Natural Values of the Inshore Waters of Australia's Indian Ocean Territories - Christmas & the Cocos (Keeling) Islands

JAMES COOK UNIVERSITY
Contact author: Professor Morgan Pratchett,
ARC Centre of Excellence for Coral Reef Studies, James Cook University, Townsville QLD 4811.
MORGAN.PRATCHETT@JCU.EDU.AU | (07) 4781 5747 | (07) 47881 6722

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ii Executive Summary

Australia's Indian Ocean Territories (IOTs), Christmas and Cocos (Keeling) Islands, are surrounded by important and unique marine environments. Of particular importance, are extensive areas of shallow-water habitat, including seagrass and diverse coral reef habitats, in the lagoon at South Keeling (Cocos) atoll. This large area and diversity of marine habitats support a wide range of marine species, including resident populations of green turtles (*Chelonia mydas*) and other important marine species (e.g., gong gong; *Lambis lambis*) that would not otherwise occur in the IOTs.

Six distinct *Key Ecological Features* (KEFs) are proposed for the IOTs, encompassing habitat areas and features that are nationally and regionally significant, and also recognising the ecological importance of a highly abundant endemic species that has a major influence on local productivity:

i) Extensive lagoon system at South Keeling (Cocos) Island;
ii) Outer reef habitat at Cocos Keeling Islands;
iii) Fringing coral reef at Christmas Island;
iv) Areas of high productivity around Christmas Island
v) Caves (including anchialine caves) at Christmas Island, and
vi) Annual spawning migrations of land crabs at Christmas Island

Australia's IOT waters also encompass many areas where species display biologically important behaviours, such as feeding, foraging, migrating or resting. A number of these areas, which relate to listed and threatened species, may qualify for more formal recognition as *Biologically Important Areas* (BIAs) within the framework of the *Environment Protection and Biodiversity Conservation Act 1999*. There are 11 species of sharks (including a seasonal aggregation of whale sharks; *Rhincodon typus*), five species of turtles, 10 cetacean species, a dugong, and both species of manta ray (*Mobula birostris* and *M. alfredi*), reported from waters of the IOTs. Importantly, many of the green turtles (*C. mydas*) that occur in the IOTs are part of a resident population that nest at North Keeling Island (NKI) and are critically dependant on seagrass habitats at the Southern Atoll of the Cocos (Keeling) Islands (SKI).

The diversity and abundance of land crabs at Christmas Island (CI) is the highest in the world, and although these crabs spend most of their life on land, they migrate to coastal habitats to reproduce and have a marine larval phase. The annual spawning migration of Christmas Island red crabs (*Gecarcoidea natalis*) is a globally recognised phenomena, resulting in large aggregations of crabs in coastal habitats both during spawning and also during the emergence of juveniles after they have completed larval development in waters surrounding CI. The marine larval phase of land crabs is short (weeks), but may have a significant influence on biological productivity and partly account for seasonal aggregations of pelagic species (e.g., whale sharks) near CI.

There are a wide range of specialist marine species (dependent on either corals reefs or seagrass habitats) that occur in the IOTs. Due to its unique biogeographic location, local assemblages of marine species contain a unique mix of Indian and Pacific Ocean species, including many Indian Ocean species that do not occur anywhere else within Australian territorial waters. The overlap between these major biographical provinces also gives rise to high incidence of hybridisation, and there are also a large number of endemic species that only occur within the IOTs.

While there has been significant and increasing research on shallow, nearshore marine systems within Australia's IOTs (highlighting the unique and important marine species, environments and habitats within this region) further research is needed. Most critically, extensive and recurrent surveys across all major habitats are needed to establish status and trends in the abundance and composition of habitat-forming organisms (e.g., corals and seagrasses). Systematic and widespread sampling should also encompass the broad range of motile species (fishes and non-coral invertebrates) that might be sensitive to changes in habitat structure. Experimental studies are also warranted to better understand potential impacts of environmental change and other major disturbances on the demography and resilience of key habitat-forming organisms and other important species. There is also scope for extensive sampling and taxonomic research across poorly studied groups and habitats (including mesophotic reefs) to better understand the unique flora and fauna that exists within Australia's IOTs.

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BIA	Biologically Important Area
CI	Christmas Island
CKI	Cocos (Keeling) Islands (including both NKI and SKI)
EEZ	Exclusive Economic Zone
EPBC Act	Environment Protection and Biodiversity Conservation Act (1999)
GBR	Great Barrier Reef
IOTs	Indian Ocean Territories
ITF	Indo-Pacific Through Flow
KEFs	Key Ecological Features
Ma	Million years ago
MSL	Mean Sea Level
NKI	North Keeling Island
SBT	Southern bluefin tuna
SKI	South Keeling Islands
SST	Sea Surface Temperature

1. Introduction

Australia's Indian Ocean Territories (IOTs) comprise distinct and independent oceanic islands located in the eastern Indian Ocean; Christmas Island (CI) and Cocos (Keeling) Islands (CKI). These islands are extremely isolated and represent the only emergent structures located within the volcanic province of the otherwise very deep (> 5,000 m) and abyssal plain of the Wharton Basin (Brewer et al., 2009). CI is located 975 km ENE of CKI (Figure 1.1). Both CI and CKI are part of an extensive series of seamounts (Vening-Meinesz Seamounts) which includes the Umitaka-Mary (or Muirfield) seamount, located ~100km south-west of the CKI. The Umitaka-Mary seamount extends to within 16 m of the surface and supports Muirfield Reef.

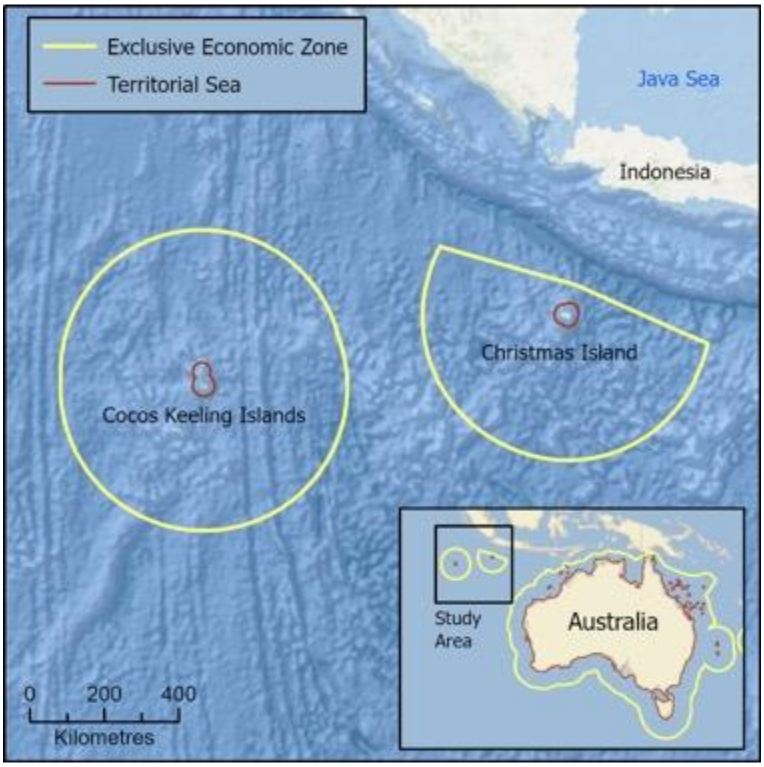


Figure 1.1 Location of Australia's Indian Ocean Territories, namely Christmas and Cocos (Keeling) Islands.

1.1. Context for this Report

To assist with planning and future management of new marine parks in the IOT, Parks Australia has asked James Cook University to summarise existing scientific information about the natural values of the inshore waters of Christmas and Cocos

(Keeling) Islands. This report provides a comprehensive and up-to-date assessment of these natural values, including those values identified in previous reports for management agencies (Alder et al., 1996; Brewer et al., 2009). This report includes the identification of potential *Key Ecological Features* (KEFs), *Biologically Important Areas* (BIAs), and other *Key Natural Values* (KNVs), using (where possible) established practice in other marine regions throughout Australia to identify the full range of important values and potential monitoring priorities.

1.2. Physical Setting

The CI Exclusive Economic Zone (EEZ) is 277,042 km^2, mostly encompassing deep (up to 6,420 m) ocean habitat in an extensive area of abyssal plain (Brewer et al. 2009). The CI EEZ encompasses many seamounts, which are mostly 1,000-3,000 m tall and extend into depths <2,000 m (Harris et al., 2005). CI (10º 28' S, 105º 38' E) is the largest and tallest seamount within the area, and the only geomorphic structure that extends above sea level, forming a densely vegetated, elevated (uplifted) island. The island (CI) is 135 km^2 in area, and mostly comprises a limestone plateau that is up to 361 m above sea level.

Christmas Island is almost completely encircled by steep limestone cliffs, reflecting the steep sides of the underlying seamount, which greatly constrains the areal extent of shallow marine habitat (Brewer et al., 2009). The dominant shallow-water marine habitat is a narrow fringe of coral reef (up to 200 m wide) that encircles much of the island (Richards and Hobbs, 2014). There are no lagoons and very little sandy habitat, and the limited diversity of marine habitats is reflected in the highly restricted faunal composition (e.g., Allen 2000). However, CI has a very unique and extensive network of subterranean and anchialine caves, which contribute greatly to regional biodiversity and endemism of marine species (Humphries, 2014).

The CKI EEZ is 467,250 km^2 (Harris et al. 2005). The majority of the area (92%) is 4,000-6,000 m deep, mainly comprising abyssal plain, which is intersected by a prominent ridge, the Investigator Ridge (Brewer et al., 2009). The Cocos Keeling Islands (CKI) comprise two distinct atolls which are connected by a deep (up to 1,000m) ridge (Woodroffe et al., 1994); North Keeling Island (11º 50' S, 96º 50' E) and South Keeling or Cocos Atoll (12º 10' S, 96º 52' E). The islands have formed on a steep-sided seamount (the Cocos Rise), which rises from a depth of 5,000 m (Harris et al. 2005). North Keeling Island (NKI) is a single island atoll, which is ~1 km^2 in area, and completely encloses a shallow lagoon. SKI comprises 26 vegetated, but very low lying islands (coral cays), with a combined land area of 14 km^2, encircling an extensive (190 km^2) shallow lagoon that is connected to the surrounding ocean mostly along the northern edge. Unlike NKI, most of the original native vegetation has been cleared from SKI (Bunce, 1998).

Cocos (Keeling) Islands support a wide diversity of shallow marine habitats. Despite representing the top of a seamount, the outer slope at SKI is also much less steep compared to CI, allowing for extensive area of reef growth extending up to 2 km wide along the outer edge of the atoll (Williams, 1994). Of particular importance, however, are extensive areas of shallow lagoon with seagrass and diverse coral reef habitats (e.g., Williams, 1994). This large area and diversity of marine habitats supports a wide range of marine species, including resident populations of green turtles (Whiting et al., 2014) and other species reliant on seagrasses and shallow sandy habitats. However, the average cover and areal extent of seagrass has declined significantly at SKI in recent years (Buckee et al., 2021), and seagrass habitats at NKI were lost following the closure of the shallow lagoon in 2005 (Hobbs and Newman, 2016). Such changes in habitat structure, which are partly attributable to the inherent dynamics of coral atolls (Hobbs and Newman, 2016), but are increasingly compounded by environmental changes and increasing anthropogenic pressures (e.g., Commonwealth of Australia, 2005; Buckee et al., 2021), may have significant consequences for the natural value and biodiversity of marine species at CKI.

1.3. Geomorphology

Both CI and CKI are formed from carbonate reef capping sitting atop volcanic seamounts, though CI is greatly elevated (up to 361 m above sea level), compared to CKI (maximum 7 m above sea level). The increased elevation of CI is attributed to geological uplifting that mostly occurred 4-6 Ma (Ali & Aitchison, 2020). Since being uplifted, the carbonate reef capping of CI has been subject to significant dissolution and erosion resulting in a highly developed karst landscape and an extensive (and largely unexplored) system of subterranean caves (West et al., 2020).

In contrast to CI, CKI are low lying coral atolls (Australia's only true atoll; Australian State of the Environment Committee 2001) that are fundamentally dependent upon the production and accumulation of carbonate material (Smithers, 1994). However, the islands of CKI are also supported by a conglomerate platform that is positioned up to 0.5 m above mean sea level (Woodroffe et al., 1994), likely formed by island accretion during periods of higher sea level (Woodroffe et al. 1999). This conglomerate platform provides resilience against inundation and island erosion, though CKI is subject to ongoing subsidence (Woodroffe et al., 1994), which may partially account for seemingly rapid sea level rise recorded at CKI (e.g., Mackay et al., 2009; Carvalho and Wang, 2019).

The geomorphological structure and function of coral atolls is critically dependent on the local production, distribution, and degradation of carbonate material (Smithers et al., 1992). The primary source of carbonate material in the SKI lagoon are relatively large skeletal elements of scleractinian (reef-building) corals which likely grew on the windward reef flats or along the outer rim (Smithers, 1994) and were deposited inside the lagoon during extreme wave action associated with major storms or cyclones. Additional particles may also be generated by the gradual erosion of the ancient conglomerate platform (Smithers, 1994). Moreover, strong or sustained water movement may cause winnowing of finer particles, further contributing to the predominance of larger carbonate particles, which are mostly derived from coral skeletons. There are, however, some areas that are dominated by finer particles, characterised by low hydrodynamic energy, or restricted movement and sorting of sediments by seagrasses or other flora (Smithers, 1994). Importantly, the geomorphic structure of coral atolls and composition of different habitats are inherently dynamic, but also very sensitive to climate change and direct anthropogenic pressures (Stoddart, 1968; Duvat et al., 2017).

1.4. Oceanography

The predominant surface current features affecting the IOT are westward flowing currents generated by the South Equatorial Current (SEC), which carry oligotrophic waters from the Indo-Pacific Through Flow (ITF). The ITF provides strong connection between the Indo-west Pacific and IOT, especially CI (Brewer et al., 2009), but generally delivers limited nutrients and suppresses upwelling of nutrient rich waters from below 400 m. The activity and influence of the SEC is generally greatest from November-December through May-June (Brewer et al., 2009), but is strongly influenced by the timing and intensity of monsoons. Importantly, peak periods of upwellings around CI occur at the end of the south-east monsoon (around September) and coincide with peak densities of zooplankton in surface waters (Davies and Beckley, 2010). These seasonal peaks in productivity are potentially important in attracting pelagic fishes to Australia's IOT, and especially CI (Brewer et al., 2009).

Localised currents and hydrodynamics at CI and CKI are further influenced by the wind forcing, oceanic waves, and tidal movements (Harper et al., 2001). The prevailing winds and waves originate from the SSE, with moderate (2 m) waves affecting the most exposed (southern) coastlines (Harper et al., 2001), especially during the austral winter (June-September). There is some refraction of waves around the islands, but water movement on the sheltered sides of the islands (including water exchange through the deepest channels on the northern side of SKI lagoon) are mainly influenced by moderate (range up to 1.3 m) tides (Harper et al., 2001).

