth Australian Fisheries Management Authority (AFMA) retains governance of fisheries under the *Fisheries Management Act 1991*, with specific management for certain species provisioned by the *Western Tuna and Billfish Fishery Management Plan 2005.*

The only commercial fishery that operates within the 12nm "excepted waters" region of the Cocos (Keeling) Islands is the Cocos (Keeling) Islands Marine Aquarium Fish Fishery (CKIMAFF). Likewise only one licensed fishery, the Christmas Island Line Fishery (CILF), operates out of Christmas Island. Additionally, there are two operators licensed to fish the Western Tuna and Billfish Fishery in the commonwealth waters surrounding the island (12-200nm except where they abut Indonesia's fishing zone; AFMA, 2002b).

Several applications have been made to develop various commercial fisheries on the Indian Ocean Territories including harvesting of bêche-de-mer, finfish, deep-sea crabs and sharks. The possibility of a commercial exploitative fishery for bêche-de-mer within the Cocos atoll lagoon has been the raised on several occasions. The viability and sustainability of this resource has been the subject of several stock assessments, which have made very disparate recommendations. Also, the commonwealth government body AFMA allowed an exploratory exercise to assess the viability of developing a demersal scalefish fishery in the waters surrounding the atoll (0-200nm) with the exception of the lagoon area and an expression of interest was lodged for the development of a deep-sea crab fishery in 2008 which would straddle state (0-12nm) and federally managed (12-200nm) waters.

The remainder of the extractive activity in the marine environment on Christmas Island and the Cocos (Keeling) Islands is regarded as recreational. The Applied Act is nominally in force at the IOT's; and while a number of recreational fishing rules still apply at the IOT's such as minimum size limits, they have not been enforced to date. DoF has developed Island specific recreational fishing management arrangements for the IOT's, which will be legislated as an overarching Commonwealth Ordinance.

Considerable recreational fishing effort is present on the islands, for example. the recreational harvest just on Cocos was estimated in 2002 to include 85-120 tonnes of finfish and a further 3.7 tonnes (without shell) of the prized mollusc, gong gong (*Lambis lambis*). In addition to finfish and gong gong, other prized recreational target species include clams (*Tridacna* spp.), rock lobster (*Panulirus* spp.) and mudcrabs (*Scylla* sp.; AFMA, 2002b).

Due to the relatively recent history of habitation on the islands, there are no indigenous native title claims related to fisheries as is the case on parts of mainland Australia (Alder *et al.*, 2000).

However, there is recognition of recreational and cultural use of various areas, such as in the national park at Christmas Island.

Other commercial activities that may have ecological implications for the sustainable exploitation of marine resources at Cocos (Keeling) Island include the development of aquaculture and ecotourism enterprises, development of port facilities and shipping traffic. While detrimental effects of introduced marine pests are a potential concern, there is no evidence to date of any significant marine pest species on the IOTs (GHD, 2004).

4.2 Risk assessment process

The DoF conducts an ongoing risk assessment process for the fisheries of the IOTs, which is updated annually. This risk assessment process is used to direct the short to medium term research and management foci for the ensuing year and beyond.

Identification of at risk-stocks is made on a species-by-species basis for each island group separately, and examines all of the species that are, or could potentially be, commercially or recreationally exploited. The matrix incorporates a variety of factors to provide a meaningful and easily ranked system to identify priority species. The inputs include:

- The inherent vulnerability of the stock. This is based on aspects of a species' biology that may make it inherently vulnerable. *e.g.* endemism such as the Cocos Pygmy Angelfish, or fisheries that are typically prone to overexploitation such as bêche-de-mer.
- The current risk to the local wild stocks. High scores in this parameter may reflect the IOT stocks currently being fished heavily or have been significantly depleted, such as giant clams.
- Current management information requirements. Assesses the amount of research which has been invested in a species' stock, *e.g.* clams may score highly because there has not been a formal stock assessment.
- Ecological significance. Species which fill an ecological role with little functional redundancy in the IOTs will score highly, *e.g.* sharks as apex predators or bêche-de-mer as large scale nutrient recyclers.
- Recreational significance to the various community groups such as Cocos-Malay, Chinese or European communities, *e.g.*, gong gong are a significant part of the diet of the Cocos-Malay community on the Cocos (Keeling) Islands.
- Ecotourism significance. Iconic and charismatic species such as whale sharks, reef sharks, manta ray and humphead maori wrasse are rated highly in this parameter.

The above parameters are scored, weighted and combined into a single "risk value" for each species, which is ranked and used to determine the highest research and management priorities. Since the matrix is updated annually, the outcomes for the previous year's efforts can be incorporated, allowing a species' rank to be reassessed and increased or decreased as needed.

4.3 Cocos (Keeling) Islands Marine Aquarium Fish Fishery

The long-term viability of this fishery at the current rate of harvest has been demonstrated. However, the current rate of harvest is much lower than that permitted by the license conditions. It is suggested that the fisheries' quota be examined as a precautionary measure for the continued wellbeing of the fishery, and of the endemic primary target species.

The Cocos (Keeling) Island Marine Aquarium Fish Fishery (CKIMAFF) is the only regulated commercial fishery operating within the DoF managed 12nm boundary around the Cocos (Keeling) Islands. This fishery is a highly targeted activity which specifically takes the IOT endemic, Cocos Pygmy Angelfish *Centropyge joculator* and to a lesser degree the Lemonpeel Angel *C. flavissima*. The fishery comprises a single licensed operator and there is an effort limit of 2000 fish per family and 4000 fish in total per year, as well as gear restrictions. Although the fishery is currently targeted on *C. joculator*, there is scope within the license conditions to take fish from other families including Toxotidae (Archerfish), Ephippididae (Batfish), Chaetodontidae (Butterflyfish), Pomacentridae (Damselfish) as well as other species of Pomacanthidae (Angelfish).

Lincoln-Smith *et al.* (1993b) noted that this fishery was operating in 1993 and that 30-50 individuals were harvested per month. It is further stated that the fishery is "self sustaining" but provides no quantitative data to support the supposition. A relatively recent assessment of this fishery indicated that the amount effort in the fishery was very small, with <400 fish collected per year, and only 245 collected in 2004 (DEH 2005a). More recent records appear in the Fletcher & Santoro (2009) where 800 fish were reported in 2006 and 600 in 2007. This time series shows that catches have been relatively consistent since the fisheries commencement almost 20 years ago, and the catch rates are well below the allowable total.

Fisheries Biology

The dominant target species of this fishery, the Cocos Pygmy Angelfish*,* is a dwarf angelfish of the genus *Centropyge*. This species is expected to have a similar behaviour and life history as other species of this genus since this group appears to exhibit remarkable homogeneity in this respect (Baensch, 2003). Harem groups of one male and several females are normal, and all species of the genus display socially-controlled protogynous hermaphroditism (Bauer & Bauer 1981). Individuals of *C. joculator* are expected to become mature females relatively quickly at about 60-70mm and a fully grown male it about 90mm.

The specific reproductive strategy employed by this species is expected to make it reasonably resilient to fishing pressure. The socially-controlled hermaphroditism allows the population to rapidly and effectively maintain sex ratios, and the relatively early age at maturity allows a high generation turn over.

The population of Cocos pygmy angelfish in the CKI lagoon were determined by Hender *et al* (2001) to be in a healthy state. Densities of this species were up to 232/ha and it was encountered at most sites within its preferred depth range (15-20m).

Despite their apparent resilience, the fact that they are endemic to the two relatively tiny and isolated reefs of the IOTs should garner the Cocos pygmy angelfish special consideration (Hobbs *et al*., 2010). The total population of this species is obviously relatively small and their range is very restricted. The combination of these two factors make this species vulnerable to overfishing, and also to catastrophic environmental changes triggering fish-kills.

DEH (2005a) considers that this fishery is being managed in an ecologically sustainable way and that there is little prospect of unacceptable impacts. It was also noted that the fishery was somewhat economically self-regulating in that it is in the interest of the single operator to keep the annual catch small in order to maintain the high market demand and unit price (US$600-1000 retail). This case is fairly unusual and is possible since only a single operator is licensed to harvest and market this species worldwide.

Current and recommended management

Through comparison of the current catch rates and the license quota it is obvious that a very high amount of unexploited quota exists in this fishery, in the order of 60%. It is considered that this level is somewhat unnecessary and indeed, given the small size of this species' population, is of some concern. It is therefore recommended that the license quota of 2000 individuals/year for a single species be reconsidered in light of the considerable amount of unexploited quota and the small population size of the target species. This reduction in quota need not impact the financial viability of the existing commercial operation, and would greatly decrease the potential for overexploitation.

4.4 Christmas Island Line Fishery (CILF) and Western Tuna and Billfish Fishery (SWTBF)

There is very little commercial fishing activities conducted in the IOTs. Only one license in the DoF managed Christmas Island Line Fishery was used during 2008-09 and the AFMA managed Western Tuna and Billfish Fishery was completely unfished in the IOT waters during that same period. The effects of these commercial fisheries fishing is considered negligible.

Other than the CKIMAFF, only two commercial fisheries operate within the 0-200nm EEZ around the islands of the IOTs, the Christmas Island Line Fishery (CILF) and the Western Tuna and Billfish Fishery (WTBF).

The CILF operates within the 0-12nm zone around Christmas Island and as such is managed by DoF on behalf of the Commonwealth government. The fishery is small, comprising only a few licensed operators, with only one of those licenses reportedly being active in 2008-09. Only a few species are targeted with the most common being the wahoo (*Acanthocybium solandri*) and lesser contributions being made by yellowfin tuna (*Thunnus albacares*) and mahi mahi (*Coryphaena hippurus*; Fletcher & Santoro, 2009). The primary market for this fisheries' produce is domestic, with several local businesses using and actively marketing locally caught fish. Fletcher & Santoro (2009) note that some deep-slope demersal species such as ruby snapper (*Etelis* spp.) are also occasionally targeted by the CILF.

The WTBF is an AFMA regulated fishery and the IOT component is managed as part of the federal mainland fishery. Target species include wide-ranging pelagics such as big-eye tuna (*Thunnus obesus*), yellowfin tuna (*T. albacares*) and broadbill swordfish (*Xiphius gladius*). Longlining is permitted in the 12-200nm area of the Australian EEZ, however very little fishing activity is recorded in this area, presumably as a result of the islands location and the economic implications of this remoteness (Caton & McLachlan, 2004; Wilson *et al.*, 2009). In fact, Wilson *et al.*, (2009) reported that no licensee was active in the IOT waters as part of the WTBF in 2008.

Exploratory commercial fishing exercises were conducted in 2001-2003 for deep-sea demersal species by AFMA, using trawl and non-trawl gear-types. The defined region was between 12 and 200nm of the Cocos (Keeling) Islands, with the exception of shallower (<50m) waters around the Muirfield seamount (AFMA 2002b). Although the exploratory management report for this project is available detailing the scope of the project (AFMA, 2002b), the results were not formally published. The status report for commonwealth managed fisheries in 2004 mentions that the exploratory fishing was conducted, but that there was "nothing of commercial interest at the depths where trawling was permitted" (Caton & McLachlan, 2004). No mention of the result from the study using non-trawl methods was made by that latter document.

There are no commercial food-fish fisheries based out of the Cocos (Keeling) Islands, although some non-licensed "recreational" fishers do sell produce to local small businesses.

Fisheries biology

For fish species that are open-ocean pelagic as adults, such as tuna, biogeographic isolation has little relevance since they are not tied to nearshore locations, the typically isolating open-ocean is their preferred habitat. The fisheries and the stocks of these species must be managed over a very large area. In the case of the Indian Ocean Territories, commercial catches of these species in commonwealth waters are managed by AFMA under the *Fisheries Management Act, 1991* as part of the WTBF and at the regional level through the Indian Ocean Tuna Commission.

Fish such as wahoo, despite being pelagic are thought to remain within a home range, that is, are at least semi-residents. As for other species on the IOTs, their association with nearshore waters has implications for recruitment into their stocks, as the biogeographic isolation of the islands limits allochthonous recruitment of juveniles. The home-range size of wahoo and the degree of genetic connectivity between mainland and IOT stocks are the subject of ongoing research at the DoF.

Current and recommended management

The commercial catches in the CILF are regarded as having relatively small impact on the local stocks of target species. Furthermore, overall catch rates were lower in 2008 than in previous years. Fletcher & Santoro (2009) highlight that the level of allochthonous recruitment to local stocks is largely unknown, particularly for demersal species. This knowledge gap has been identified and research is currently underway to assess the level of stock connectivity for selected species.

The EEZ waters around Christmas and Cocos (Keeling) Islands form only a very small portion of the total area managed under the WTBF and Wilson *et al.* (2009) indicate that there was in reality little to no activity in this fishery in the EEZ around the IOTs during 2008. The WTBF can be considered to have very little impact on the fish stocks around the IOTs beyond the effects caused by harvesting of a stock near the mainland that is presumed contiguous through out the Indian Ocean.

The commercial fisheries in the IOTs are considered to have a minimal impact on local fish stocks.

4.5 Recreational Finfish

Recreational fishing at both CI and CKI is currently completely unregulated. The heavy artisanal and recreational exploitation of the local fish stock (particularly on CKI) has resulted in the severe local depletion and in some cases extinction of certain fish species. It is highly recommended that interim management arrangements be implemented while a tailored and long-term management strategy is developed, in order to remediate the condition of the fish stocks.

The recreational fishing practices, target species and stock sizes are quite different between Christmas Island and The Cocos (keeling) Islands. This is largely a product of the different areal extent and subtidal habitat types that are available at each of the islands.

Christmas Island is mountainous, with narrow fringing reefs giving way to steep underwater slopes and then rapidly to abyssal depths. There is not much habitat diversity at a broad scale with patchy to high-density coral reef being the dominant substrate. The main difference between demersal habitats is the depth of the water, with both shallow water and deep slope habitats being fished. The Cocos atoll has fringing reef, deep slope and pelagic habitats comparable to Christmas Island but also has a large, shallow lagoon providing additional habitats such as sand flats, sheltered bombies and seagrass meadows (Figure 2). Importantly, the lagoon area is usually very sheltered, which makes it accessible to fishing in most weather conditions.

In those instances where habitats are comparable between the two Island groups, similar fish are available. For example, species such as dog-tooth and yellowfin tuna as well as wahoo are targeted by fishers in the pelagic waters on both Christmas and Cocos. Likewise, deepwater snapper such as species of *Etelis* and *Pristipomoides* can be fished from deeper reefs and slopes. The lagoon at the Cocos (Keeling) Islands has historically been a very productive fishing ground, yielding groper species such as *Plectropomus areolatus*, *Epinephelus merra* and *Cephalophus argus*, as well as shallow water snapper like *Lutjanus gibbus* and *L. monostigma* and Emperor such as *Lethrinis xanthochilus.* Although several of these species are also found on the shallow reefs of Christmas Island, they are in relatively small numbers due to the scarcity of suitable habitat.

The historic abundance of fish at Cocos, and the scarcity of other forms of protein has lead to a local way of life that is heavily dependent on the lagoon fish stocks for food. This has unfortunately lead to considerable pressure and in some cases significant depletion or local extinction of certain species. Lincoln-Smith *et al.* (1993b) identifies that barramundi (*Lates calcarifer*) were historically favoured by the locals, as was threadfin (*Polynemus indicus*; although this latter species was considered rare even at that time) (Gibson-Hill, 1949) but both of these species were absent from the surveys by Allen & Steen (1987), Allen (1989) and all subsequent studies. More recently, the squaretail coral trout (*Plectropomus areolatus*) was identified as one of the most abundant Serranids on both shallow and deep reefs (Lincoln-Smith *et al.*, 1993b) but according to recent local reports, this species now occurs in extremely low abundances island-wide and may now be completely absent (Fletcher & Santoro, 2009). Within the lagoon at Cocos (Keeling) Island, there is substantial anecdotal evidence and mounting scientific evidence of significant overfishing by the recreational sector, with the many medium to large species now being rare or absent in the lagoon.

Previous assessments

Most previous assessments of fish stocks and fishing activities in the IOTs have been concerned with the shallow waters of the inshore reefs and Cocos lagoon. This is largely a product of the most common survey method, Underwater Visual Census (UVC), being limited to maximum SCUBA diving depth. A few studies have also incorporated fisher interviews and creel surveys to quantify fishing activities.

The earliest documented survey of the fishing practices on Christmas Island is that of Lincoln-Smith *et al.* (1993a), being preceded only by taxonomic catalogs (*e.g.* Allen and Steen (1987) and Berry (1989)). Lincoln-Smith *et al*. (1993a) included boat ramp surveys of fisher catches as well as UVC to estimate the fish stock composition and size and the comparisons between the two methodologies yielded interesting results. The most commonly caught species were the orange, honeycomb and redtip cods (*Cephalophus argus, Epinephelus merra* and *E. retouti*, respectively), smalltooth jobfish (*Aphareus furca*), barracuda (*Sphyraena barracuda*) and flame snapper (*Etelis coruscans*).When compared to the UVC data, the two last species, barracuda and flame snapper were not recorded since they were outside the census area in deeper waters. This highlights the limitations of the UVC technique in fisheries that span pelagic, shallow and deep-water habitats. On the basis of levels of exploitation, and aspects of life history, Lincoln-Smith *et al*. (1993a) identified that certain members of the Serranidae, Lutjanidae and Carangidae were susceptible to overexploitation, with the most at-risk being orange cod and ruby snapper. It also made mention of the location of the recreational fishing effort, saying that it was concentrated on the sheltered northern side of the island because the southern and eastern coasts were often too exposed for boat access. Those researchers caution that while it is tempting to assume that these inaccessible areas act as a refuge for stocks of at-risk species, there is no evidence to support this supposition and it should not be relied on.

Allen *et al.* (2007), unlike its first edition (Allen & Steen, 1987), provides some information in addition to the taxonomic catalog of fishes. It identifies that certain species conspicuous in other oceanic locations appear to be absent from Christmas Island (*e.g.* fish of the of the genera *Lethrinus* and *Plectropomus*). It provides some biological information on some recreationally important species including the considerable longevity of some cod (25 years) and snapper (20 years). It also notes the relative scarcity of cod and snapper species in general and attributes it to the small areal extent of suitable habitats.