Although located in the Indian Ocean, CI represents the western edge of the Western Pacific marine biogeographic region, whereby the westward flowing ITF facilitates strong links and species overlap with shallow marine habitats in the Indo-West Pacific (Woodroffe and Berry, 1994; Allen, 2000; Hobbs et al., 2009a). Perhaps even more importantly, CI and CKI represent an area of contemporary overlap for Indian and Pacific Ocean provinces, providing secondary contact for species that were isolated and diverged during low sea level. Accordingly, there is very high incidence of hybridisation recorded among coral reef fishes at these locations (Hobbs and Allen, 2014).

Sea-surface temperatures (SST) in Australia's IOT are reported to have increased 0.5^{o}C in the last few decades (Mackay et al., 2009), broadly reflective of impacts of global (anthropogenic-induced) climate change in the eastern Indian Ocean (Brown et al., 2019). Rates of ocean warming at CI and CKI are moderate compared to other low latitude areas and may be moderated by ITF (Hennekam et al. 2018). Hennekam et al. (2018) showed that the recent strengthening of the ITF, linked to the Pacific Decadal Oscillation (PDO), has moderated increases in ocean temperatures at CKI since 2000. Significant periods of elevated temperature (heatwaves) have however, occurred at CI and CKI in the last few decades (contributing to mass coral bleaching and fish kills; Hobbs and McDonald, 2010; Director of National Parks, 2011; Hughes et al., 2017), and rates of ocean warming will accelerate with inevitable regime shifts in the PDO and projected weakening of the ITF (Hennekam et al., 2018). Effects of ocean warming may also be compounded by ocean acidification, the effects of which, may be particularly pronounced in oceanic environments and particularly dire for systems dependent on continued carbonate production (Director of National Parks, 2011), though there is not currently any data on current or projected changes in seawater chemistry for CKI.

1.5. Objectives and scope

The information presented in this report is intended to provide a comprehensive assessment of natural values for the *inshore waters* of Australia's Indian Ocean Territories (IOTs), as distinct from deep offshore waters (>2,000 m deep) across the broader EEZs of CI and CKI (Harris et al. 2005). However, the often very steep slopes that occur on the outer edge of CKI, and especially CI, mean that very deep-water habitats (>2,000 m deep) may occur in relatively close proximity (often within 2000 m) of the islands (Brewer et al., 2009). As such, there is no fixed distance from the shoreline of CI and CKI used to distinguish relevant natural values. Rather, we focus on relatively shallow features of pelagic environments (<50 m deep), which may occur throughout the IOTs, but also nearshore habitats (such as mesophotic reefs on the steep walls of the seamounts supporting CI and CKI) down to a maximum of 150 m.

Relevant information regarding the natural values of Australia's IOTs is organised into four sections:

- *Key Ecological Features*
- Significant Marine Species and corresponding *Biologically Important Areas*
- Inshore Marine Habitats and *Key Natural Values*, and
- Important *Knowledge Gaps* and corresponding recommendations for *Future Research*

The sections relating to *Key Ecological Features* (KEFs) and *Biologically Important Areas* (BIAs) have been prepared in accordance with established processes and criteria, to ensure that the information presented complements existing bioregional planning undertaken across Australia's other marine regions (e.g., Commonwealth of Australia, 2012).

Key Ecological Features (KEFs) represent either i) a species or a group of species, ii) an area or habitat, or iii) a unique sea floor feature, that is identified as being nationally or regionally important as per existing Marine Bioregional Plans[1]. The full criteria are outlined in Section 2. This report focusses on nationally or regionally important aspects and features of nearshore and shallow water marine habitats that warrant consideration for designation as KEFs.

Biologically Important Areas (BIAs) are spatially defined areas where protected species are known to display biologically important behaviour such as breeding, foraging, resting or migration (Commonwealth of Australia, 2014). This section (Section 3) discusses and maps possible BIAs for marine species listed as threatened species (critically endangered, endangered, vulnerable, or conservation dependent), migratory species, or cetaceans, which are afforded protection under the Environment Protection and Biodiversity Conservation Act (1999). Other species of importance in the IOTs are also discussed.

Additional information relating to other *Key Natural Values* (KNVs) is focussed on identifying important habitats or habitat features that should be prioritised in future

[1] Marine Bioregional Plans are available at: https://www.environment.gov.au/marine/marine-bioregional-plans.

monitoring efforts. KNVs are not intended to necessarily represent entire habitat areas or coral reef zones (see Section 4). However, distinct habitat types (e.g., as represented by distinct reef zones) are important in their own right, such that independent inshore habitat areas are presented prior to presenting KNVs. Given there are inherent synergies across KEFs, BIAs and KNVs, careful consideration was also given to minimising duplication and redundancy of natural values and information presented.

2. Key Ecological Features

Key Ecological Features (KEFs) are elements of the marine environment that, based on current scientific understanding, are considered to be of regional (or national) importance for either biodiversity or ecosystem function and integrity.

56 KEFs have been identified across Australia's marine regions and are described in the Marine Bioregional Plans for these regions (e.g., DSEWPaC, 2012). The criteria used to identify these 56 KEFs are the same criteria used in this report to identify potential KEFs in IOT inshore waters.

Those criteria are:

- a species, group of species or community with a regionally important ecological role, where there is specific knowledge about why the species or species group is important to the ecology of the region, and the spatial and temporal occurrence of the species or species group is known
- a species, group of species or community that is nationally or regionally important for biodiversity, where there is specific knowledge about why the species or species group is regionally or nationally important for biodiversity, and the spatial and temporal occurrence of the species or species group is known
- an area or habitat that is nationally or regionally important for
    - enhanced or high biological productivity
    - aggregations of marine life
    - biodiversity and endemism
- a unique seafloor feature with ecological properties of regional significance.

Hayes et al. (2015) suggested that the 56 identified KEFs could be broadly categorised into i) canyons, ii) deep sea beds, iii) areas of enhanced pelagic productivity, iv) seamounts, v) shelf reefs, and vi) shelf sea beds. These habitats, seafloor features and pelagic areas are mostly recognised as areas of enhanced productivity, or valued for both productivity and biodiversity (Dambacher et al., 2012). Interestingly, twice as many KEFs have been identified in temperate environments, compared to tropical environments (Dambacher et al., 2012).

Aside from nationally or regionally important habitats or areas, or seafloor features, KEFs may also represent species, or species groups, that are ecologically or functionally important. There are however, very few species or species groups identified as KEFs. One notable exception is the Western rock lobster (*Panulirus cygnus*), which is considered to be ecologically important in the South-west bioregion (MacArthur et al., 2007). There are also some species groups (e.g., sea birds, corals, and herbivorous fishes) that are included as key characteristics of broadly defined KEFs (Dambacher et al., 2012). For example, herbivorous fishes are explicitly listed as part of broadly defined KEFs (Queensland Plateau and Marion Plateau) for the Coral Sea, recognising the functional importance of these fishes for coral reef ecosystems (e.g., Bellwood et al., 2004).

Given the criteria used for identifying KEFs, and predominant focus on areas or habitats that are valued for productivity and/ or biodiversity (e.g., Dambacher et al., 2012; Commonwealth of Australia, 2012), we propose that there are six KEFs in the inshore waters of Australia's IOTs (Table 2.1).

Table 2.1. Proposed Key Ecological Features of inshore waters of Australia's IOTs.

Feature	Relevant KEF criteria	Description
1. Extensive lagoon system at South Keeling (Cocos) Islands **(Figure 2.1)**	*An area or habitat that is nationally or regionally important for* *- aggregations of marine life* *- biodiversity and endemism* *A unique sea floor feature with ecological properties of regional significance*	The extensive lagoon system (190 km^2) at SKI is the predominant shallow water marine habitat in the IOT and comprises a diversity of different habitat types (outlined in Section 4). There are critically important marine habitats within the SKI lagoon. For example, extensive areas of seagrass in the lagoon at SKI represent the main food source for resident green turtles. The lagoon at SKI is regionally unique, not just unique within IOTs. There are habitats and species that occur here that do not otherwise exist anywhere within the eastern Indian Ocean.
2. Outer reef habitat at Cocos (Keeling) Islands **(Figures 2.1 and 2.3)**	*An area or habitat that is nationally or regionally important for* *- biodiversity and endemism* *- aggregations of marine life*	Coral reef habitats encircling the Cocos (Keeling) Islands (both NKI and SKI) include important shallow reef habitat with high coral cover (40-60%) and extensive areas of reef slope and mesophotic reef habitat (see Section 4). These habitats support a high diversity and biomass of reef fishes (including trevally, snappers and emperors) and many other reef-associated organisms. The production and accumulation of carbonate material in outer reef habitats is also fundamental to the geomorphological structure and function of these coral atolls, considered to be Australia's only true atolls.

Table 2.1 continued. Proposed Key Ecological Features of inshore waters of Australia's IOT.

Feature	Relevant KEF criteria	Description
3. Fringing coral reef at Christmas Island **(Figure 2.4)**	*An area or habitat that is nationally or regionally important for* *- biodiversity and endemism* *- aggregations of marine life*	Shallow (<150 m depth) marine habitat at CI is almost entirely composed of fringing coral reef, including narrow platform reefs and very steep (near vertical) reef slopes (outlined in Section 4). These habitats support a diverse assemblage of Indian Ocean and Pacific Ocean species, including many hybrids. Coral reef habitats at CI are regionally significant, characterised by high (>60%) coral cover, high diversity of reef species, and a large number of species not otherwise found in Australian waters.
4. Area of high productivity around Christmas Island **(Figure 2.5)**	*An area or habitat that is nationally or regionally important for* *- enhanced productivity* *- aggregations of marine life*	High levels of productivity occur periodically in offshore waters of the IOT within a broad area to the north and east of CI. High levels of surface productivity are attributed to upwellings, caused by the interplay of ocean currents and seasonal winds. Areas of high productivity broadly correspond with important areas for pelagic fishes, especially the Southern bluefin tuna. These areas are probably also important foraging grounds for endangered seabirds (e.g., Abbott's Booby).

Table 2.1 continued. Proposed Key Ecological Features of inshore waters of Australia's IOT.

Feature	Relevant KEF criteria	Description
5. Caves (including anchialine caves) at Christmas Island **(Figure 2.6)**	*An area or habitat that is nationally or regionally important for* *- biodiversity and endemism* *A unique sea floor feature with ecological properties of regional significance*	The extensive system of caves (including anchialine caves) at CI represents a very unique habitat, with very limited connectivity to other such habitats. Based on preliminary sampling conducted at CI thus far, and extensive research in comparable habitats in other locations, these habitats are expected to contribute greatly to regional biodiversity and endemism of marine species. Anchialine caves are rare throughout Australia.
6. Annual spawning migrations of land crabs at Christmas Island	*A species that is ecologically or functionally important in the region* *An area or habitat that is nationally or regionally important for* *- enhanced biological productivity* *- aggregations of marine life*	Land crabs, including the Christmas Island Red crabs (*Gecarcoidea natalis*) are keystone species, responsible for maintaining the structure and integrity of Christmas Island's rainforest vegetation. Seasonal mass spawning by millions of land crabs, and the corresponding larval development in the marine environment, greatly enhances surface productivity in waters surrounding CI during November-January. The annual mass spawning of land crabs coincides with seasonal aggregations of whale sharks at CI, which feed on the crab larvae.

2.1 Extensive lagoon system at South Keeling (Cocos) Island

The lagoon system at SKI (including the inner lagoon flat, the shallow lagoon and deep lagoon zones; Figure 2.1) is a very important and unique feature, accounting for a substantial proportion of shallow (<150 m deep) marine habitat throughout Australia's IOT (Figure 2.1; see also Table 4.1). More importantly, this extensive lagoon system encompasses a variety of unique and distinct habitats (see Figure 4.3) that are not otherwise represented in the IOTs. These habitats (e.g., seagrass meadows) support a high diversity of marine species, including many significant (functionally important, endemic or threatened) species (see also Section 4.10 and 4.11). Most importantly, extensive areas of seagrass (*Thalassia hemprichii*) represent the main food source for resident green turtles (*Chelonia mydas*), which nest at NKI (see Section 3.2). However, critical habitat-forming organisms and biogenic structures (e.g., seagrass and corals) within the lagoon at SKI are reported to be in decline (e.g., Buckee et al., 2021; see also Sections 4.10 and 5.1).

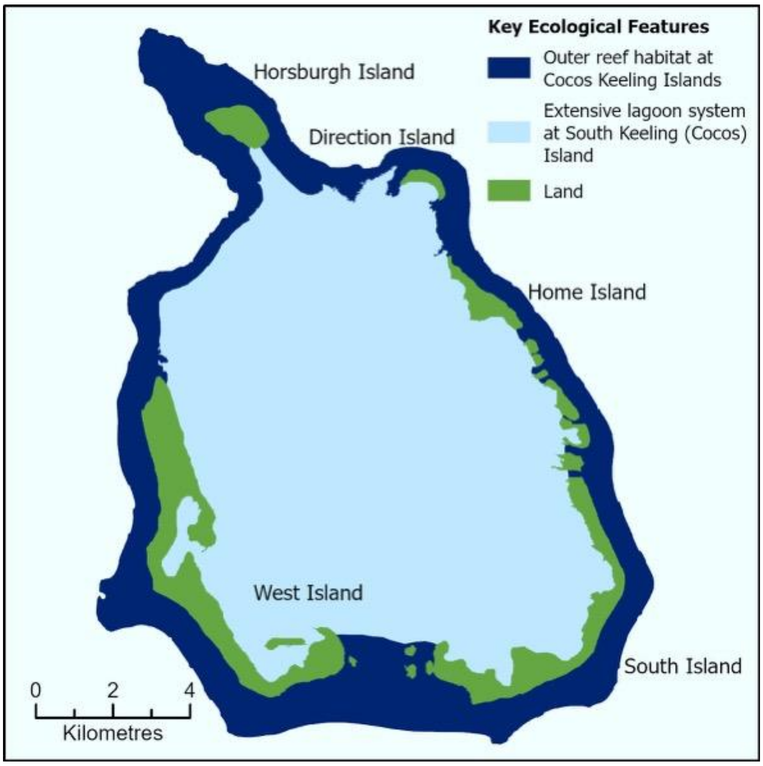


Figure 2.1. Proposed Key Ecological Features at South Keeling Islands include the extensive lagoon system and outer reef habitat. The outer reef habitat is also present at North Keeling Island (see Figure 2.3).

The regional importance of the lagoon system at SKI is further demonstrated by the range of species that are found predominantly, if not exclusively, within these habitats. For example, >70 species of fishes from 26 families have been recorded living among seagrass at CKI (Cocos Senior High School, 1999; Buckee et al., 2021). This includes listed marine species (e.g. *Micrognathus andersonii* - Anderson's pipefish) and locally important fisheries species (e.g. pufferfish *Arothron hispidus* Figure 2.2). Ecologically important invertebrate species (which are also fisheries targets) that inhabit seagrass beds at CKI include mud crab (*Scylla* sp. Figure 2.2) and night octopus (*Gurita malam*). There are some suggestions that night octopus may have declined at the same time as the seagrass declined. This could be due to direct (loss of habitat), or indirect effects (decline of prey species that associate with sea grass). Further research would be required to identify the invertebrates most dependent on seagrass at CKI.