The most recent UVC-based stock assessment (Gilligan *et al.*, 2008) had very similar outcomes to that of Lincoln-Smith *et al.* (1993a). It identified that the orange cod was still a commonly targeted species, and that cod and snapper were still considered the most commonly targeted types of fish. Interestingly, different species were identified as common by the UVCs. Gilligan *et al.* (2008) also concluded that the species stocks were in a healthy state but were naturally small due to the small amount of available habitat at Christmas Island. The terrestrial national park was mentioned as it includes marine adjacencies to 50m from shore, however it was considered to have very only marginal effect on the recreational fishing activity since it "recognises the recreational and cultural use of the national park" and permits fishing throughout the area (Cochrane, 2002). Interestingly, *Variola louti*, and *Lutjanus bohar* were both considered common in shallow reefs by Gilligan *et al.* (2008), but they were not even recorded by the 1993 UVCs (Lincoln-Smith *et al.*, 1993a). This discrepancy between studies is a common feature among consecutive studies at both Christmas and the Cocos (Keeling) Islands. It may be due to differences in sampling methodology, incorrect species identifications or may be valid changes in species compositions, however, as is common in biological studies, the causative factors are difficult to discriminate.

Brewer *et al* (2009) provides only a brief synopsis of previous studies and adds little new knowledge in this topic. As in previous studies, no assessments of deepwater or pelagic stocks were made. It does, however, mention that the green jobfish (*Aprion virescens*) is an incidental recreationally targeted species, which has not been documented in the above studies. Also, this report notes that the majority of the recreational fishing activity occurs on the western, northern and northeastern parts of the coastline, similar to the assessment of Lincoln-Smith *et al.* (1993a). This refers to the area from Egeria Point, along the northern coast, around to Ethel beach (Figure 3).

Recently gathered, unpublished data (DoF) and anecdotal reports indicate that certain pelagic species are becoming increasingly rare *e.g.* dog-tooth tuna (*Gymnosarda unicolor*) as are stocks of deep-slope species, particularly around the main boat access point of Flying Fish Cove. The south and east coast stocks remain poorly studied due to difficulty in accessing the areas.

The documented history of recreational fishing at the Cocos (Keeling) Islands extends much longer than at Christmas, beginning with a substantial survey in 1949 (Gibson-Hill, 1949). This study identified that most of the fishing effort was concentrated in the lagoon, which allowed a variety of techniques to be employed and a broad range of fish to be targeted. Handlining from boats was the preferred method of fishing, and was typically conducted in the southern lagoon, at an area called the "blue holes". Similarly to Christmas Island, cod and snapper were targeted, as were the emperor notably absent from Christmas Island. Various netting techniques in the shallow areas of the lagoon were also documented, which allowed harvesting of a very broad range of fish including mullet, milkfish and threadfin as well as juveniles of most edible fish species. The practice of spearfishing was also noted but was not common

Lincoln-Smith *et al* (1993b) was the next to make an in-depth study of recreational fishing the area. This study identified that handlining from boats over the blue holes was still a preferred fishing activity, with emperor most commonly taken, followed by shallow water snapper, cod, and notably humphead maori wrasse or "greenfish" (*Cheilinus undulatus*). Netting was also common and the diversity of species taken was quite large, including milkfish, bonefish, roach, triggerfish, squirrelfish, wrasse and parrotfish as well as juvenile emperor, cod and snapper. As remains the case, the lack of fishing restrictions regarding size, species and numbers of fish was identified, but that "fishing was discouraged" at popular recreational sites. The means of discouragement was identified by Lincoln-Smith *et al.* (1995) as being a by-law of the Home Island Council prohibiting fishing at the "the Rip" and "Trannies Breach". Fishing for pelagic species such as barracuda, wahoo and sailfish tended to be restricted to the relatively small european community rather than the Cocos-Malay, and overall "little or no harvesting of fish in very deep water" was observed, with the rationale that there was plenty of fish in more accessible areas. UVCs were once again conducted and the general view was "Generally [the authors] were impressed with the numbers of large fishes on the shallow reefs" (Lincoln-Smith *et al.,* 1993b), a sentiment that was reiterated for deeper reefs within the lagoon.

Hender *et al.* (2001) were the first to document decreases in Cocos (Keeling) Island fish stocks, noting that target species were now most abundant in the northern lagoon, with emperor and cod being previously heavily exploited at the blue holes and becoming increasingly rare. Throughout the entire lagoon, numbers of emperor and cod were substantially lower than recorded previously (Lincoln-Smith *et al.,* 1993b). Greenfish were only present as juveniles inside the lagoon and total of four adults were observed on the outer reefs. The conspicuous rarity of coral trout (*Plectropomus areolatus*) throughout the lagoon was also specifically noted, as was the practice of netting large quantities of this species when they formed spawning aggregations in the shallow water. Hender *et al.* (2001) conclude by recommending amendments to the management of the fishery including limits on net mesh sizes and protecting certain at-risk species (*Plectropomus*, *Lethrinus, Cheilinus* and *Variola*). The rarity of Lethrinids in the

Cocos (Keeling) lagoon noted by Hender (2001) is somewhat contradicted by local anecdotal evidence which indicates that *Lethrinus xanthochilus* is still relatively common, and present across a broad range of size classes. These incongruous reports may be a product of the highly mobile nature and habitat preferences of these Emperors (C. Skepper, Pers Com).

The results of an eight-year time series of UVC observations conducted by the resident Parks Australia staff as a part of the Reefcheck program were published, detailing changes in the fish assemblages at various sites throughout the Cocos lagoon (DEH, 2005b). This study found that the density of cod was low, being similar to that found by Hender *et al.* (2001) and much lower than that of Lincoln-Smith *et al.* (1993b). Likewise, snapper were rare at all monitoring sites and more detailed surveys on this group was recommended. Populations of non-harvested species such as butterfly fish (Chaetodontidae) did not exhibit any significant differences in abundance over the eight years.

Brewer *et al.* (2009) offers little further insight into the current state of fishing and the fish stocks on Cocos, stating only the species of fish which are typically caught at different parts of the lagoon. The fish caught in the southern part of the lagoon are species typically netted (mullet, roach and rabbitfish) whereas those from the north are predominantly line caught (greenfish, cod and snapper).

Recent fieldwork indicates that stock of many of the larger targeted fish species such as cod and snapper are in very low abundances, particularly in areas that are easy to get to (*e.g.* inside the lagoon). Those species that once impressed Lincoln-Smith *et al.* (1993b) with their abundance are now almost absent from that lagoon, and are found in low density only on the outer reefs. This rarity has changed the behaviour of the fishers, who now target deep lagoon and slope species such as *Etelis* spp.. Also noteworthy is the high abundance of reef sharks in the lagoon, which are not harvested due to cultural restrictions. This had lead to an unusual situation where up to 80% of fish hooked by fishers in the deep parts of the lagoon are taken by the extremely abundant shark population before they are landed (S. Newman, pers com).

Several comprehensive studies of the fish populations have been completed in the waters of the IOTs, however there are some discrepancies in the species of fish recorded. For instance, the green jobfish (*A. virescens*) was recently indicated as a popular recreational species however it had never even been recorded in previous assessments. Another species in a similar situation is *Etelis carbunculus.* Although these discrepancies may be a product of misidentification, it may also be a genuine reflection of changing fisher behaviour. Since both of the above species are occur in deeper water this change may be indicative of a shift towards fishing deeper slope waters rather than shallow reefs. Indeed, Brewer *et al.* (2009) does note that a shift towards deepwater fishing is evident with the increasing use of electric fishing reels allowing waters of 100m+ to be fished effectively. Anecdotal reports indicate that waters of 500+ m are now also being fished, targeting obligate deepwater species such as southern rays bream, *Brama australis* (C. Skepper, pers com).

Fisheries Biology

The planktonic larval duration of the many types of fish caught at the IOTs varies considerably from species to species, with planktonic phases lasting anywhere up to 80+ days (*e.g.* Balistidae). Based on published literature, Lindeman *et al.* (2000) estimated that members of the grouper family, Serranidae, usually had planktonic larval durations in the order of 30-50 days. The same authors estimated that snapper (Lutjanidae) had a slightly shorter larval duration, in the order of 20-40 days. This larval period is much shorter than the 80 days estimated by the Aus-ConnIe model required for significant recruitment, assuming passive transport (Condie et al, 2005).

Several researchers have proven that a passive transport model is not strictly appropriate for estimation of larval fish transport, and that pelagic larvae are capable of active movement over significant distances (Fisher *et al.*, 2000; Planes *et al.*, 2009). Cowen *et al.* (2006) produced a model to estimate the scale of larval transport for coral reef fish in the Caribbean, which incorporated data for many species and allowed for active transport of larvae. That study determined that even allowing for active larval movement, the limit of significant larval recruitment was between 50 and 100 km for most species, and important contributions of allochthonous recruitment did not occur over distances greater than 200-300 km. Since Christmas Island is at the outer limit of the estimates provided by Cowen *et al.* (2006), we can surmise that only the species with particularly long larval durations such as certain triggerfish (Balistidae) wrasse (Labridae) and surgeonfish (Acanthuridae) would have any kind of ecologically relevant larval transport onto the island. Cocos (Keeling) Island, being considerably more distant, is even less likely to receive allochthonous fish recruits.

The supposition that the fish stocks at the IOTs are very insular to mainland fish populations is borne out by recent genetic analyses. Many of the demersal slope and lagoon species at the IOTs are thought to be largely isolated stocks, without appreciable gene flow or recruitment from mainland stocks. To date this has been demonstrated with genetic comparisons of IOT and mainland Australian populations of orange cod (*C. argus*) for which there was very little genetic connectivity (S. Newman, unpublished data). Currently, similar genetic connectivity studies are being conducted on the IOT fish stocks for the other groupers *Epinephelus polyphekadion, Variola louti* and *Plectropomus areolatus* as well as the snappers*, Pristipomoides filamentosus, Etelis carbunculus* and *Etelis coruscans*.

The changes in fisher behaviour noted in several studies towards taking more deep-slope fish in preference to inshore reef and lagoon species has significant implications for the health of those deep-slope stocks. Lincoln-Smith *et al.* (1993a) states that deep water fish species may be more sensitive to fishing pressure than their shallow reef counterparts because they are typically slower growing, mature later, and have extended longevity. Considering the current less-than-pristine state of Cocos lagoon fish stocks, the translation of fishing effort offshore, and the greater sensitivity of deep-slope stocks to fishing pressure, it is logical conclusion that those latter stocks are likely to be at significant risk of overfishing.

Current and recommended management

It is apparent that the compositions of the fish stocks have changed, particularly in the last 10 years, with several studies noting a decline in abundance of grouper and snapper species in particular. This decline in the abundance of target species is of particular concern because the DoF currently has no means to curb or even consistently monitor these changes. Currently there are no enforcement officers nor any enforced Island-specific recreational regulations on the IOTs, only guidelines. It is recommended that improving the level of management of recreational fishing be a priority.

Over recent years, DoF have undertaken significant work to develop a tailored set of Island-specific fishing regulations for the IOTs, which acknowledges the local culture of artisanal fishing while protecting the integrity of the fish stocks; this process is ongoing. It should be noted that at the time of publication of this document the Attorney Generals Department has recently approved the development of IOT specific recreational fisheries management arrangements as well as the stationing of fisheries enforcement staff on the islands.

The fact that several species of fish and molluscs are severely depleted or locally extinct in the IOTs, combined with the apparent rapidity with which stocks of grouper, snapper and emperor species are reputed to be declining, it is particularly concerning that there are currently no means to manage these stocks. It seems prudent, under the precautionary principle, to at least introduce some interim recreational fishing regulations to gain time in which to conduct the appropriate research into the health of fish stocks at the IOTs. This research would facilitate the development of regulations based on sound scientific advice and are tailored to meet the needs of both the local population as well as the region's unique ecosystems.
During the development of both interim and permanent recreational fishing regulations certain fish species should be given special consideration given that they are either currently locally very scarce or they are a protected species. This list includes, but is not exclusive to:

- Humphead maori wrasse (*Cheilinus undulatus*). Currently a completely protected species in Australia under the *FRMR, 1995* but still harvested at the IOTs.
- Coral trout (*Plectropomus areolatus*). Thought to be close to locally extinct at the Cocos Atoll.
- Coronation trout (*Variola louti*). Considered "at-risk" on the Cocos Atoll.
- Dog-tooth tuna (*Gymnosarda unicolor*). Locally very rare at Christmas Island.
- Lagoon emperor species (Lethrinidae). Noted as very rare in the Cocos lagoon by Hender *et al.* (2001).

4.6 Deep Sea Crystal Crabs (*Chaceon albus*)

Deep sea crabs are typically slow-growing and long-lived species, which inhabit the relatively low productivity sea floor between 500 and 1000m deep. Given the expected low density and the slow growth rate of these crabs, as well as the small amount of preferred habitat (500-1000m deep) in the Australian EEZ around the IOTs, it is unlikely that the stock present is capable of supporting a long-term sustainable fishery.

Crabs of the genus *Chaceon* are among the most commonly caught and marketed deep sea crab species throughout the world. The species most commonly caught species in Western Australia was thought until recently to be *Chaceon bicolor*, the Crystal Crab, which has a distribution through the western pacific, northern and southern Australian waters and into the eastern Indian Ocean. Recently, Davie *et al.* (2007) identified the Western Australian individuals as belonging to an undescribed species, subsequently named *Chaceon albus.* The market name of Crystal or Snow Crab has been retained.

An investment group based in Western Australia expressed interest in exploiting stocks of Crystal Crab in the waters of the IOTs in 2008 (Grant 2008). This interest has resulted in the inclusion of this potential fishery in the present review document, despite the fact that there is currently no commercial, recreational or artisanal fishery for crystal crabs in the waters around the IOTs. Likewise, there has not been any research into the size, state and commercial viability of any resident stocks.

Previous assessments

Since *C. albus* forms the basis of the West Coast Deep Sea Crab Interim Managed Fishery (WCDSCIMF), data and research from that mainland fishery may be used to deduce preliminary information regarding stocks of this species on the IOTs in the absence of other information.

The majority of the catch from the WCDSCIMF is exported to Asian markets such as Singapore, and Hong Kong, with an approximate value to the local economy of $13/kg. The effective area of the fishery (500-1000m deep) is in the order of 50,6000km^2 and the Total Allowable Catch (TAC) is 140T(Fletcher & Santoro, 2009), which equates to approximately 3kg/km^2. This level of exploitation is considered sustainable at the present time, however due to the long lived and slow growing nature of the species it may be some years before long-term trends in catch rates are detected (Melville-Smith *et al.*, 2007).

Fisheries Biology

A considerable amount of work on the fisheries biology of *C. albus* has been conducted by Melville-Smith *et al*. (2007), with specific reference to the WCDSCIMF. This document details work on the age, growth, reproduction, movement and stock size estimates for *C. albus* and is the most comprehensive source on the fisheries biology of this species.

C. albus is typically a slow growing crab, inhabiting the cold (ca 5-8°C) waters between 500 and 1000m deep, with commercially viable densities typically occurring in the narrow band between 700 and 800m. Melville–Smith *et al.* (2007) found that males take about 15 years to reach the minimum legal size of 120mm carapace width and that most females never recruit into the fishery due to their smaller maximum size. As such, the current minimum legal size regulations in place for the WCDSCIMF are believed to adequately protect the long-term viability of the stocks through protecting almost all females, and the majority of males until well above their size at maturity.

Although the larval dispersal for *Chaceon* species is reputedly planktonic, specific details remain unknown for all but a few species in this genus. The deep-sea red crab (*Chaceon quinquidens*), which is widley distributed throughout the western Atlantic, is one such species. Steimle *et al.* (2001) indicate that the larval duration of this species varies considerably, being as short as 23 days or as long as 125 days. If this same plasticity is exhibited by *C. albus*, allochthonous larval transport to the IOTs is likely to be a viable means of replenishing fished stocks. However, this supposition would require further investigation before it is confirmed.

The level of exploitation in the WCDSCIMF can be coarsely applied to a potential fishery for deep-sea crabs around the IOTs. Within the 744,000 km^2 of the Australian EEZ surrounding the IOTs, there is approximately 641 km^2 within the 500-1000m depth range. It largely consists of narrow bands around the slopes of islands and seamounts and is fragmented across much of the EEZ area. As a very coarse approximation, applying the yield rate of 3kg/km could potentially translate to a Maximum Sustainable Yield (MSY) of 1.9T with an estimated market value of about $25,000 (at $13/kg).

The nature of the fishing grounds presents a considerable disadvantage to the development of a crystal crab fishery at the IOTs. As mentioned previously, there is only a very small area of sea bottom in the depth range preferred by these crabs, this is likely to translate to a very small stock size. Additionally, the small pockets of suitable habitat are often separated by expanses of abyssal sea floor 4000-6000m deep. This fragmentation of the fishing grounds not only isolates sections of the crab stocks, inhibiting stock regeneration, but would also dramatically decrease the efficiency of the fishers by increasing travel between pot drops. Operators would need to traverse the length and breath of the IOT's EEZ to access the small pockets of suitable habitat.

The location of the IOTs presents a second problem to the development of this fishery. Fishers located on the mainland have direct access to processing, transport, export and retail market services, streamlining the service chain. Furthermore, being close to major transport hubs, these services are relatively cheap. Christmas Island, and even more so the Cocos (Keeling) Islands are not major transport hubs and consequently services are expensive. The remote location of the IOTs would severely impact on the economic viability any commercial fishery in this location.

Current and recommended management

Currently there is no commercial or recreational fishery for deep-sea crabs in the waters surrounding the islands of the Indian Ocean Territories. As such there are currently no official management strategies or operational regulations.

In response to an application to develop an exploratory fishery for crystal crabs in the region, it is considered highly unlikely that a crystal crab fishery at the IOTs would prove viable due to the economic impacts of isolation, as well as to lack of suitable habitat. Furthermore, it should be noted that the greater proportion of area between 500 and 1000m deep lies outside the 12nm boundary imposed by the service delivery agreement between the AGD and the DoF, and as such would fall at least partially in the waters under the AFMAs control.

4.7 Gong Gong (*Lambis lambis*)

The ongoing risk assessment process undertaken by the WA Department of Fisheries has identified that the stocks of gong gong in the Cocos (Keeling) Islands are at high risk, the present rates of recreational exploitation are heavy, and that further research is required to adequately manage these stocks. It is recommended that there is no scope for commercial exploitation of this resource

The common spider shell (*Lambis lambis*) is widespread throughout the tropical regions of the Indian and western Pacific Oceans from Madagascar to Fiji (Abbott, 1961) and is locally known on the Cocos Islands as gong gong. The world-wide harvest of *L. lambis* is usually limited to artisanal collection with some small commercial operations taking this species as part of mixed specimen shell fisheries with varying levels of exploitation and regulation (Anon., 2004; Hermosilla, 2007). On the Cocos (Keeling) Islands, artisanal collection of gong gong occurs for the purpose of consumption by the local Cocos-Malay population and on occasions it is shipped back to their relatives on mainland Australia. There are no commercial operations that harvest this species but there are a considerable numbers of animals caught by locals, particularly during certain cultural events when several thousand individuals may be collected at a time (Bellchambers *et al.*, 2010). The algal-dominated lagoon habitat preferred by gong gong is completely absent from Christmas Island. As such the population of this species on Christmas Island is extremely small (Berry & Wells, 2000). The rarity of gong gong on Christmas Island means that local fishers do not harvest it.