Figure 2.2. Pufferfish (*Arothron hispidus*) and mud crab (*Scylla* sp.) are caught among seagrass beds in the southern inner lagoon flats at CKI.

2.2 Outer reef habitat at Cocos Keeling Islands

Despite the critical and unique importance of the lagoonal habitats at SKI, the outer reef habitats (including the outer reef flats, reef crest, and extensive reef slop) at

Cocos Keeling Islands (both SKI and NKI) are very extensive (Figure 2.1 and 2.3) and nationally and regionally important habitats both for *biodiversity and endemism*, as well as for *aggregations of marine life*. Most importantly, the outer reef habitats are dominated by both hard (order Scleractinia) and soft (order Alcyonacea) corals, and have high diversity and abundance of reef fishes and other reef-associated species (e.g., Hobbs et al., 2010a; Mallela 2020b; see also Section 4.3). For example, the Cocos angelfish (*Centropyge joculator*), which is endemic to CKI and CI, is abundant in outer reef habitat at SKI and NKI (Section 3.17). Spiny crayfish (*Panulirus pencillatus*) are also most abundant in outer reef habitat (Section 3.14).

The biodiversity and regional importance of coral reef habitats is heavily contingent on reef health, and especially live coral cover (e.g., Pratchett et al. 2011). While there has been extensive coral loss and degradation of reef habitats in the lagoon at SKI (mostly since 2010), reported coral cover along the outer reef habitat at SKI has been high (40-60%) and relatively unchanged over this period (e.g., Mallela 2020b; see also Section 5.1). At NKI, reported coral cover in 2019 (28%) was much lower than for outer reef habitat at SKI (Mallela 2020b), but also varied greatly among sites with exposure to prevailing hydrodynamic forces. The unique structure of these outer reef habitats, with steeply sloping reef walls directly exposed to oceanic conditions and high hydrodynamic forces, may be important in moderating the extent and severity of coral bleaching during marine heatwaves (*sensu* Choukroun et al., 2021).

The production and accumulation of carbonate material in outer reef habitats is also fundamental to the geomorphological structure and function of NKI and SKI (Smithers, 1994; see also Section 1.3), which are both low lying coral atolls. Importantly, extensive carbonate material produced along the forereef at SKI (e.g., Hamylton and Mallela, 2019) is periodically deposited within the lagoon during extreme weather events (Smithers et al., 1994).

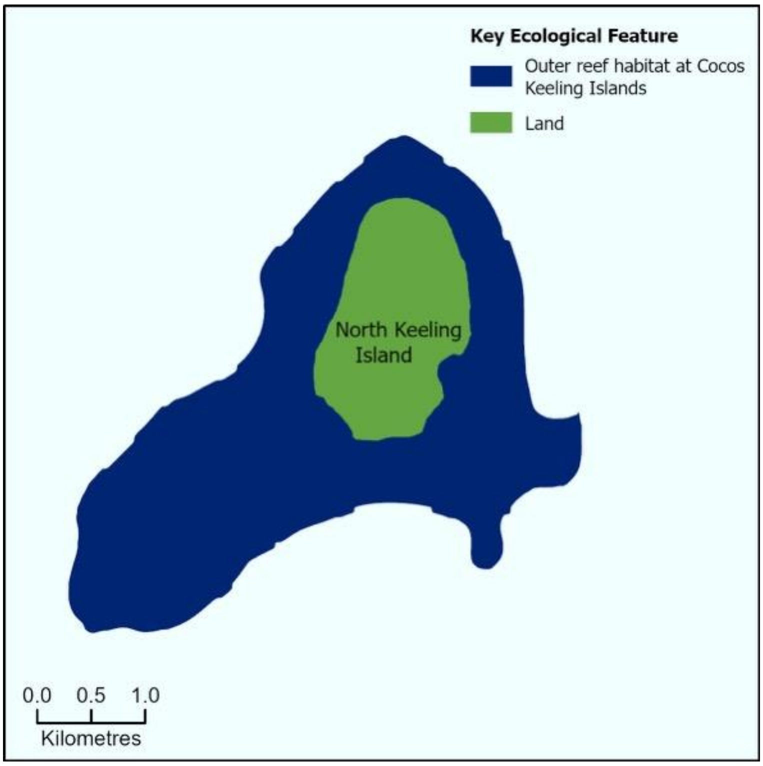


Figure 2.3. Proposed outer reef habitat KEF at North Keeling Island, including an extensive area of mesophotic reef. See also Figure 2.1 (South Keeling Island).

2.3 Fringing coral reef at Christmas Island

The nearshore marine habitat at CI is dominated by fringing coral reef, which almost completely encircles the island (Figure 2.4). The fringing coral reef at CI typically comprises a shallow reef platform (up to 20 m deep), which extends seaward (up to 200 m) from the island's limestone cliffs, to the very steep reef slope (Gilligan et al., 2008). These shallow coral reef habitats contribute greatly to regional biodiversity and endemism of marine species. Importantly, they support a rich diversity of reef fish and corals (Allen et al., 2007; Hobbs et al., 2014a; Richards and Hobbs, 2014), representing a mix of species from two distinct bioregions (Indian and Pacific species) and also including many endemic species (Section 3.14) and hybrids (Section 4.8). The most extensive areas of shallow coral reef habitat at CI occur at Flying Fish Cove (see Section 4.9), which also has the highest recorded diversity of hard (order Scleractinia) corals and reef fishes (Hobbs et al., 2010a; Richards and Hobbs, 2014). Further research and study of the outer reef slope is likely to demonstrate the importance (e.g., biodiversity and endemism) of mesophotic reef habitats, which are far more extensive than shallow water reef habitats at CI (Figure 2.4; see also Table 4.1) for corals, non-coral invertebrates and reef-associated fishes. The steep reef slopes surrounding CI are also likely to attract and concentrate a wide range of pelagic species, as shown in other reef regions (Pratchett et al., 2011).

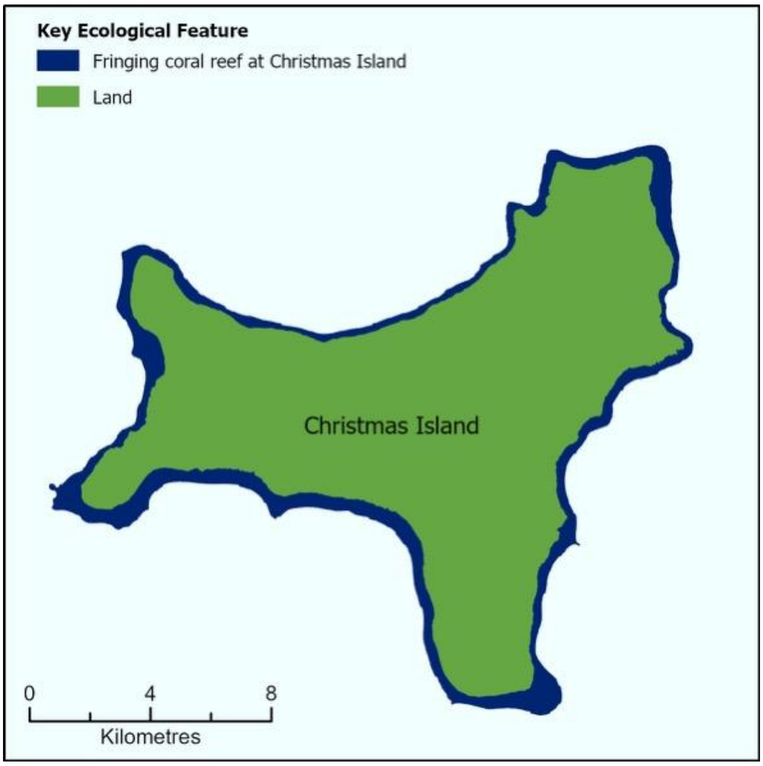


Figure 2.4. Proposed fringing coral reef KEF at Christmas Island.

Coral reef habitats at CI are regionally significant. Most notably, reported coral cover at CI (>60%) is much higher than at other coral reefs throughout Western Australia (e.g., Speed et al., 2013), reflecting unexpected resilience to widespread marine heatwaves (Gilmour et al., 2019; Mallela 2020a) and thereby supporting a wide range of reef-dependent species that may be in decline following sustained degradation of reef habitats elsewhere throughout the region (Gilmour et al., 2019). Moreover, many of the reef fish species (at least 50) recorded at CI have not been reported anywhere else in Australian waters (Allen et al., 2007; Hobbs et al., 2014b).

2.4 Area of high productivity around Christmas Island

High levels of productivity occur periodically in offshore waters within a broad area to the north and east of CI, largely reflected in seasonal pulses of surface productivity (mostly in July-August) that are apparent based on elevated chlorophyll (ChlA) concentrations (Brewer et al., 2009). High levels of surface productivity extending along the southern coast of Sumatra (Figure 2.5) are attributed to upwellings, caused by the interplay of ocean currents and seasonal winds (Brewer et al., 2009). Importantly, these plumes of surface productivity extend to CI, but rarely reach CKI. It is acknowledged, however, that there may be periodic pulses of high productivity in deep-water environments that are important for local trophodynamics, but cannot be detected. There are also likely to be concentrations of productivity within the immediate vicinity of major seamounts (Boehlert, 1988), owing to both current-topography interactions and the intrinsic productivity of biological communities associated with the seamounts.

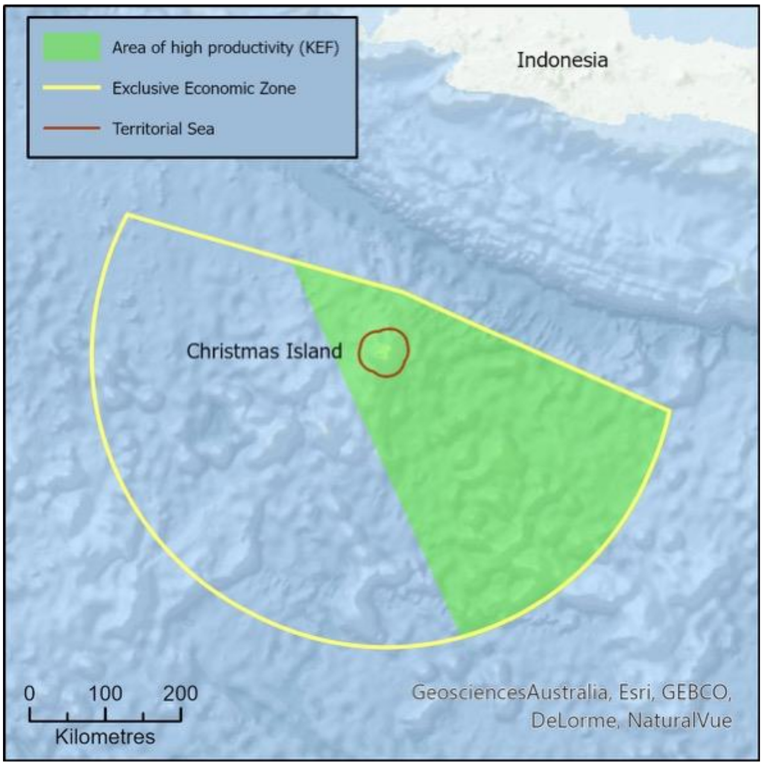


Figure 2.5. Proposed area of high productivity KEF around Christmas Island, largely reflecting seasonal pulses of surface productivity attributed to upwellings along the southern coast of Sumatra. Data from Brewer et al., 2009.

These areas of high productivity broadly correspond with highest reported catches of tuna and billfish (Brewer et al., 2009), highlighting the important role of productivity gradients in attracting and concentrating pelagic fishes. High levels of surface productivity also provide important foraging grounds for seabirds. For the endangered Abbott's booby (*Papasula abbotti*), which is endemic to CI, documented foraging areas are within 100 km to the NW and SE of CI (Hennicke et al., 2015; Section 3.6), which corresponds with areas of high productivity around CI (Figure 2.5).

2.5 Caves (including anchialine caves) at Christmas Island

The unique geological structure and history of CI has given rise to an extensive network of caves (Grimes, 2001; Humphreys, 2014), including several marine and anchialine caves. The anchialine caves at CI are of particular significance because they are only known to occur in one other location in Australia (Director of National Parks, 2014). Given the isolation of CI and lack of connectivity to equivalent habitats in other locations, many of the specialist species that occur within the marine and anchialine caves at CI are likely to be endemic (Humphreys and Eberhard, 2001; Humphries, 2014), or genetically distinct from species that occur in other regions. However, the caves also provide a diversity of habitats that are used by unique or specialist species not normally found within caves (e.g., Hui et al., 2014).

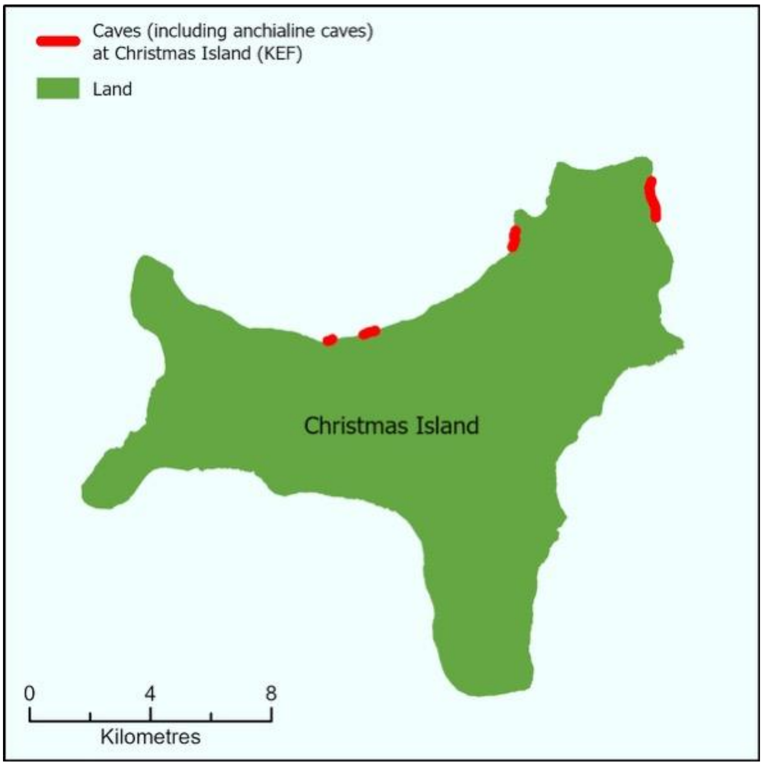


Figure 2.6. Documented entrances to anchialine caves at Christmas Island are proposed KEFs. Data from Hui et al., 2014; Humphreys, 2014.