Previous assessments

The reports of Gibson-Hill (1949) make no mention of harvesting of gong gong as an artisinal fishery, and we must assume that the harvesting of this species began after this time. Bunce (1988) was the first published reference to the recreational harvesting of gong gong followed by Wells (1989). Both accounts note that this species is common in shallow water, is easily harvested and is considered a delicacy by the locals. It was also noted by Wells (1989) that *Lambis lambis* may be vulnerable to localised overfishing and that a study of the biology of this species was urgently required to adequately manage their stocks.

Lincoln-Smith *et al.* (1993b) was the next to detail the exploitation of gong gong on the Cocos (Keeling) Islands and on the basis of interviews with local Cocos-Malays, estimated that fishing for gong gong only became popular relatively recently during the 1970s. During their study period, gong gong was identified as one of the three most at-risk species of overfishing on the island and that there was still a dearth of research regarding its fisheries and reproductive biology. Lincoln-Smith *et al.* (1993b) estimated that between 40,000 and 55,000 gong gong were taken per year and that densities in the lagoon were approximately 5925 ind/ha.

Hender *et al.* (2001) conducted a baseline study for the range of exploited marine resources at the Cocos (Keeling) Islands, of which a small portion was an assessment of the gong gong. This study estimated that the standing stock of *L. lambis* on the Cocos (Keeling) Islands was in the region of 6 million and that the estimated exploitation rate of <1% of the standing stock per annum was sustainable. Densities were estimated at between 520 per hectare in highly accessible areas to 7920 in the south-eastern part of lagoon. This stock assessment was somewhat qualified however by the recognition that research on fisheries and reproductive biology of *L. lambis* was no more advanced than when it was identified as a priority by Wells (1989). Hender *et al.* (2001) recommended that current exploitation rates were sustainable and that continued harvesting was appropriate but cautioned that the potential for overfishing remained due to the easily harvestable and gregarious nature of the species. Furthermore, research into the biology of this species and ongoing stock monitoring was recommended.

Brewer *et al*. (2009) make only passing reference to the stocks of gong gong at the Cocos (Keeling) Islands, but does note that they are easily collected, regarded as a delicacy by the locals and that because of these two factors may be easily fished out.

Bellchambers *et al*. (2010) is the most recent, targeted and comprehensive assessment of the stocks of gong gong on the Cocos (Keeling) Islands. Stock assessment was begun in 2007 and remains ongoing. The study was designed to provide data which would allow integration of the data from Lincoln-Smith *et al* (1993b) and so provide a comparison of the current stock relative to that in 1993. At the three sites surveyed by Lincoln-Smith *et al.* (1993b) densities had decreased dramatically from the estimated average of 5925 ind./ha. in 1993 to 2781 ind./ha. in 2007 and 1333 ind./ha. in 2008. This translates to a decrease of 77% between 1993 and 2008. Including the additional 29 sites surveyed by Bellchambers *et al.* (2010), the average density of gong gong on the Cocos (Keeling) Islands as of 2008 was approximately 1485 ind./ha. This study also determined that the locations within the lagoon where gong gong were abundant had also changed over since 1993. Both published and anecdotal reports indicate that historically the southeast area of the lagoon contained high densities of gong gong. Bellchambers *et al*. (2010) found that this was no longer the case, and that the macroalge habitat preferred by gong gong was absent. This represents an environmental change, which has dramatically altered the distribution of this species on the atoll. Anecdotal reports indicate that the change in the habitat and stocks occurred in about 2003 and while several possible environmental causes are suggested, none are definitively linked. Another important finding was that areas thought to be unexploited and acting as a refugeum for breeding populations were actually largely devoid of gong gong and were of an unsuitable habitat type. This most recent assessment of the Cocos (Keeling) Island stock of *L. lambis* is that they are under significant pressure from both recreational fishing and changes in habitat availability. To combat this increased pressure, management measures should be introduced and enforced to create a sustainable fishery for this species. As for all previous stock assessments for gong gong, Bellchambers *et al*. (2010) highlights the need for studies of the reproductive biology of the gong gong as well as ongoing assessment of their distribution and movement patterns.

Fisheries biology

Adult *L. lambis* are herbivorous, typically inhabiting algal dominated shallow reef flats in preference to deeper and/or sandy areas. This habitat preference makes them easily gathered by wading from the shore. This association is of particular relevance to the Cocos (Keeling) Atoll where shallow reef habitats in the southern part of the main lagoon have reputedly been lost due to substantial sedimentation.

The scant reports of the fisheries and reproductive biology of *L. lambis* indicate that spawns consist of gelatinous threads laid into an egg mass. The eggs hatch after three days into veliger larvae, which enter the planktonic community for an unknown period of time (Hamel & Mercier (2006). Once the larvae have matured into their benthic morphology, juveniles tend to be cryptic with only a very few specimens being reported. On the Cocos (Keeling) Islands. Hender *et al.* (2001) mention that a few juvenile specimens were encountered during their 2001 study, and that they were buried in the sand and associated with crab burrows. Additional local anecdotal evidence suggests that juveniles may also be present at the sandy bottoms of the "blue holes" in the southeast portion of the lagoon. While this latter assertion remains to be confirmed, Bellchambers *et al*. (2010) also located a few juvenile specimens around the tops of the blue holes lending support to the anecdotal evidence. The burrowing and cryptic behavior of juvenile *L. lambis* has implications for this fishery with juveniles effectively remaining unexploited until they migrate to the reef flat where they become accessible. It is not known whether this is before or after the age at first reproduction.

At maturity, individuals stop growing in size, and develop the characteristic flared lip and spines, giving rise to the common name of Spider Conch. Further growth is expected to result in a thickening of the flared lip, as in other members of the Strombid family, although this is yet to be formally documented.

Since most aspects of the fisheries and reproductive biology of *L. lambis* are poorly understood and research on the topic is still in its infancy or remains unreported, the majority of assessments on this species use aspects of the biology of the Queen Conch (*Strombus gigas*) as a proxy. *S. gigas* is cited because it is relatively closely related, is expected have similar biological characteristics, is commercially exploited in the Caribbean and has been researched extensively. Age at first maturity is approximately 3 –4 years, and is morphologically indicated by the development of a flared lip on the shell (Appeldoorn, 1988), this is though to be homologous to the flared lip and spines exhibited by gong gong at maturity. The Queen Conch is considered overfished throughout much of its range, is considered "commercially threatened" by the IUCN and has been on the CITES Appendix II list for almost 2 decades. One of the biggest concerns for the Queen Conch, aside from over exploitation, is that in some areas of its range populations are not recovering despite a ban on their removal. This is considered to be the result of the "Allee effect" whereby the remnant population is so small that the encounters between mature individuals rarely occurs for spawning. For *S. gigis*, the minimum density to avoid the Allee effect is 56 ind./ha. *L. lambis* may have a similar biological constraint on its minimum density given that it is also aggregates to spawn.

Critical elements of the fisheries and reproductive biology of *L. lambis*, which currently remain unknown, and which have significant implications on the health of the stocks on the Cocos (Keeling) Islands include:

- When spawning occurs and its duration, this may influence duration and timing of any potential closed seasons.
- Whether individuals remain at one location or move substantially, will determine the size and effectiveness of closed / sanctuary areas.
- Critical density of individuals at which the "Allee effect" may inhibit spawning.
- Period of the planktonic larval stage, will determine whether planktonic larvae are retained on the atoll or are being lost to the open ocean and whether local stocks are replenished from other populations.
- Whether individuals are reaching "age at first reproduction" before they harvested, will influence minimum sizes and/morphology requirements (*e.g.* spines of a certain length)

Current and recommended management

As mentioned previously, the recreational fishery on the Cocos (Keeling) islands for gong gong is a harvests a substantial number of individuals in the order of 3.7 tonnes in 2002 (without shell). Recreational fishing guidelines on the island recommend that no more than 9 litres (with shell) of gong gong may be harvested per person per day (DoF, 2006).

Personal comments from members of the local community recorded by Bellchambers *et al* (2010) suggest that this bag limit is not regarded, with “commonly, as many *L. lambis* as possible are collected, which may be 200, or up to 1000 if available”.

With the balance of evidence suggesting that the stocks of *L. lambis* on the Cocos (Keeling) islands are under significant pressure from overexploitation, amongst other stressors, it seems reasonable to suggest that the existing bag limit regulations for this species be mandatory and be enforced. Furthermore, knowledge of the fisheries and reproductive biology of *L. lambis* was identified as a requirement of effective management of this species more than 20 years ago by Wells (1989). To date, this research is still not part of the management of this fishery, despite evidence to suggest that the stocks underpinning this locally important fishery are under pressure.

4.8 Bêche-de-mer

Documented evidence suggests stocks of bêche-de-mer are notoriously prone to overexploitation, even in situations where best practice is employed. The most recent and comprehensive feasibility study regarding the development of a commercial Bêche-de-mer fishery on the Cocos (Keeling) Islands recommends that it does not occur.

The common commercial term "bêche-de-mer" is used to describe a diverse range of sea cucumbers (Echinodermata; Holothuria) as well as the food product made from their treated and dried body wall. Although sea cucumbers are present in almost all benthic marine environments, they are often most abundant in shallow tropical reef/lagoon areas, such as those found on the Cocos (Keeling) atolls. The commercial value of bêche-de-mer species is very variable and is primarily determined by the thickness of the body wall and the size of the animal, with thicker bodied and larger species being more commercially attractive. As an example of the diversity in the value of bêche-de-mer species, Uthicke (1996) quotes the then current price of *Holothuria scabra* (Sandfish) as $38.00/kg, whereas *H. atra* (Lolly fish) was worth only $5.00/kg. In a mixed species fishery such as bêche-de-mer, both the species composition and number of individuals present will be relevant to whether a commercial venture is economically viable.

Since there is currently no commercial fishery for bêche-de-mer on the Cocos (Keeling) Islands and they do not form part of a cultural/recreational fishery for the local population, the stocks in this area are considered to be in a relatively natural and unexploited state. The most recent study of the bêche-de-mer species on the Cocos (Keeling) Islands found that 18 species were present in the area, and that *H. atra* was by far the most common overall contributing > 90% to the total abundance (Bellchambers *et al.*, 2007). The marked prevalence of *H. atra* is presumed to reflect this species' cosmopolitan feeding behavior and relatively protracted reproductive period. Species of high commercial value that occur on the Cocos (Keeling) Islands include *H. scabra*, *H. whitmaei*, and *H. nobilis*, however, these species only make up an extremely small proportion of the population. Likewise, the medium value species *Actiopyga echinites, A. mauritiana, A. miliaris, Stichopus hermanni* and *Thelenota ananas*, also contribute very small amounts to the total number of individuals.

Fishing for bêche-de-mer tends to be the province of island communities such as found in Maldives, Fiji, New Caledonia, Galapagos and Seychelles. This is primarily an outcome of the abundance of shallow lagoon habitat, which is preferred by the sea cucumber. Although the physical size of these islands and archipelagos tend to be larger than Cocos (Keeling) Islands, important comparisons can be drawn on the likely long-term trends of any potential fishery in the region, given the history of those island fisheries world-wide.

Gilligan *et al.* (2008) assessed the population of holothurians on Christmas Island and found very few individuals on the fringing reefs.

Previous assessments

The development of a commercial bêche-de-mer fishery on the Cocos (Keeling) Islands was proposed to AFMA, and in 2002 an exploratory management report was compiled in response (AFMA 2002a). The outcome of that report was that insufficient information was available to adequately predict the abundance and viability of commercial species in the lagoon. Since that time several assessments have been conducted commenting on the viability of this proposition, with a considerable variety of conclusions.

An initial estimate by Hender *et al* (2001) of the total density of all sea cucumber species on the atoll was 7512 ind./ha., comprising nine species. Although *H. atra* was the most abundant in almost every environment around the atoll, habitat associations were discernable in the distribution of the lesser contributing species, *e.g. Bohadschia argus* and *Chiridota rigida* were more abundant in the lagoon, while *H. edulis* and *Stichopus chloronatus* were more prevalent on the outer reefs. Hender *et al* (2001) concluded that the commercial viability of a bêche-de-mer fishery on the Cocos (Keeling) Islands was dependant on the marketability of *H. atra* since that was the species which was by far the most abundant and likely to form the bulk of any commercial catch. Uthicke (1996) considered *H. atra* to be a very low value species with poor marketability.

Seymour (2006) concurred with Hender *et al* (2001) that the viability any commercial fishery for bêche-de-mer on the island would be dependant on *H. atra* and asserts that higher value species would need to be harvested if it was to be an economically viable fishery. The stock assessment of bêche-de-mer by Seymour (2006) was very limited in terms of time and labour, which has required very large extrapolations and hence very large margin of error in estimating stock size. Thus, the density of animals on the atoll was estimated at 16592 ind./ha., more than double that of the previous assessment, and that nine species were present in suitable numbers for commercial exploitation (sometimes assessed on the basis of a single individual). On the strength of these greatly extrapolated estimations, this report recommended that a fishery for bêche-de-mer was viable providing that the more lucrative species could be taken and that an annual harvest of 1646-2471 t would be sustainable.

To benchmark the intensity of activity proposed, this rate of harvest equates to approximately 18 t / km^2 of subtidal area. This can be compared to the bêche-de-mer harvest in the Maldives in 1992, of 15 t per km^2 (Joseph, 1992). The Maldives fishery is now considered drastically overexploited (Toral-Granda *et al.*, 2008).

Bellchambers *et al.*, (2007) is the most recent and comprehensive assessment of the feasibility of a bêche-de-mer fishery on the Cocos (Keeling) Islands. This report is based on extensive sampling and is considered to provide the most robust estimate of stock sizes and composition. The species composition of the stock was found to be similar to that of previous studies, *i.e.* predominantly *H. atra* with the 17 other species present showing a propensity for habitat-specific aggregations. Higher value species such as *H. nobilis*, were very uncommon and, when present, had very restricted distributions. Total density of bêche-de-mer was estimated at 3252 ind./ha., less than 20% of that extrapolated by Seymour (2006). Given the relatively low commercial value of the dominant species, *H. atra*, and the estimated stock size, Bellchambers *et al.,* (2007) recommended that commercial harvesting of bêche-de-mer does not occur on the Cocos (Keeling) Islands. It was reasoned that the benefit of the unexploited bêche-de-mer population to the atoll's ecological well-being far outweighed the benefits any marginally profitable fishery.

Gilligan *et al.* (2008) assessed the abundances of holothurians on Christmas Island and found that abundances were very low, finding a total of only 4 individuals. This is presumably an expression of a naturally small population and a result of the small amount of preferred habitat at Christmas Island.

Fisheries Biology

The FAO's 2008 review of bêche-de-mer fisheries and trade globally (Toral-Granda *et al.*, 2008), indicates that these fisheries are extremely prone to overexploitation, with collapses of holothuroid fisheries being reported worldwide often within a very short period of initial exploitation. This seems to be especially true for isolated islands, *e.g* Galapagos (1990 –1992/1994), Maldives (1987-1992), Kiribati (2000-2002) Tonga (1998) and throughout Micronesia (2005-2007) (Toral-Granda *et al.*, 2008). It was also noted that these overexploited fisheries exhibited very poor natural recovery after they had collapsed or were closed.

Dalzell *et al*. (1990) examined the potential to exploit bêche-de-mer on the island nation of Niue. Although the morphology of Niue is somewhat different to that of the Cocos Keeling islands, the stock composition of the island groups were found to be very similar, *i.e.* both have a very high preponderance of *H. atra*. That study on Niue concluded that a bêche-de-mer fishery should not be initiated, with the reason being that *H. atra* was not a viable basis for a sustainable commercial fishery.

Uthickie (1996) identified that patterns of recruitment and recolonisation of exploited bêche-de-mer stocks were foremost among the research gaps which hindered the effective management of their fisheries. Since that time research has been conducted into the fisheries biology of bêche-de-mer, with the general consensus being that recruitment is highly irregular and variable (Toral-Granda et al., 2008). This inherent variability is likely to be exacerbated on isolated islands such as the Cocos (Keeling) atolls by its biogeographic isolation.

Larval durations of commercial bêche-de-mer species are typically in the order of 2 –3 weeks (Conand 2007; Bell et al., 2008). As previously discussed, this time period is likely to be too short for fishery-relevant recruitment events onto the Cocos Islands from distant landmasses. Furthermore, the 2-3 weeks planktonic larval drifting is long enough to allow many of the settling larvae to be washed out of the lagoon and lost to the open ocean. Although specific studies on bêche-de-mer recruitment onto the Cocos (Keeling) Islands have not been conducted, the weight of evidence suggests that recruitment from allochthonous recruitment is close to nil, and autochthonous recruitment is very variable and dependent on local-scale hydrology. Genetic evidence from world wide stock assessments suggests that "on evolutionary time scales, sea cucumber stocks could be replenished from a large variety of sources, but are not highly relevant on the ecological time scales required for fisheries management" (Toral-Granda et al., 2008).

Current and recommended management

Since there is currently no commercial fishery and bêche-de-mer do not typically form part of the recreational and artisinal fishery on the Cocos (Keeling) islands, no formal management tools have been developed for these species. To date, applications to develop a commercial bêche-de-mer fishery in the IOTs have been rejected. In the light of recent research into the stock on the islands and the FAO global review of bêche-de-mer fisheries, it is recommended that a commercial fishery for these invertebrates not be developed. The worldwide collapse of similar stocks and their importance to local ecosystem processes represents a greater inherent value than does a commercial fishery, which is at best likely to be marginally profitable. The naturally low stocks of holothurians at Christmas Island, are incapable of supporting a fishery.

4.9 Giant Clams (*Tridacna gigas, T. maxima* and *T. derasa*)

Giant (*Tridacna*) clams are harvested for food on the Cocos Islands despite fishing guidelines to the contrary. The largest species, *T. gigas*, previously occured in the lagoon but is now considered locally extinct due to exploitation. The smaller species, *T. derasa* and *T. maxima,* continue to be exploited despite moderate to low standing stocks in comparison to historical data.

Of the three *Tridacna* species historically present on the islands of the Indian Ocean Territories, *T. gigas* and *T. derasa* are both listed as vulnerable on the IUCN red list while *T. maxima* is considered lower risk. Although never recorded on the Cocos (Keeling) Islands, *T. squamosa* has been reported from Christmas Island and may or may not also be present at the former location. *T. crocea* has never been recorded at any location in Australia's Indian Ocean Territories.

Clams are often taken from the Cocos (Keeling) Island lagoon for their meat by the local artisanal fishery and form a significant portion of the diet of some Cocos-Malay families. Like the gong gong, they are predominantly collected while walking along the shallow reef flats on low tide. The highest densities of clams tend to be found in the slightly deeper and inaccessible reefs in the lagoon, and in areas around ecotourism hotspots (northern and north-western sections). Densities recorded from the outer reef are substantially lower, and on the southern sand flats are close to nil (Hender *et al.*, 2001).