Thus far, biological sampling of marine species in the caves at CI has been largely opportunistic and very limited, especially compared to the extensive network of caves (Humphreys, 2014) and high diversity of cave-adapted fauna recorded in comparable habitats in other locations. It is almost certain, therefore, that further research will reveal many more endemic or distinct marine species living within the extensive network of caves, further increasing understanding of the regional biodiversity and reported levels of endemism for CI. Documented entrances to anchialine caves occur within three distinct locations along the northwest coast (Figure 2.6).

2.6 Annual spawning migrations of land crabs at Christmas Island

The Christmas Island red crab (*Gecarcoidea natalis*) is one of the most iconic species at CI (Orchard, 2012), which is shown to have a key ecological role in terrestrial ecosystems, influencing the structure and function of rainforest ecosystems (e.g., Green et al., 1997). However, the red crab and other species of land crabs at CI (e.g., coconut or robber crabs - *Birgus latro,* and blue crabs - *Discoplax celeste*) have an obligate marine larval phase (e.g., Davies and Beckley, 2010). The crabs migrate to the coastline each year (in summer) to release their eggs into the marine environment, where larval development occurs (over weeks), before juveniles (megalope) emerge and begin the terrestrial phase of their life-cycle. The very large numbers (millions) of land crabs that aggregate at the water's edge to release their eggs, and their substantial collective spawning output, is likely to represent a very significant input of nutrients into nearshore marine environments (Davies and Beckley, 2010), thereby contributing to enhanced biological productivity.

The diversity and abundance of land crabs at CI is without parallel anywhere in the world (Director of National Parks, 2014). Red crabs and coconut crabs do occur at CKI, but in much lower densities, and red crabs at NKI have never been known to breed. At CI, crabs travel to various locations around the island to spawn, though mostly along the northern coast, and not necessarily to the nearest coast (Orchard, 2020). The distribution, abundance and fate of eggs, and ultimately larvae, in the marine environment is largely unknown (Davies and Beckley, 2010). Davies and Beckley (2010) failed to detect significant concentrations of planktonic organisms associated with spawning events in 2005-2006, though red crab spawning events were very minor and sporadic during this period. Very large spawning events involving millions of crabs and multiple species, will almost certainly lead to temporary increases in the productivity of nearshore waters around CI, which may attract large planktivores. Notably, the annual mass spawning of red crabs mostly coincides with seasonal aggregations of whale sharks (Hobbs et al., 2009), which feed on the crab larvae (Meekan et al., 2009). However, it is yet to be clearly established whether whale sharks travel to CI in summer, specifically to take advantage of significant nutrient inputs from mass spawning of the various land crabs, and especially red crabs.

3. Significant Marine Species and Biologically Important Areas

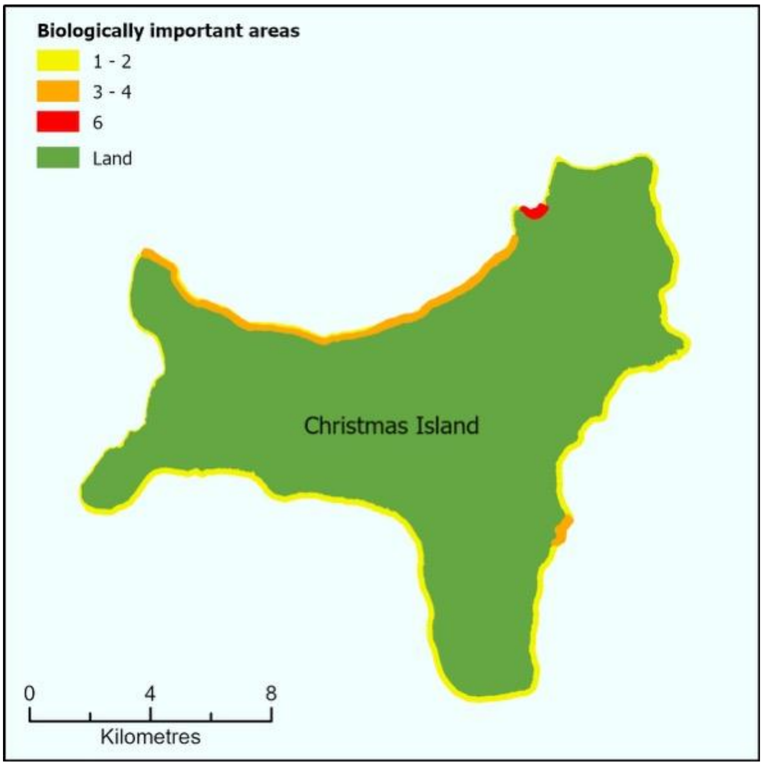
Areas where marine species are known to aggregate or display important behaviours, such as breeding, foraging, resting or migration are considered biologically important for those species.

Biologically Important Areas (BIAs) have been identified throughout Australia's marine regions (except for in the IOT) for marine species which are protected under the EPBC Act. These are species listed as threatened species (critically endangered, endangered, vulnerable, conservation dependent), migratory species, cetaceans, or other protected marine species (e.g., pipefishes; family Sygnathidae). This report identifies potential BIAs for such species in inshore IOT waters with the information presented in accordance with the Department of Agriculture, Water and Environment's BIA Protocol[2].

BIAs for other marine species that are not listed are also considered in this section due to their importance for conservation, ecology, fisheries and/or tourism in the IOTs. However, only EPBC listed species can be considered for formal BIA designation under the BIA Protocol.

Potential BIAs have been identified and mapped based on available data, expert knowledge and interviews. BIAs for individual species have been mapped separately wherever there is sufficient information. To highlight areas that are important for more than one species, a summary compilation of BIAs for CI and CKI is also provided (Figure 3.1). These maps reveal areas where there are several to many overlapping BIAs, highlighting Flying Fish Cove at CI (see also Section 4.9) and the outer reef habitats on the northern side of SKI as key areas for several different significant marine species (Figure 3.1). These areas do not however, encompass all the individuals BIAs. For example, the most important foraging areas for turtles (seagrass beds) at SKI are not included in the areas of highest overlap.

[2] The *Protocol for creating and updating maps of biologically important areas of regionally significant marine species* is available at: www.environment.gov.au/marine/publications/bias-protocol



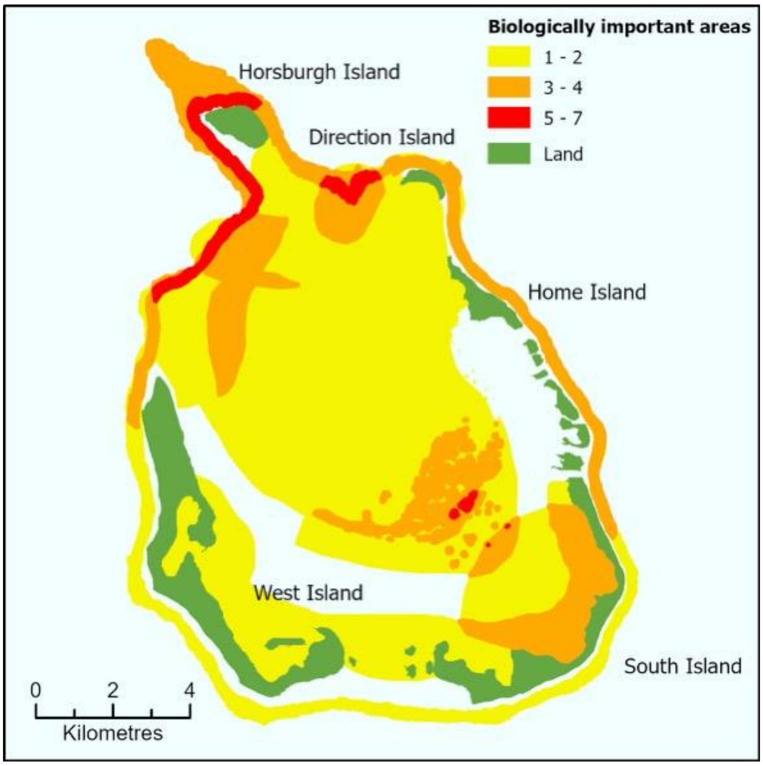


Figure 3.1. Coincidence of proposed BIAs at CI (top) and SKI (bottom). The colours illustrate the number of overlapping BIAs with red representing the highest number. The red areas do not include all possible BIAs.

3.1 Sharks

Eleven species of sharks have been recorded in IOT waters and most are on the IUCN Red List due to their elevated risk of extinction (Hobbs et al., 2014a,b; Figure 3.2; Table 3.1). Globally, sharks are an important fisheries species; however, they are not targeted by local anglers in the IOTs. Sharks are frequently caught unintentionally when they eat fish already hooked on the line. These sharks are usually released without harm. The main species involved are the blacktip reef shark (Carcharhinus melanopterus) on the shallow sand flats and outer reef flat at CKI, grey reef shark (*Carcharhinus amblyrhynchos*) in the moderate and deeper sections of the lagoon and the outer reef slope at CKI, and silky shark (*Carcharhinus falciformis*) in the pelagic waters around CI. Ten shark species have been documented at CI and eight at CKI. There has been much less survey effort at NKI and only two species (grey reef shark and blacktip reef shark) have been reported (Hobbs, 2009).

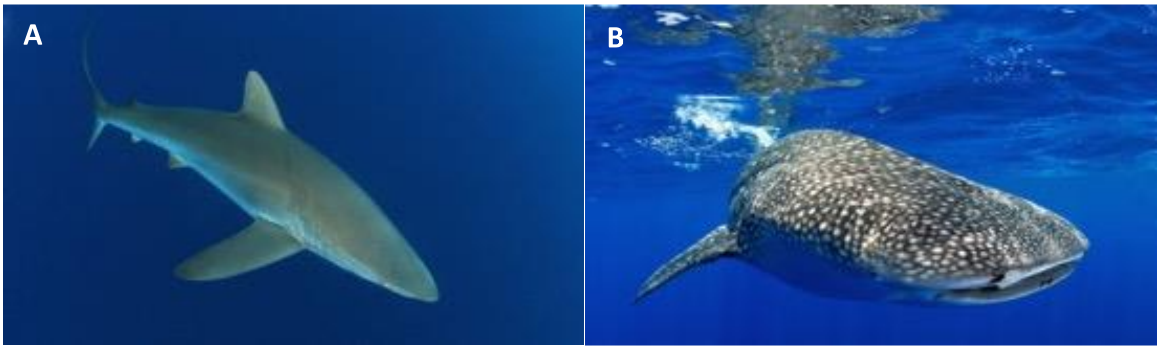


Figure 3.2. A) Silky shark (*Carcharhinus falciformis*) and B) whale shark (*Rhincodon typus*) are both listed under the IUCN Red List and EPBC Act. Photographs from Christmas Island by Justin Gilligan.

3.1.1 Whale shark

The whale shark (*Rhincodon typus*) is listed as Vulnerable under the EPBC Act and is an iconic tourist attraction at CI. Whale sharks (predominately juvenile females) aggregate at CI during the months of December to April (summer monsoon, Hobbs et al., 2009b). Their presence coincides with the spawning season of the land crabs. Although, they are known to eat the larvae of CI's endemic red crab (Meekan et al., 2009), they have also been observed feeding when these larvae are absent (Hobbs et al., 2009b). CI and Ningaloo Reef are the only locations in Australia that are known to support whale shark aggregations. Thus, CI is an area of national significance for whale sharks because it provides habitat and food to support a seasonal aggregation.

The most common habitat where whale sharks are encountered at CI is on the surface within 200 m of the coastline (Figure 3.3), or on the outer reef slope. Satellite tagging studies reveal whale sharks also transit through the offshore waters around the IOTs and within the EEZ (Sequeira et al., 2013). Tagging of one whale shark at CI revealed that this individual spent most of its day in the surface waters (>10 m depth) with occasional descents to 400 m depth (Meekan et al., 2015). At night, this individual spent considerably less time at the surface and its descents were shallower (~100 m depth: Meekan et al., 2015). These diving patterns may reflect diel movement of plankton, and basking at the surface to thermoregulate (Meekan et al., 2015). Whale sharks have been sighted on all sides of CI; however, they are most frequently observed along the north coast. Observations of feeding are also based on reports from the north coast (Hobbs et al., 2009). Due to a lack of people visiting the other coastlines, it is unknown if these coastlines support similar densities of whale sharks or adequate food resources. Thus, the waters immediately adjacent to the north coast of CI comprise the most biologically important area for whale sharks because it is known to provide habitat and food for relatively high densities of whale sharks (Figure 3.3).

Given that whale sharks aggregate at specific locations around the globe to feed on seasonal mass spawning events (Rowat and Brooks, 2012), it is most likely that they are aggregating at CI to take advantage of the annual mass spawning of land crabs by feeding on their larvae. If this is the case, the future of the whale shark aggregation is dependent on the conservation of land crab populations. Further research is required to quantify the diet of whale sharks at CI and to determine the distribution and abundance of whale sharks around the island and whether this is linked to their food source.

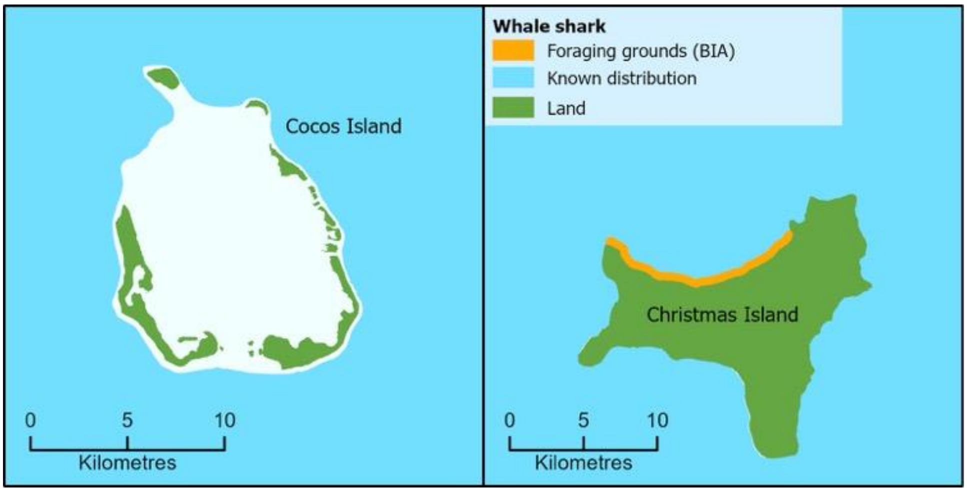


Figure 3.3. The distribution (blue) of the whale shark at CKI (left) and CI (right). The orange area highlights a proposed whale shark BIA representing the known area where whale sharks aggregate and feed in summer at CI. Data from Hobbs et al., 2009; Sequeira et al., 2013; Hobbs et al., 2014c).

3.1.2 Reef sharks

There are three species of reef sharks (blacktip, whitetip and grey) that inhabit the shallow coral reefs in the IOTs. All three species occur at SKI and their densities are among the highest in the world, probably due to the isolation of the IOTs and the lack of fishing mortality (Hender et al., 2001; Robbins et al., 2006; Bennett et al., 2018; Birt et al., 2021). The blacktip reef shark has not been recorded at CI. Juveniles of this species are found in the shallow seagrass beds at CKI, a habitat that is lacking at CI. At NKI, the seagrass nursery habitat has been lost due to the lagoon closure (~ 2005). This could affect the ability of the blacktip reef shark to maintain its population there. It is most likely that the reef sharks (white tip and grey) at CI represent self-sustaining populations, which use, forage and breed within coral reef habitats. At CI, reef sharks are found in waters on the outer reef slope and mesophotic reefs (Figure 3.4) and these habitats are proposed BIAs.

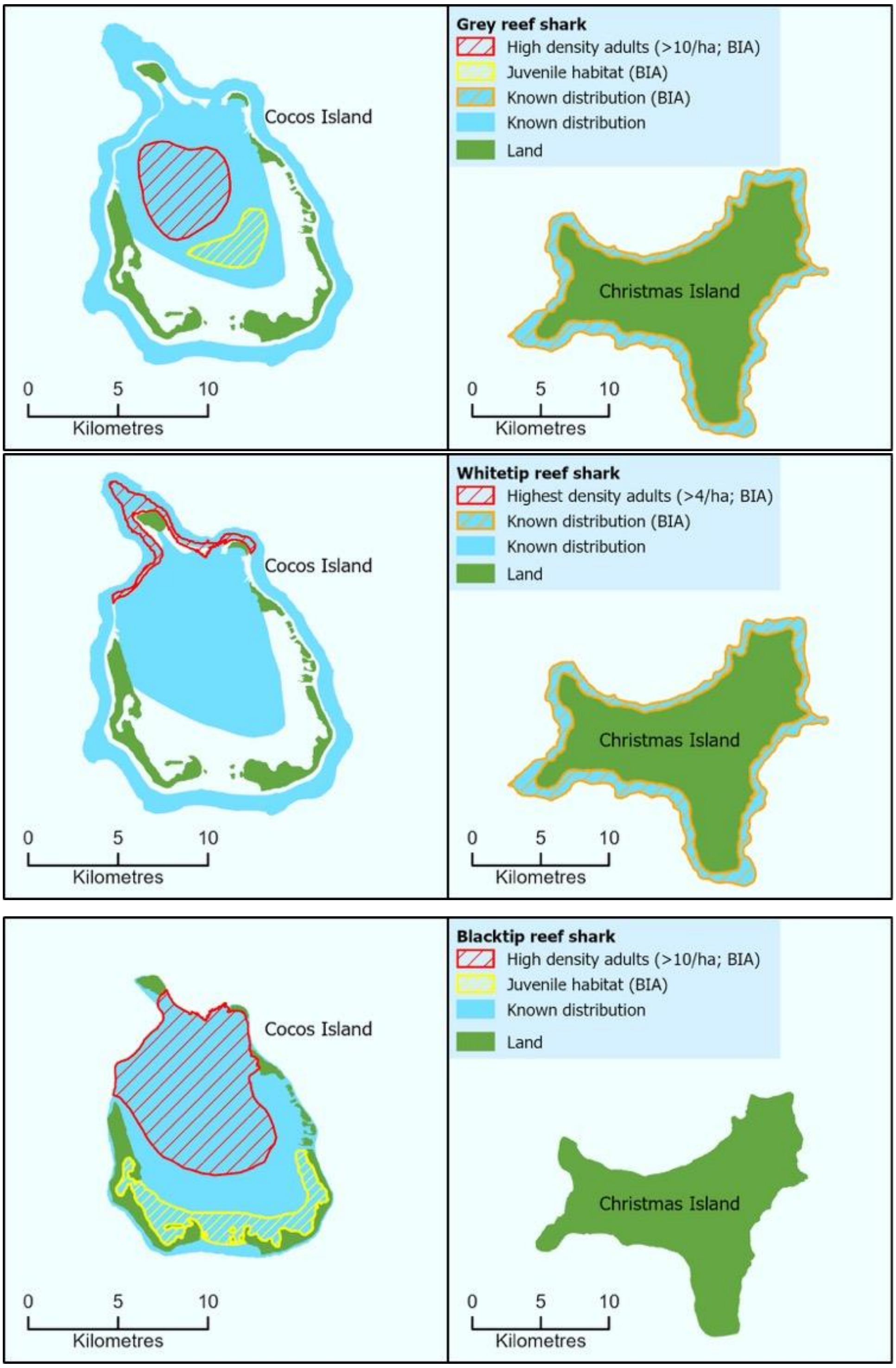


Figure 3.4. Known distributions (blue areas) of reef sharks at CKI (left) and CI (right), including grey (top), whitetip (middle) and blacktip (bottom). At CKI, the habitats that support the highest densities of adults (red), and critical nursery habitats (yellow) are proposed as BIAs for these species. At CI the known distribution areas of grey and white tip reef sharks are proposed as BIAs for these species. Data from Hender et al., 2001; Robbins et al., 2006; Allen et al., 2007; Hobbs et al., 2014b,c; Hobbs unpubl. data.

At SKI, some data is available to help identify BIAs (Hender et al., 2001; Robbins et al., 2006; Hobbs, unpubl. data). For blacktip reef sharks, the shallow inner lagoon areas are important nursery habitats for newborn sharks, and the central and northern lagoon support the highest densities of adults (Figure 3.4). For whitetip reef sharks, the outer reef slope on the northwest of the atoll supports the highest densities of adults and includes many sandy areas that are the preferred resting habitat for this species (Figure 3.4). For grey reef sharks, the blue holes in the southern lagoon provide important nursery habitat, and the central and northern lagoon support the highest densities of adults (Figure 3.4). Collectively, these spatial patterns indicate that certain areas are biologically more important to grey reef sharks because they provide the necessary resources (food, habitat, shelter) to support high densities or particular life stages.

3.1.3 Other sharks

In addition to the above-mentioned sharks, there are another four and seven sharks that have been reported at CKI and CI respectively (Table 3.1). Some of these sharks (e.g. silvertip shark, thresher shark) associate with mesophotic reefs and are probably resident and thus feed and breed in the IOTs. Other larger sharks (e.g. tiger shark, great hammerhead) are probably visitors to the IOTs and hunt for food on the surrounding reefs (shallow and deep). Other sharks (e.g. silky shark, oceanic whitetip) inhabit the pelagic waters throughout the IOT EEZ where they feed on pelagic fishes. It is unclear if these sharks are residents or visitors. Similarly, the scalloped hammerhead is occasionally seen on the outer reef slope, where it most likely feeds, but it is unknown if it is a resident. For sharks that are (or could be visitors) to the IOTs, there is no evidence that they breed in the IOTs. Using a combination of published descriptions (Froese and Pauly, 2021) and observations, the preferred depth zones inhabited by each shark has been mapped (Figure 3.5). But within these preferred habitats, there is no data to indicate whether some areas are biologically more important than others. There is insufficient data to propose BIAs for these shark species in IOT inshore waters.

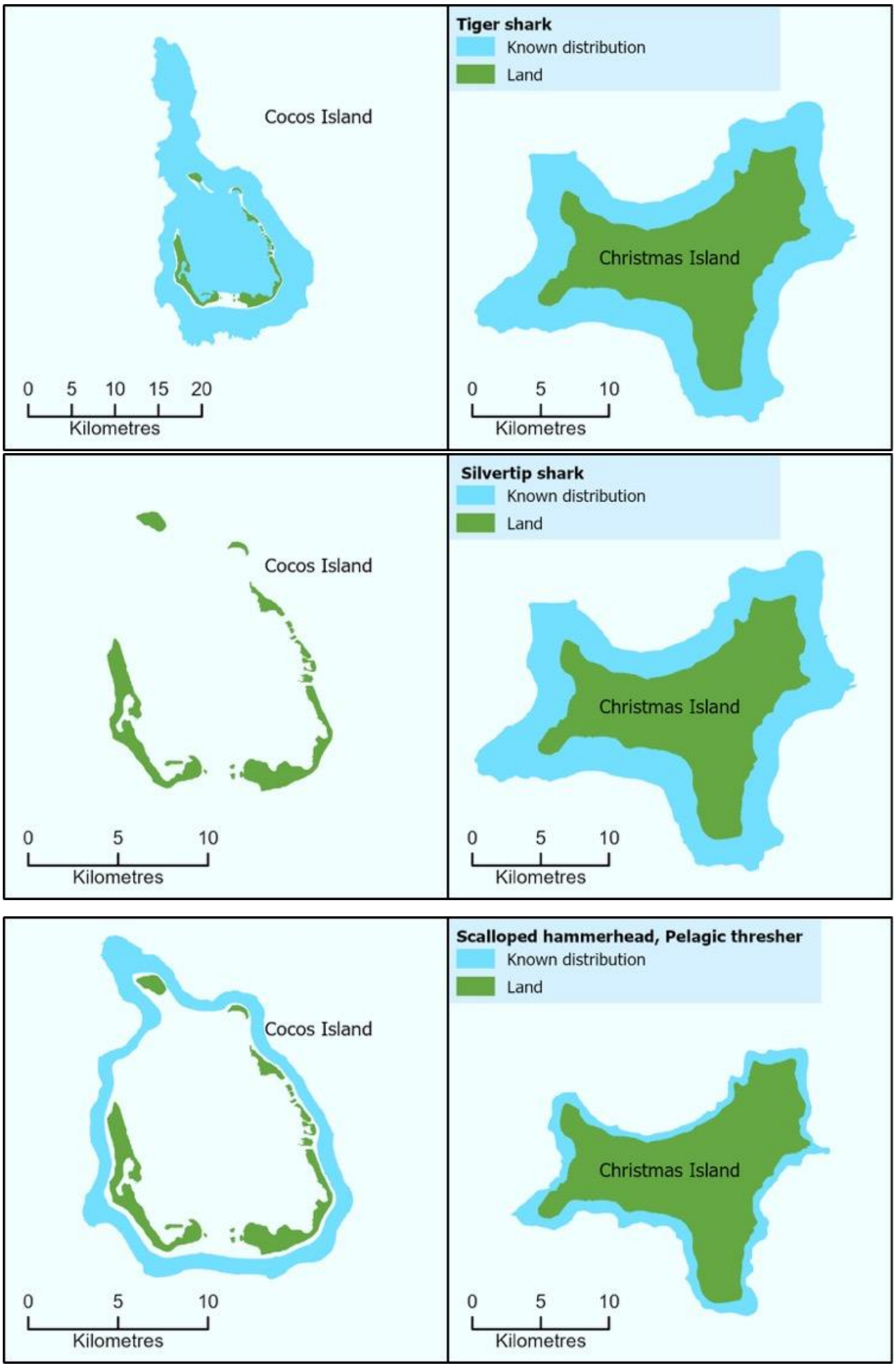


Figure 3.5. Distribution of seven uncommon or pelagic sharks at CKI (left) and CI (right). Note that scalloped hammerhead and pelagic thresher shark are shown together because they share the same distribution. Data from Allen et al., 2007; Hobbs et al., 2010; 2014b,c; Hobbs unpubl. data.

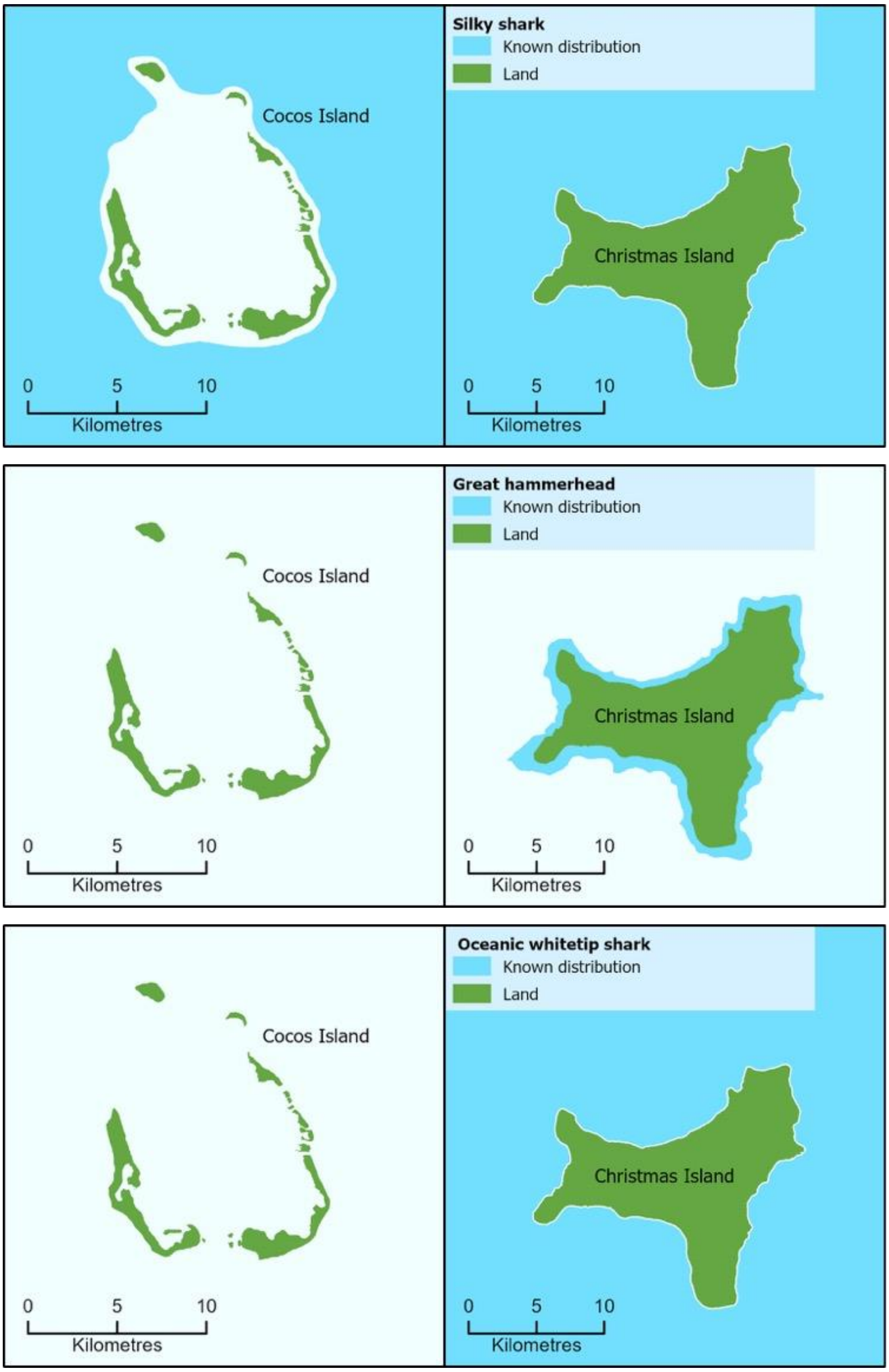


Figure 3.5. Continued.