Berry (1989) noted that in 1989 no live *T. gigas* were found in the lagoon on South Cocos Atoll but that their empty valves were present along the beach outside the local village where they had been harvested for food and the shells discarded. Lincoln-Smith *et al.* (1993b) adds no further information, only noting Berry's (1989) assertion that they were likely to be locally extinct. One or two individuals of *T. gigas* were thought to still be present in the lagoon up until no more than two years ago, at which time anecdotal reports suggests that they were harvested for a local celebratory feast. *T. gigas* is now though to be locally extinct on Cocos (Keeling) Islands as a direct result of artisanal harvesting. Hender *et al.* (2001) provides a preliminary indication of the stocks of *T. derasa* and *T. maxima* in the Cocos lagoon and found stocks levels to be "moderate to low" with an average density of 300 ind/ha.

Tridacnid clams do occur on the reefs around Christmas Island but are less common than in the Cocos Lagoon, as low as 30 ind./ha (Gilligan *et al.*, 2008) The lower density of clams at Christmas than at Cocos is thought to be a natural phenomenon rather than human-induced, and as a result of the differences in habitat availability (Gilligan *et al.*, 2008). The highest densities of clams at Cocos are found in the reefs within the sheltered lagoon, a habitat that is absent from Christmas Island. *T. derasa* and *T. maxima* are the most common species, with a few *T. squamosa* also being recorded by Berry &Wells (2000). There are no reports of *T. gigas* on the reefs at Christmas Island. While it cannot be stated categorically that clams are not recreationally or artisanaly harvested on Christmas Island, they are not recorded as being collected in appreciable quantities by the local population.

Fisheries Biology

Tridacnid clams typically have a slow to moderate growth rate, with 15cm long clams in *T. maxima* aquaculture trials being greater than 2 years old (Hart *et al.*, 1998). Giant clams are hermaphrodites and may be protandrous or simultaneous depending on the species. *T. maxima* is a simultaneous hermaphrodite and matures at about 2 years. In contrast, *T. derasa* is protandrous with males maturing at about 5 years and hermaphrodites at 10 years (34 cm)

(Raymakers *et al.*, 2003). Despite remarkable fecundity at spawning (Jameson, 1976), the relatively late age at maturity and substantial larval mortality means that giant clams may recruit poorly and be quite vulnerable to over exploitation. This is particularly the case for *T. derasa,* which must attain a relatively large size before female functionality is present.

Given the isolated location of the Indian Ocean Territories the potential for allochthonous recruitment must also be considered. The larval duration of both *T. derasa* and *T. maxima* are in the order of 8-9 days (Benzie & Williams, 1997), which is very short given the >80 day predicted passive travelling time via ocean currents from the nearest landmass. The extreme shortfall in larval duration translates to a very small chance of allochthonous recruitment for these species to the Cocos atolls. The vast majority of recruitment must then be from the existing population.

Giant clams are exploited throughout tropical regions worldwide, being used for meat or shell products, or as live specimens for the aquarium trade (Gilbert *et al.*, 2006). In the past, wild populations have been exploited, however some species have proven adaptable to aquaculture, and are farmed in both land and lagoon based systems. One such aquaculture system currently operates on the Cocos (Keeling) Islands. The broodstock for this facility has been taken from the local lagoon and the spat are raised to sellable size for the food and aquarium markets in land-based systems.

In a small, isolated and fragile system such as on the Cocos Islands it is important to maintain strict quarantine protocols for aquaculture facilities to ensure diseases or pest species are not released. It is also highly recommended that broodstock be of the same species and genetic composition as local wild stocks to maintain the genetic integrity of the region.

It should be noted that *T. derasa, T. maxima* and *T. gigas* are the three naturally occurring species on the Cocos (Keeling) Islands (Wells, 1994). Other Tridacna species, in particular, *T. squamosa* and *T. crocea* do not naturally occur there and as such should not be considered as viable aquaculture species in this locality. There are currently no clam aquaculture ventures on Christmas Island, presumably due to the unsuitability of both the aquatic and terrestrial landscapes of the island for large aquaculture facilities.

Current and recommended management

Proposed recreational fishing regulations for the IOTs provide for a no-take policy on all clam species (DoF, 2006). To date, these fishing regulations remain as non-enforced guidelines, and the artisanal collection of clams continues to occur on Cocos. Anecdotal reports indicate that the locals voluntarily do not harvest clams below a certain size, however, this arbitrary threshold is almost certainly not high enough to adequately protect breeding stocks of the larger of the species, *T. derasa*.

A dedicated study of the stocks of giant clams in the IOTs is planned but has not yet been implemented. That study will provide a clear indication of the current state of the stocks, which can in turn be used to advise recreational fishing regulations.

Commercial fishing of giant clams is not recommended for the Cocos (Keeling) Islands given the restricted recruitment and substantial recreational pressure already on stocks. The same recommendation is made for Christmas Island due to the naturally small stock size of these invertebrates.

Commercial aquaculture of Tridacnids already occurs on the Cocos (Keeling) Atoll, however an assessment of the impacts and sustainability of this operation is outside the scope of this review. Additional reports on this activity and an in-depth assessment of the existing operation is recommended prior to any additional venture being approved or expansion of existing operations.

4.10 Shallow-water Decapods

Some decapods, including rock lobster and mud crab species have very long pelagic larval stages, potentially allowing recruitment from distant source populations. There is currently no commercial exploitation and low to moderate recreational exploitation on these species and as such their stocks are not considered to under considerable stress. The recreational collection of small shore crab species is effectively unmanaged, however bag limits or no-take rules are currently being considered.

Rock lobsters are the most commonly encountered large marine decapods in the Indian Ocean Territories. The dominant species is *Panulirus penicillatus* but *P. versicolor* and *P. ornatus* also occur in lower abundances (Morgan, 1994). These species are relatively common on Christmas Island and the outer reefs of Cocos but are only occasionally seen on reefs inside the Cocos lagoon. There is no commercial fishery for lobsters on the islands, and recreational catches of lobsters are typically moderate, with the majority of catches taken opportunistically by SCUBA divers as well as snokellers at low tide, and by the inhabitants of both Home and West Islands.

Mud crabs, *Scylla* sp., are also know to occur on the Cocos (Keeling) Islands, and in contrast to the lobsters prefer the sheltered sand/mud habitats of the lagoon. Morgan (1994) indicates that they are only rarely seen and are present in only low numbers. While they are typically too uncommon to be specifically targeted, recreational fishers opportunistically collect them when they encountered. The scarcity of muddy habitats at Christmas Island obviously translates to a scarcity of mud crabs.

Smaller crab species such as those belonging to the families Ocypodidae, Diogenidae and Portunidae are also present and relatively conspicuous on the sand flats at the Cocos (Keeling) Islands. These species are often collected, but due to their small size they are typically used as fishing bait rather than for food. Once again, there is no commercial operation for the harvest of these species, with their collection being limited to recreational and artisanal fishers. Given that recreational and artisanal fishing is a very important part of the lifestyle on the Cocos (Keeling) Islands, the pressure on these small crabs is appreciable and there are reports of localised depletions around populated areas.

The "Kingdom of the Crab" title given to Christmas Island reflects the abundance and conspicuous population of land crabs present on this Island. This notoriety tends to garner a certain amount of local ownership and voluntary protection to most species of crab on the island in addition to the official protection of certain species, regardless of whether they are the endemic red crab (*Gecarcoidea natalis*) or a common shore crab. As such, the crabs of Christmas Island are largely safe from any kind of recreational or commercial harvesting.

Fisheries Biology

The *Panulirus* species and *Scylla* sp. are relatively unusual among the marine fauna of the IOTs in that they have a very long planktonic larval duration. *Panulirus* species are known to have a very complex planktonic larval phase, which may take 10 months of planktonic drifting to complete. And although not to the same extent, *Scylla* spp. have extended larval durations of up to 6 weeks, and larval transport of $<$1000km has been recorded under certain conditions (Gopurenko *et al.*, 2003).

The extended larval duration of these species has important ramifications for their recruitment onto the isolated islands of the IOTs. The southern equatorial current begins in the Indonesian archipelago (the Indonesian throughflow) and is largely responsible for macroscale water transport past the IOTs. As such, any long-duration larvae, such as of *Panulirus*, within this water mass are also likely to have originated in Indonesia or northern Australia (Morgan 1994).

The other side of the coin regarding the elongated larval phase of these species is that any larvae that are spawned on the islands are likely to be lost to the same current which seeded the previous generation.

The ongoing health of *Panulirus* spp. and *Scylla* sp. stocks on the Cocos (Keeling) Islands are not likely to be severely impacted by ongoing harvest, since recruitment of these species is almost entirely allochthonous. Although over harvesting is to be avoided, its most likely outcome would be the depletion of the individuals of catchable size, without having long term detrimental effects on the health of the stocks (Morgan 1994).

The larval duration of most of the smaller decapod species such as fiddler (Ocypodidae) and hermit (Diogenidae) crabs are not nearly as long as that of the larger *Scylla* and *Panulirus* species, however, there are species in these groups which may have a planktonic larval duration of more than 50 days (Rodrigues & Jones, 1993). As such, it can be expected that a combination of allochthonous and autochthonous recruitment maintain the populations of these small decapods on the Cocos (Keeling) Islands. Since this is a mixed species fishery, sustained by a combination of allochthonous and autochthonous recruitment, it is probably prudent to regulate it according to the more vulnerable, locally recruited species.