Table 3.1. Occurrence and abundance of sharks in their preferred habitat at CI and CKI, based on average abundance recorded during dives of approximately 60 minutes and encompassing approximate 5000 m^2 (Common = > 5 per dive; moderately common = 2–5 per dive; uncommon = 0.5–2 per dive; occasionally seen = 0.2–0.5 per dive; seldom seen = 0.1–0.2 per dive; rare = <0.1 per dive). Sources: Allen et al., 2007, Hobbs et al., 2010; 2014b,c; Hobbs, unpubl. data.

Family/ Species	CI Abundance	CKI Abundance	IUCN Listing	EPBC Act Listing
Rhincodontidae				
Whale shark (*Rhincodon typus*)	Occasionally seen	Rare	Endangered	Vulnerable + Migratory
Carcharhinidae				
Silvertip shark (*Carcharhinus albimarginatus*)	Rare	Not recorded	Vulnerable	
Grey reef shark (*Carcharhinus amblyrhynchos*)	Occasionally seen	Common	Endangered	
Silky shark (*Carcharhinus falciformis*)	Common	Uncommon	Vulnerable	Migratory
Oceanic whitetip (*Carcharhinus longimanus*)	Rare	Not recorded	Critically endangered	Migratory
Blacktip reef shark (*Carcharhinus melanopterus*)	Not recorded	Common	Vulnerable	
Tiger shark (*Galeocerdo cuvier*)	Rare	Rare	Near threatened	
Whitetip reef shark (*Triaenodon obesus*)	Uncommon	Moderately common	Vulnerable	
Sphyrnidae				
Scalloped hammerhead shark (*Sphyrna lewini*)	Rare	Not recorded	Critically endangered	Conservation dependent
Great hammerhead shark (*Sphyrna mokarran*)	Rare	Rare	Critically endangered	
Alopiidae				
Pelagic thresher shark (*Alopias pelagicus*)	Rare	Rare	Endangered	

3.2 Marine turtles

Five species of marine turtles are known to occur in waters of the IOTs. The two species listed as Vulnerable (EPBC Act) are commonly seen (green and hawksbill), and the three species listed as Endangered (EPBC Act) are rarely encountered (loggerhead, leatherback and Olive Ridley).

There are two distinct groups of green turtles (*Chelonia mydas*) at CKI, including a resident population that breeds at CKI and transient individuals that remain in the area for only a limited duration. Genetic analyses reveal that the majority of green turtles sampled at CKI were born locally, and the remaining turtles have come from rookeries in north-western Australia and Peninsular Malaysia (Dethmers and FitzSimmons, 2005; Jensen, 2010). The turtles born at CKI are a genetically distinct stock that is unique to CKI (Dethmers et al., 2010), and therefore, are a management unit of high conservation value.

Green turtles are common at CKI and are most frequently seen in the SKI lagoon where they feed and rest (Figure 3.6). The highest densities occur in the shallow waters of the western and south-eastern lagoon (Whiting et al., 2014). The high abundance of green turtles in this area is linked to the seagrass beds (*Thalassia hemprichii*) that they feed on (Whiting et al., 2014). They also feed on seagrass on the outer reef flat at West Island (Whiting et al., 2014). Green turtles are commonly encountered resting on the outer reef slope around the atoll, and in the same habitat at NKI (Whiting et al. 2014; K. Willshaw, pers. comm.; J. Hobbs, pers obs.). Dietary analyses of two turtle species at CKI indicate that green turtles appear more reliant on seagrass than hawksbills (Whiting et al., 2014). When seagrass has declined in other locations, green turtles do not appear to switch to alternate foods but overgraze the remaining seagrass (Gangal et al, 2021). Over the past 25 years seagrass in the inner lagoon of SKI has declined significantly due to a combination of episodic die-off events, sediment disturbance, and increased turbidity (Buckee et al., 2021). Following this decline, there is evidence that green turtles are overgrazing the remaining seagrass in this area (Buckee et al., 2021).

For the local population of green turtles, most of the nesting occurs on the northwest beach at NKI (Figure 3.7; Whiting et al., 2014). Field surveys from

November to March (1999-2009) found that most (90%) of the nesting occurs on the northwest beach at NKI (Whiting et al., 2014). Nesting also occurs, albeit at much lower densities, on the southern beach at NKI, and rarely on beaches on West, Home, South and Horsburgh Islands in the southern atoll (Figure 3.6; Whiting et al., 2014). The nesting area on the northwest beach at NKI, together with seagrass beds in the shallow southern lagoon of SKI that provide critical food, represent the proposed BIAs for green turtles (Figures 3.6 and 3.7).

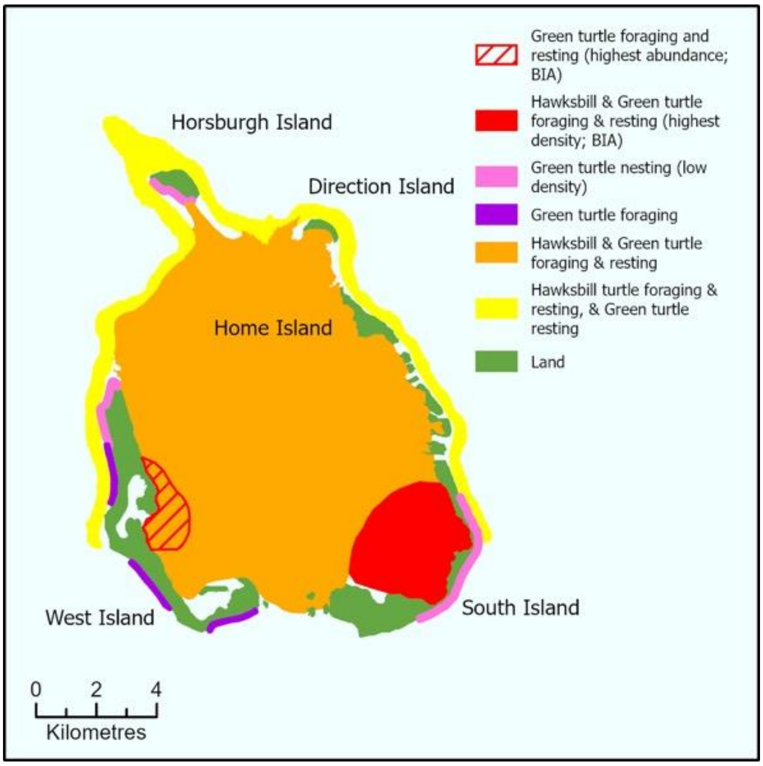


Figure 3.6. Foraging and resting habitats of green and hawksbill turtle at SKI. The proposed BIAs are shown in red represent seagrass/algae habitats that support high densities of feeding and resting green and hawksbill turtles. Low density nesting is a mean of less than 0.1 tracks from nesting turtles per night per km of beach. Data from Whiting et al., 2014.

The hawksbill turtle (*Eretmochelys imbricate*) is common at CKI where it is seen foraging and resting in the lagoon and outer reef habitats (Figure 3.6). Their diet at CKI is comprised mainly of sponge, algae, and seagrass (Whiting et al., 2014). CKI appears to be a developmental habitat where juveniles arrive to feed and grow, and eventually return to the central (Chagos) and western (Seychelles) Indian Ocean to nest (Whiting and Koch, 2006; Whiting et al., 2010; FitzSimmons, 2010). There are suggestions that hawksbill turtles may have nested at CKI over 50 years ago, but in the past 40 years there has been no evidence of nesting (Whiting et al., 2014). The most important area for CKI for hawksbill turtles is the south east lagoon (Figure 3.6) because it supports a high density of individuals that use this area to feed and rest.

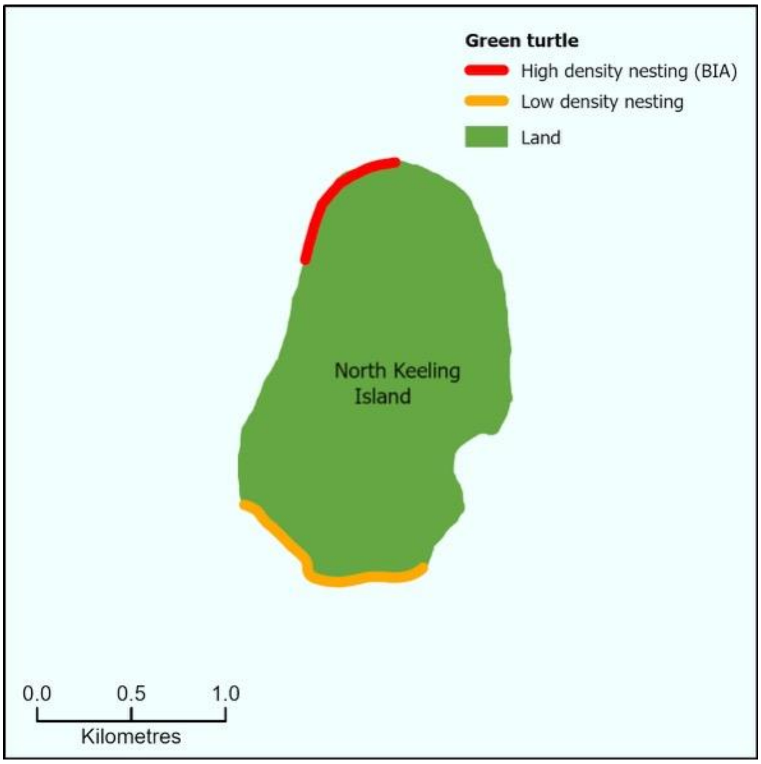


Figure 3.7. Nesting habitats of the green turtle at NKI. The proposed BIA is shown in red and represents the section of beach that supports high densities of nesting green turtles. High density is greater than a mean of five tracks from nesting turtles per night per km of beach. Low density nesting is a mean of less than 0.1 tracks per night per km of beach. Data from Whiting et al., 2014.

Compared to CKI, green turtles are much less abundant at CI, probably because CI lacks a lagoon and seagrass. They are occasionally seen feeding and resting on the outer reef slope (Figure 3.8). A small number of green turtles nest on Dolly Beach and Greta Beach; however, the latter is usually unsuccessful due to inundation of nests (Director of National Parks, 2014). Genetic analyses are required to determine if this small population at CI is a unique stock. If this is confirmed, then its conservation value will rise, and management of this local population will need to be adjusted accordingly. Dolly Beach is the area of most importance for green turtles at CI because it provides critical nesting habitat (Figure 3.8). Hawksbill turtles are occasionally seen resting and foraging on the outer reef slope At CI (Figure 3.8). Nesting may possibly occur (rarely) at Dolly Beach (Brewer et al., 2009).

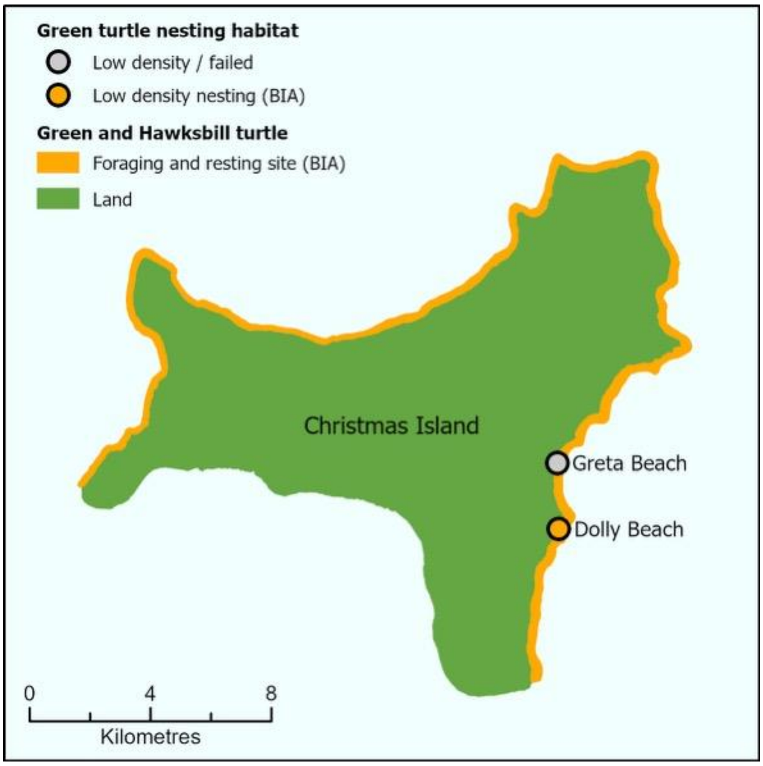


Figure 3.8. The known foraging, resting and nesting habitats of green and hawksbill turtles at CI. The foraging and nesting site shown in orange for Green and Hawksbill turtles, and the low-density nesting site for Green Turtles (represented by an orange circle) are proposed as BIAs for these species. Data from Brewer et al., 2009.

Based on observations of turtles that have been caught in ghostnets or washed ashore, the Olive-Ridley (*Lepidochelys olivacea*) is known to occur in the open ocean around CKI (Whiting et al., 2014) and likely to occur in the same habitat around CI (S. Whiting, pers. comm.). It is likely to be foraging in these waters and appears to be in low densities (S. Whiting, pers. comm.).

Although rare, the loggerhead turtle (*Caretta caretta*) is known to occur at CKI and CI based on sightings and photographs (Brewer et al., 2009; K. Willshaw, pers. comm.). The loggerhead turtles are likely to be passing through the open ocean waters and feeding on molluscs and crustaceans in shallow benthic habitat (reefs and lagoon) at CI and CKI (S. Whiting, pers. comm.).

Based on satellite tracking of tagged individuals, the leatherback turtle (*Dermochelys coriacea*) is known to occur in the open ocean around CKI

(Namboothri et al., 2012), and likely occurs in the same habitat around CI (Whiting pers. comm.). This species is probably foraging as it passes through these waters (S. Whiting, pers. comm.). Data show that Olive-Ridley, loggerhead and leatherback turtles are present in IOT waters, but there is no data that indicates these waters are of particular biological importance to these species.

3.3 Pipefishes

Pipefishes and all other members of the family Sygnathidae (e.g., seahorses and seadragons) are listed marine species (EPBC Act) and eight species of pipefishes have been recorded at CKI (Table 3.2). While some species are commonly found on reef habitat at CKI (e.g. Bluestripe pipefish, Benedetto’s pipefish, K. Willshaw, pers. comm.), others associate mainly with seagrass (e.g. Thorntail pipefish, Sculptured pipefish, Cocos Senior High School, 1999; Froese and Pauly, 2021). Many species of Sygnathidae have particular microhabitat preferences, making them particularly vulnerable to habitat degradation or loss (Hughes et al., 2009; Scappin et al., 2018). While studies elsewhere show that many pipefishes are dependent on seagrass and are often affected by declines in the cover or extent seagrass, explicit research is required to determine the range and extent to which pipefishes were affected by the reported decline in the areal extent seagrass habitat at SKI (Buckee et al., 2021). At this stage, there is insufficient data to propose BIAs for pipefishes in IOT inshore waters.

Table 3.2. Species of syngnathids (pipefishes and seahorses) recorded in the IOTs. Information from Allen et al., 2007; Hobbs et al., 2014a,b; K. Willshaw pers. comm. Syngnathids are listed marine species under the EPBC Act, but due to their cryptic behaviour and camouflage colouration very little is known of their distribution and abundance in the IOTs and this prevents delineating BIAs for these species.

Species	Location	Habitat
Pacific Shortbody Pipefish (*Choeroichthys brachysoma*)	CI	Reported to occur on seaward reefs, 1-20 m depth
Sculptured pipefish (*Choeroichthys sculptus*)	CI,CKI	Reported to occur on shallow reefs, 0-6 m depth
Reticulate pipefish (*Corythoichthys flavofasciatus*)	CKI	Reported to occur in crevices and caves on outer reef slope, 4-30 m depth
Benedetto's pipefish (*Corythoichthys benedetto*)	CKI	Observed on northern outer reef slope, 12-18 m depth
Schultz's pipefish (*Corythoichthys schultzi*)	CI	Reported to occur on sand and rubble on outer reef slopes, 2-15 m depth
Rough-ridge pipefish (*Cosmocampus banneri*)	CI,CKI	Reported to occur in crevices and rubble on outer reefs from 2-30m depth
Redstripe pipefish (*Dunckerocampus baldwini*)	CI	Reported to occur in crevices and caves on outer reef slope, 6-50 m depth
Bluestripe pipefish (*Doryrhamphus melanopleura*)	CI,CKI	Observed under ledges and in caves in the northern lagoon and outer reef slope, 1-25 m depth
Thorntail pipefish (*Micrognathus pygmaeus*)	CI,CKI	Reported to occur in caves and ledges in the lagoon and outer reefs, 1-10 m depth
Black Rock pipefish (*Phoxocampus belcheri*)	CKI	Reported in tide pools and reefs from 0 to 25 m depth
Anderson's pipefish (*Micrognathus andersonii*)	CKI	Collected in seagrass beds in south-west lagoon, 1 m depth

3.4 Southern bluefin tuna

The southern bluefin tuna (SBT: *Thunnus maccoyii*) is listed as Critically Endangered by the IUCN Red List of Threatened Species. It is listed in Australia as Conservation Dependent under the EPBC Act. The only known spawning ground for the SBT is an area covering Christmas Island's EEZ and extending towards, Java, and north-western Australia (Figure 3.9). SBT migrate here to spawn between September and April and then return south (Farley and Davis, 1998; Evans et al., 2012; Farley et al., 2015). For the first few months of their life, the larvae and juveniles are thought to inhabit the waters around CI and surrounding region (Wharton Basin) before travelling to southern Australia (Farley and Davis, 1998). The waters in this nursery area have the highest primary productivity in the IOTs due to seasonal upwelling (Brewer et al., 2009). According to long-time residents and a local commercial fishing operator, there have been no reports of SBT being caught in the immediate waters (within 1 km) around CI (M. Rochfort, pers. comm.). Thus, the data indicates that the whole of CI waters (Figure 3.9), except for the area within 1 kilometre of shore could be considered a BIA for SBT, because this area is used by adults to spawn and by larvae and juveniles to feed and grow.

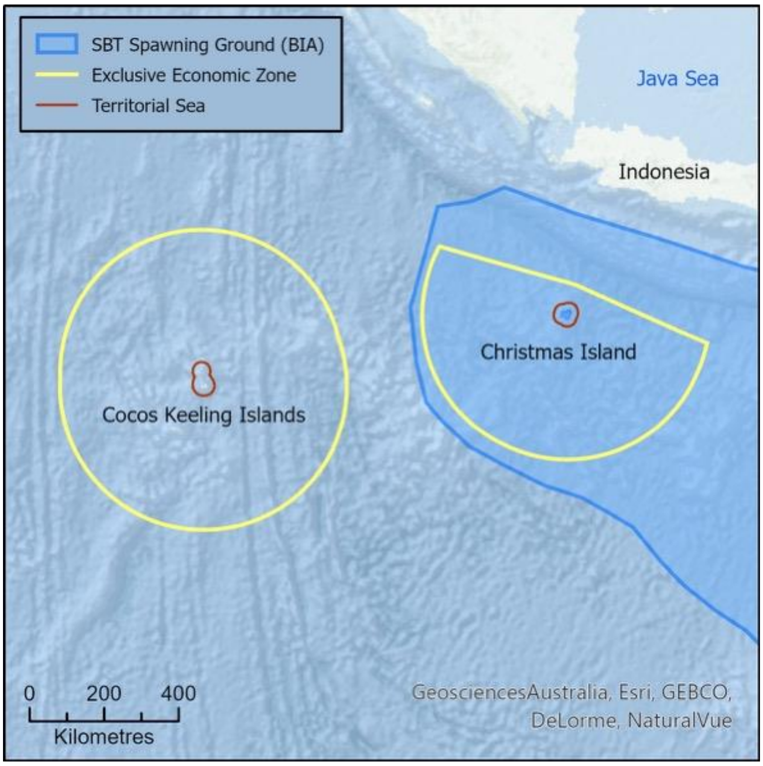


Figure 3.9. The location of the southern bluefin tuna (SBT: *Thunnus maccoyii*) within the EEZ around CI (outlined in yellow). The SBT spawning ground shown as a shaded blue area is a proposed BIA. Source: Australian Fisheries Management Authority, 2019

3.5. Cetaceans

Ten cetacean (whale and dolphin) species have been recorded, or reportedly sighted, in IOT waters (Table 3.3). Most of the cetaceans recorded in the IOTs are rarely seen. This may reflect low abundance or low levels of surveying. Limited reports mean there is little knowledge of how most cetacean species use these waters. However, there are three dolphin species that are commonly seen in the inshore waters of the IOTs and could be resident populations. Whether they are resident or not, the frequency of sightings indicates that these waters are important (Figure 3.10) for these dolphin species to forage, rest and/or breed.

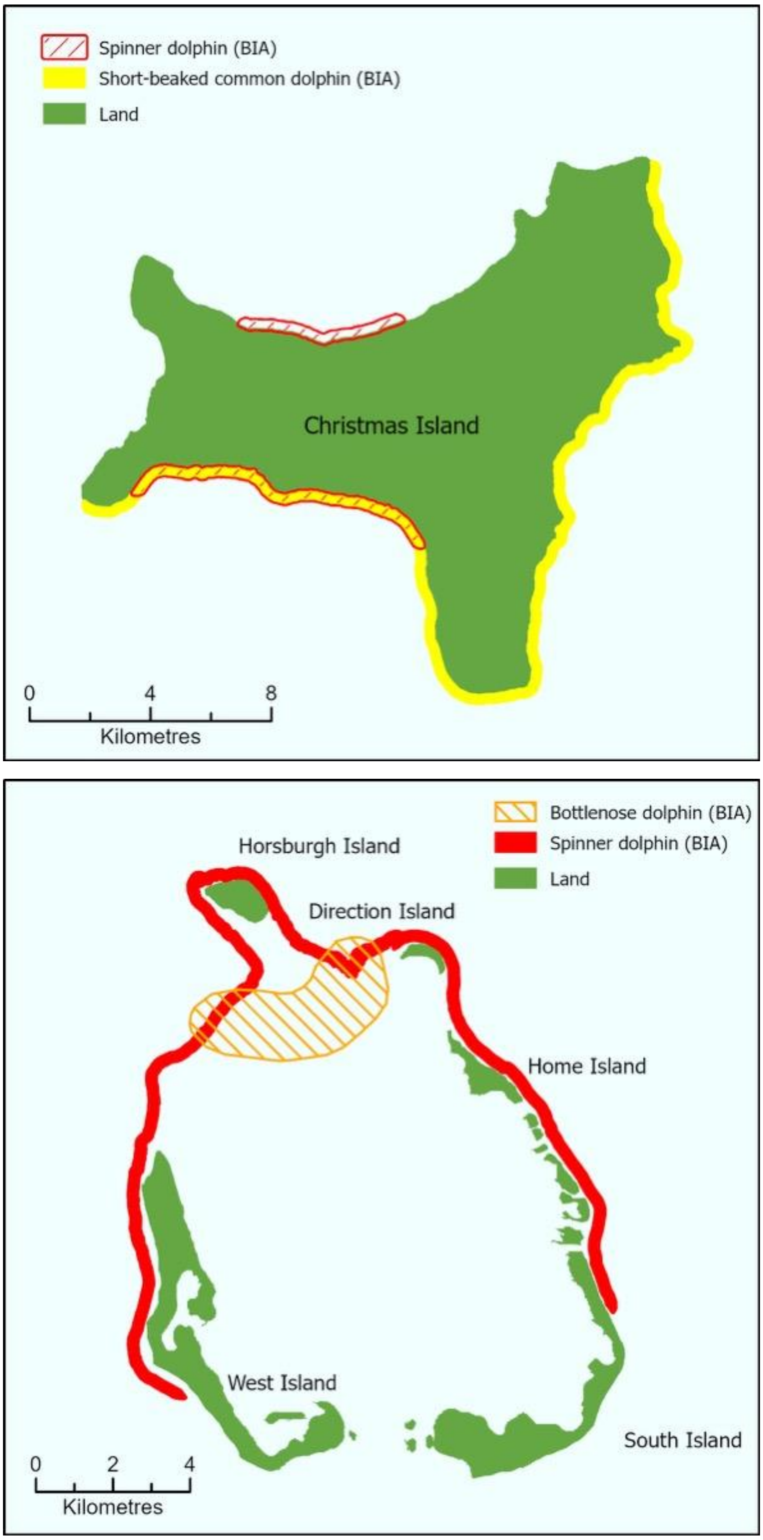


Figure 3.10. Distribution and habitat use by of dolphins at CI (top) and CKI (bottom). The areas shown in red, orange and yellow represent proposed BIAs for each of the three commonly sighted dolphin species. Data from Brewer et al., 2009; Director of National Parks, 2014; Director of National Parks, 2015; interviews with residents.

Table 3.3. Records and sightings of the dolphins and whales in nearshore waters around CI and CKI. Sources: Brewer et al., 2009; Director of National Parks, 2014; Director of National Parks, 2015; Interviews with residents

Species (EPBC status)	Sighted	Behaviour and use in IOT waters
Blue Whale - *Baleanoptera musculus* (Endangered, Migratory, Cetacean)	CKI	Rarely sighted in oceanic waters, unknown use of waters.
Bottlenose dolphin - *Tursiops truncatus* (Cetacean)	CKI	Regularly sighted in the inshore waters, particularly in the northern lagoon of South Keeling. Also sighted at NKI. Likely foraging, resting and breeding.
Cuvier's beaked whale - *Ziphius cavirostris* (Cetacean)	CI and CKI	Rarely sighted, unknown use of waters.
False killer whale - *Pseudorca crassidens* (Cetacean)	CKI	Rarely sighted, unknown use of waters.
Fin Whale - *Balaenoptera physalus* (Vulnerable, Migratory, Cetacean)	CI and CKI	Unconfirmed reports and unknown use of waters.
Humpback Whale - *Megaptera novaeangliae* (Vulnerable, Migratory, Cetacean)	CI and CKI	Rarely sighted, has been sighted within 12 nm of CI and CKI. Mothers with calves have been seen at CKI.
Killer whale - *Orcinus orca*	CI	Rarely sighted, unknown use of waters.
Long-snouted spinner dolphin - *Stenella longirostris* (Cetacean)	CI and CKI	Regularly sighted within 500 m of the coastline. Probably feeding, resting and breeding.
Sei Whale - *Balaenoptera borealis* (Vulnerable, Migratory, Cetacean)	CI and CKI	Unconfirmed reports and unknown use of waters.
Short-beaked common dolphin - *Delphinus delphis* (Cetacean)	CI and CKI	Commonly sighted within 500 m of east and south coasts of CI. Commonly seen in similar waters at CKI, including NKI. Probably feeding, resting and breeding.

3.6 Seabirds

NKI supports the greatest diversity of seabirds in the Indian Ocean and is an internationally recognised seabird rookery (Director of National Parks, 2015). Twenty-four species have been recorded on NKI, including 15 species that breed there (Brewer et al., 2009). NKI supports one the world's largest populations of red footed booby (*Sula sula*), and the second largest population of lesser frigate bird (*Fregata ariel*) (Director of National Parks, 2015). The island is critical habitat for the Cocos buff-banded rail (*Gallirallus philippensis andrewsi*). This endemic bird is listed as Endangered (EPBC Act). In addition to supporting resident populations, the island is an important stop-over for migrating birds and listed as a Wetland of International Importance under the Ramsar Convention (Brewer et al., 2009; Director of National Parks, 2015). Seabirds are relatively scarce at the southern atoll of CKI, primarily due to the destruction of habitat (vegetation clearing) and historical overharvesting.

While NKI provides key resting and nesting habitat for a diversity of seabirds, the surrounding waters provide important foraging grounds. Seabirds feed on pelagic fishes and squids around NKI. Those species nesting on NKI will return to their nests and regurgitate to feed their offspring. Thus, foraging success of the parent is linked to offspring survival. Various seabirds at NKI have been observed feeding in the surrounding waters but many are capable of foraging hundreds of kilometres away (e.g. Hennicke et al., 2015). However, no information is available on spatial patterns in foraging, and the distribution and abundance of marine species preyed upon by seabirds is most likely driven by spatial variation in ocean upwelling and productivity. It is likely that all the waters surrounding NKI up to a distance of 250 km for smaller species (e.g., common noddies; Dunlop et al., 2001) and 900km for larger species (e.g., red-footed boobies; Dunlop et al., 2001), are important for seabird foraging. However, there is no data available to suggest if particular areas of the waters surrounding NKI are more important for foraging seabirds than others.

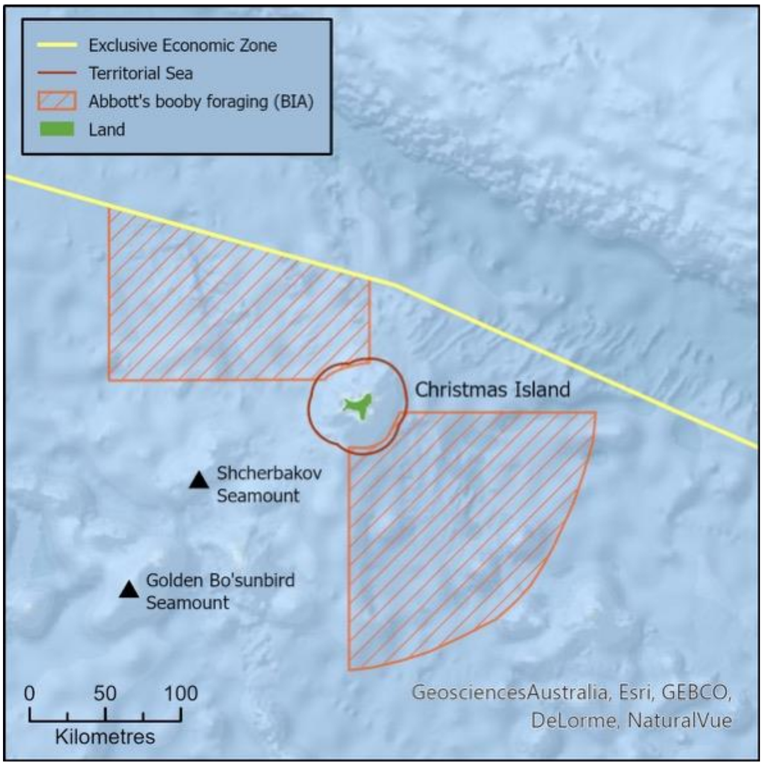


Figure 3.11. The proposed BIA (orange hatched area) representing the key foraging areas for the Abbott's booby (*Papasula abbotti*). These areas also overlap with some of the foraging areas of the Christmas Island frigatebird (*Fregata andrewsi*). Foraging area based on tracking data from Hennicke and Weimerskirch, 2014 and Hennicke et al. 2015.