Current and recommended management

All of the decapods above are encompassed in the recreational fishing guidelines for the Cocos (Keeling) Islands. The lobsters and mudcrab have minimum size and bag limit restrictions, whereas the small species just have a combined bag limit.

Recreational harvests of *Panulirus* species in the IOTs and *Scylla* sp. at the Cocos (Keeling) Islands are not expected to have detrimental effects on their existing stocks due to the probable allochthonous source of recruitment. Under heavy fishing activity local stocks of legal-sized individuals are likely to be depleted, however they are expected to be robust in the long term and resilient to local depletion. Despite their resilience, stocks of these crustaceans are unlikely to support any commercial fishery, as there are simply too few individuals to be economically viable for an extended period.

Current recreational fishery guidelines recommend a bag limit of mixed small decapods (Ocypodidae, Diogenidae and Portunidae) of 9L per day. Concerns have been raised regarding the number of small hermit and shore crabs being harvested as bait. The bag limit guideline is currently under review and may be amended at the conclusion of that process to be an enforced bag limit regulation or a no-take regulation as part of a wider review of recreational fishing regulations.

4.11 Sharks

There is no commercial or recreational fishery for sharks at either CI or CKI. This zero-take situation may be formalised in the review of recreational fishing regulations. It is recommended that no commercial fishery for sharks at the IOTs should be allowed on the basis of the proven inherent vulnerability of shark stocks world wide.

While catching sharks is not specifically prohibited or regulated in the IOTs, they are generally not exploited in an extractive manner at either Christmas or the Cocos (Keeling) Islands for several reasons. The first is for cultural reasons. Much of the local population, particularly on CKI are Islamic and as such eat according to the rules of halal. Most Cocos-Malays cite that shark is not allowed under the direction of halal and as such they do not target shark as a food source. Secondly, Both CI and CKI are known for their shark populations as an ecotourism draw card. Christmas Island is a significant waypoint on the whale shark (*Rhincodon typus*) migration route and these enormous planktivores time their migration past Christmas Island to coincide with the spawning of the endemic red land crab (Brewer *et al.*, 2009). In contrast, the Cocos (Keeling) lagoon is known for very dense populations of black-tip and grey sharks (*Carcharhinus melanopterus* and *C. amblyrhynchos*, respectively), which have an average density of about 10/ha. These latter two sharks species are typically coast-associated and are viviparous making allochthonous recruitment the most likely source of stock regeneration. Several of the local tourism operators capitalize on the presence of these animals by offering diving, snorkeling or viewing tours specifically designed to see sharks.

Previous assessments

Lincoln-Smith *et al.* (1993b) mentions that there was an expression of interest in the commercial harvesting of sharks being considered in 1993. Those authors strongly recommend against the development of this fishery, reasoning that shark fisheries are extremely prone to collapse due to the very close stock-recruitment association produced by the low fecundity of sharks in comparison to most bony fish species. The link between life-history traits of sharks and their propensity to be overexploited is reiterated by Hoenig & Gruber (1990). From the absence of further information regarding the proposal to commercially harvest sharks in the IOTs, it can be assumed that this potential fishery was considered unsuitable, and the application to develop it was denied. Hender *et al.* (2001) make a small mention of the healthy population of reef sharks at the Cocos (Keeling) Islands and reiterates the earlier assessment of Lincoln-Smith *et al.* (1993b), that a commercial fishery should not be developed, citing that the exploitation of sharks worldwide is usually followed by rapid decline of the exploited stocks.

Current and recommended management

Currently there are no regulations regarding the recreational harvesting of sharks at the IOTs, however, sharks are rarely targeted due to cultural restrictions and the acknowledgement of their greater value as a tourist attraction. Despite this self-regulation, it is recommended that sharks are included in the upcoming development of recreational fish regulations. The development of a commercial shark fishery in the IOTs is not recommended due to the unsustainable and volatile nature of shark fisheries wordwide, their allochthonous recruitment, the small stock size despite relatively high density, and their greater inherent value to the ecotourism industry and the island ecology.

5.0 Considerations for the viability of fisheries on the IOTs

5.1 Commercial exploitation

It is evident from this review that there are three primary hindrances to the commercial exploitation of marine resources in the IOTs, which are common to most of the different exploitable fisheries; a difficult economic environment, small stock size and low stock resilience. While the first issue is economic and essentially the concern of private enterprise, the latter two are related to the continued well being of the fish stocks of the region, and as such are pertinent to the fishery managers (DoF).

Difficult economic environment

The isolated location of Christmas Island, and even more so the Cocos (Keeling) Islands dramatically increases the cost of the operations for any commercial fishery. All facilities and amenities including power, space, fuel, labour and equipment will all have a premium attached to their regular price commensurate with the cost of their transport. This "remote-location excess" is likely to have a significant impact on the financial margins and economic viability of any commercial fishery. When it is considered that most possible fisheries in the IOTs could equally be conducted (and often already are) on mainland Australia without this excess, the financial competitiveness of these fisheries further decreases.

Financial consideration of the potential market also would have a bearing on the economic viability of the fisheries. The two market options would be to export the product to distant markets, which would be subject to the same remote-area excess as above, or sell direct to the local market, which is often very small given the relatively small population of the islands, and the high proportion of people willing to catch their own produce recreationally or artisanally.

In order to overcome the economic pitfalls inherent in the fishery location, any commercially exploited fishery would have to have a high per-unit value, have low overheads and be viable to transport to a sizable market. An example of this viability can be found in the CKIMAFF with the collection of the cocos pygmy angelfish for the aquarium trade (Subsection 5.3).

Stock size

The relatively small shallow water areas at Christmas and the Cocos (Keeling) Islands, surrounded by low productivity open oceans and abyssal sea-floor plains means that the stocks of commercially attractive species are small. There is simply not enough area for a sizeable fish stock to inhabit, and by logical extension, there are not that many fish to catch. While this has financial implications for the potential fishers in that the economies of scale cannot be achieved, it also means that fishing activity can deplete stocks extremely fast, faster than the stocks can regenerate. A prime example of how quickly small stocks can be overexploited can be seen in the rapidity of collapse exhibited by bêche-de-mer stocks on islands world-wide (Subsection 5.8).

Stock resilience

The small and isolated stocks that are present on the IOT islands are typically not resilient to fishing pressures, given that for many of the resident species, recruitment needs to be autochthonous. The majority of the species discussed previously do not have the ability to receive appreciable amounts of recruits into their stocks from remote locations, at a time scale relevant to fisheries. This means that if a species is fished into local extinction or to a level below a viable population density (Allee effect), it is unlikely to recover for years or decades, if at all, since there is no juvenile recruitment.

5.2 Recreational exploitation

As with the commercial exploitation of fish stocks on the IOTs, the management of the recreational fishery must also account for the small size and low resilience of the various fish stocks. The small stock size and low resilience is likely to interact with the recreational sector in a similar way to that predicted for commercial fisheries. That is, small and isolated stocks such as those on the IOTs are expected to have very little resilience to substantial and sustained fishing pressure. In situations where this type of fishing pressure occurs, it is likely that stocks of target species will rapidly shrink, and further, that heavily depleted stocks are likely to recover at a much slower rate than equivalent mainland ones, if at all.

In contrast to commercial fisheries, where it is a valid management option to simply not grant commercial access, management of recreational fishers must be approached more diplomatically, particularly in situations such as a the Cocos (Keeling) Islands where a significant portion of recreational fishers do so to supplement their diet.

Several sources have identified the need to accommodate the cultural and subsistence needs of the local communities in the development of environmental management plans (*e.g.* Alder *et al.*, 2000, Gilligan *et al.*, 2008 and Brewer *et al.*, 2009). While this is one of the primary tenets of a management plan, it is not the only one. The needs of the local fish stocks and the integrity of the ecosystem must also be considered to ensure that the fish stocks still exist to service the needs of future generations of subsistence fishers.

Currently the recreational fishing sector vastly outweighs the commercial one in terms of both number of fishers and amount of extractive activity and as such exerts a much greater influence over the well being of the local stocks. At the present time there is neither regulation of this sector nor any approriate framework with which to regulate it. At the same time there is a series of documented reports, synthesised in this review, indicating that the fish stocks and ecology of the islands are under significant pressure, even in areas where there is no commercial activity.

Three things must now be kept in mind, the requirement to balance the needs of fisher with fishery, the current state of the IOT fish stocks, and the potential ramifications of continued unregulated fishing pressure. With knowledge of these three areas in mind, it is evident that there is an urgent need for the development and enforcement of specifically tailored recreational fishing regulations in the IOTs.

6.0 Conclusions

The development of any commercial fishery that is expected to last no more than a few years before the stocks collapse, and is at the long-term expense of the local stock/ecosystem heath, is not a sensible business or management plan. For this reason, any stocks that have the potential to be rapidly depleted and to have little means of natural recovery are recommended for preclusion from commercial exploitation at the IOTs. Unfortunately, most fish and invertebrate stocks on the IOTs fall into this category due to their biogeographical and physical isolation.

Likewise, substantial, sustained and unregulated recreational fisheries are likely to have as detrimental an influence on the fish stocks as any commercial operation. While the need for recreational, artisanal and subsistence fishing is acknowledged, the counterpoint need for regulation of that fishing effort is also identified. Although the introduction of regulations into a previously unregulated recreational fishery is unlikely to be a popular course of action, the long-term benefits of such actions are seen to be of very high value.

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