CI is an internationally important island for seabirds. Over 100 bird species have been recorded, including nine resident species that breed on the island (Director of National Parks, 2014). Of these nine species, three are endemic and include the last remaining breeding colonies in the world for Abbott's booby (*Papasula abbotti*) and the Christmas Island frigatebird (*Fregata andrewsi*) (Director of National Parks, 2015). While the island provides essential habitat for resting and nesting, the surrounding waters provide food in the form of pelagic fishes and squid. Many species have been observed feeding in the immediate waters around CI, however data on foraging patterns further afield are lacking for most species. This limits the ability to propose particular areas as BIAs for particular species, but as for NKI, it is likely that all CI waters up to 200 km from shore are important for foraging seabirds. Tracking data does reveal that Abbott's booby mainly forages within the EEZ (median range of foraging trip = 56.8 km), particularly in the south-east and north-west regions (Hennicke and Weimerskirch, 2014; Figure 3.11). Their foraging patterns appear to be influenced by the wind and current (Hennicke and Weimerskirch, 2014). The Christmas Island frigatebird has also been tracked foraging in a range of habitats (oceanic, coastal, and shelf areas), including long distance trips up into Indonesia (Hennicke et al., 2015). Distance travelled from the island and foraging success has implications for the health and survival of CI's resident seabirds and their offspring (Hennicke et al., 2015). Seabirds also provide the vital link in the process of transferring nutrients from the marine to the terrestrial ecosystem (guano).

3.7 Manta rays

The giant (or oceanic) manta ray (*Mobula birostris*) and the reef manta ray (*Mobula alfredi*) both occur in the IOT. These species are listed as *Endangered* and *Vulnerable*, respectively, by the IUCN and as Migratory Species under Australia's EPBC Act. Both species are present in the inshore waters of the IOTs throughout the year. The reef manta ray has been recorded at CI and CKI, while the giant manta ray has only been recorded at CI (Armstrong et al., 2020). At CI, manta rays occur on all four coasts of the island and are most frequently observed along the outer reef slope (Figure 3.12). They have been seen feeding down to 70 m depth on the outer reef slope and in surface waters adjacent to the island (within 100 m of the coastline). While the waters adjacent to the reef slope are important for feeding, there is no data available to indicate that a particular coastline or area is more biologically important than another. At CKI, there are two areas in the northern lagoon channels that support a relatively high density of manta rays, which have been observed feeding and resting in this area (Figure 3.13). These areas are proposed as BIAs for reef manta rays at CKI.

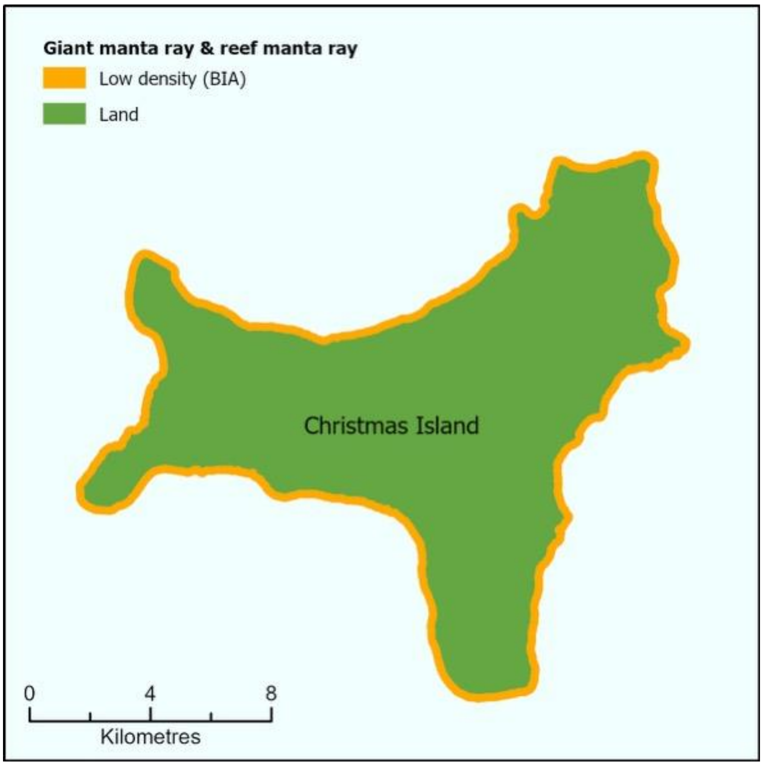


Figure 3.12. The giant (oceanic) manta ray (*Mobula birostris*) and the reef manta ray (*Mobula alfredi*) share the same distribution around CI. As is often the case for marine species at CI, it is unclear (and unlikely) that particular inshore areas are more important than others, so the full distribution range of mantas at CI is proposed as a BIA. Data from Armstrong et al., 2019; Hobbs pers. obs.; interviews with residents

At the southern atoll of CKI, the reef manta ray (*Mobula alfredi*) has been observed on the outer reef slope and in northern parts of the lagoon. In the lagoon, manta rays are often seen inside the northern entrances (Figure 3.14) and are sometimes feeding (K. Willshaw pers. comm.). Manta rays were occasionally seen feeding at night under the lights of the old jetty (Figure. 3.14). At NKI, the reef manta ray has been observed on the outer reef slope (Hobbs pers. obs.).

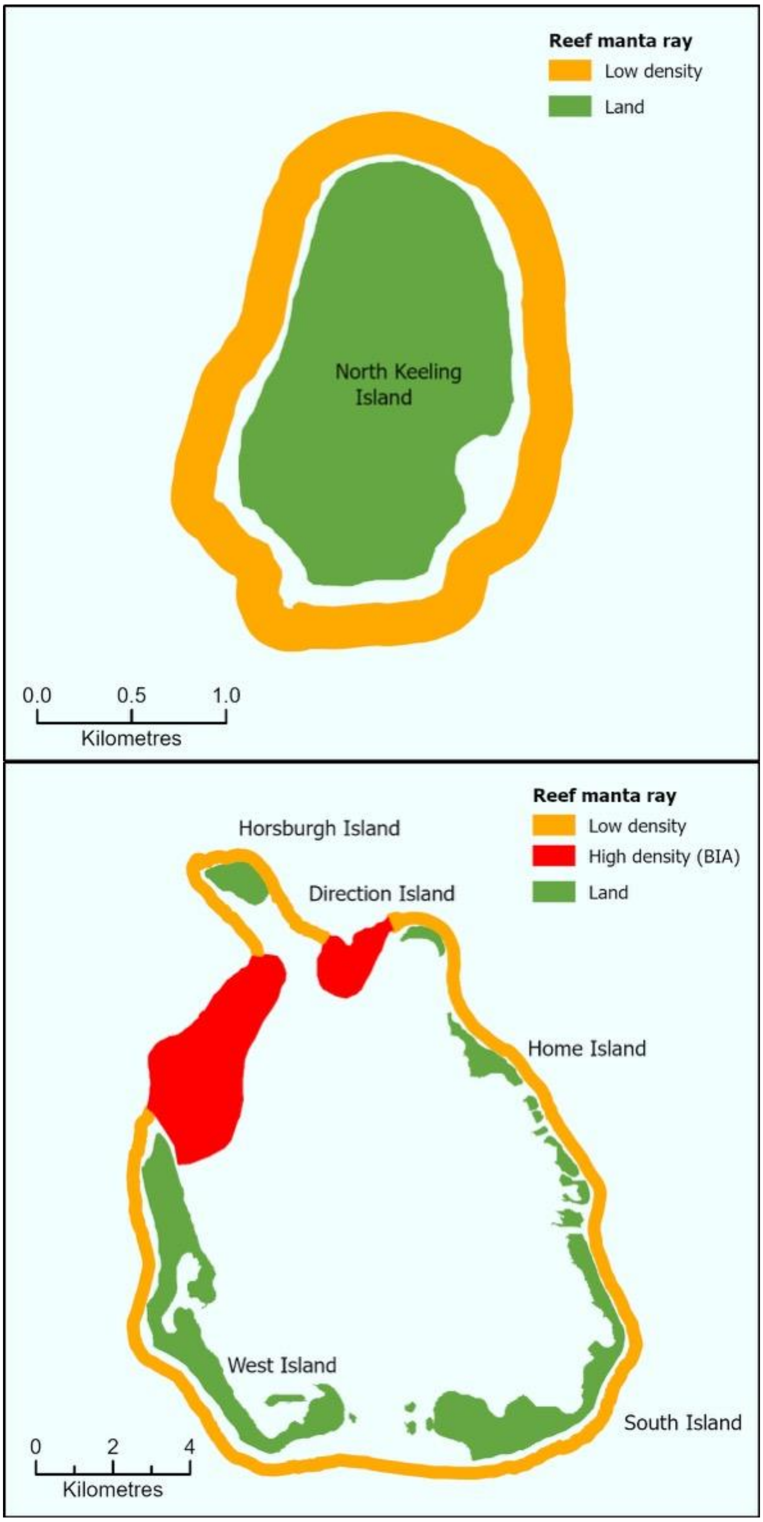


Figure 3.13. The distribution of the reef manta ray (*Mobula alfredi*) around NKI (top) and the southern atoll of CKI (bottom). The proposed BIA (red) highlights the habitat that is used the most for feeding and resting. Data from Armstrong et al., 2019; Hobbs pers. obs.; K. Willshaw pers. comm.

Figure 3.14. A reef manta ray (*Mobula alfredi*) feeding at night under the lights of the old jetty on the northwest tip of West Island. Photograph taken by JP Hobbs in 2008.

3.8 Land crabs

The diversity and abundance of land crabs at CI is the highest in the world (Director of National Parks, 2014). Although these crabs spend most of their life on land, they have a marine larval stage lasting 3 to 5 weeks (Orchard, 2020). During the summer spawning season, millions of land crabs migrate from the forest to the coastline where they release trillions of eggs into the ocean (Davies and Beckley, 2010; Orchard, 2020). This influx of spawn and subsequent larvae represents a significant introduction of plankton and nutrients into the surrounding marine ecosystem. This input varies in space and time due to differences in spawning patterns and migration routes. For example, Christmas Island red crabs (*Gecarcoidea natalis*) from the centre of CI tend to migrate to the north coast (Orchard, 2020). Similarly, freshwater streams on the west coast (the Dales) provide corridors that concentrate red, blue and robber crabs as they migrate to the coast to spawn (Butcher and Hale, 2010). The same streams also funnel recruits, particularly blue crabs (*Discoplax celeste*), as they emerge from the ocean (Butcher and Hale, 2010). These freshwater streams could potentially result in a disproportionately greater contribution of spawn and larvae in waters adjacent to the western coastline. Once the spawn enters the water, the larvae develop through a series of stages during the ensuing weeks, and eventually come ashore to begin life on land. Mass emergence of juvenile (megalope) red crabs can be equally spectacular as the spawning migrations of adult crabs (Orchard, 2020). While in the marine environment, the location of the larvae and what determines their distribution and abundance is largely unknown. Attempts have been made to study the distribution of larvae (Davies and Beckley, 2010); however, these are limited by a lack of knowledge on identification of land crab larvae (Orchard, 2020).

What is known is that whale sharks visit the island during the land crab spawning season (Hobbs et al, 2009b) and feed on red crab larvae (Meekan et al., 2009). It is also known that whatever happens in the marine environment has a significant impact on population replenishment of land crabs. Despite trillions of larvae being produced, recruitment often fails (Orchard, 2020). However, recruitment has been successful in six of the last eight years (Kerrie Bennison pers. comm.). It is thought that recruitment success is dependent on favourable oceanographic conditions, but these are yet to be determined (Davies and Beckley, 2010). Recruitment of crab larvae (Figure 3.15) has important consequences for the unique forest ecosystem at CI because land crabs are a keystone species. Furthermore, some species are threatened with extinction (e.g. coconut crab - *Birgus latro* is listed as vulnerable by the IUCN). There is no data on the temporal and spatial patterns in the distribution and abundance of land crab larvae. Consequently, it is not possible to propose BIAs with confidence. Although some land crab species may aggregate on sections of the coastline to release their eggs, it is unknown if the developing larvae remain in the adjacent waters. Given the importance of the larval stage to both the marine and terrestrial ecosystems of CI, further research on the identification and ecology of land crab larvae is needed to fill this knowledge gap.

At NKI, there is a much lower diversity and abundance of land crabs. Six species of land crab have been recorded on NKI including the coconut crab and Christmas Island red crab (Director of National Parks, 2015). On the southern atoll, some crabs (e.g. hermit crabs, purple land crabs, ghost crabs) are collected and used for bait by local fishers. Coconut crabs also used to be more common on the southern atoll but are rarely seen due to historical overharvesting (Bunce 1988).

Figure 3.15. Juvenile (megalope) red crab exiting the marine environment at Christmas Island as they begin a life on land. Photograph by Justin Gilligan.

3.9 Batfish (CI)

Batfish are important to tourism at CI because they are a popular attraction for SCUBA divers. Batfish (*Platax teira* and *Platax orbicularis*) are occasionally seen on the outer reef slope of the north, west and east coasts of CI (Figure 3.16). Due to limited surveys on the south coast, is unknown if they occur around the entire island. For at least 10 years, a school of batfish (~100 adult *Platax teira*) resided on the outer reef slope at Thundercliff Cave (Figure 3.17). For unknown reasons, this school disappeared around 2012. More recently, a similar sized school is often seen resting at Perpendicular Wall (T. Hamanaka pers. comm.). The school moves around and is not always present. Juvenile batfish have been observed (albeit rarely) in Flying Fish Cove. Collectively, these observations indicate that the outer reef slope at Perpendicular Wall (and previously at Thundercliff Cave) is an important resting area, while Flying Fish Cove may be an important nursery habitat, though this requires further investigation.

On the Great Barrier Reef, batfish are a functionally important group because they consume fleshy macroalgae (Bellwood et al., 2006). It is not clear what ecological role they play at CI, given the lack of feeding observations and scarcity of fleshy macroalgae (<1% mean cover from 2005 to 2019: Gilligan et al., 2008; Hobbs unpubl. data.; Martinez-Escobar and Mallela, 2019; Mallela 2020a). Batfish most likely spawn at CI but is unknown if any locations are more important than others for feeding and breeding.

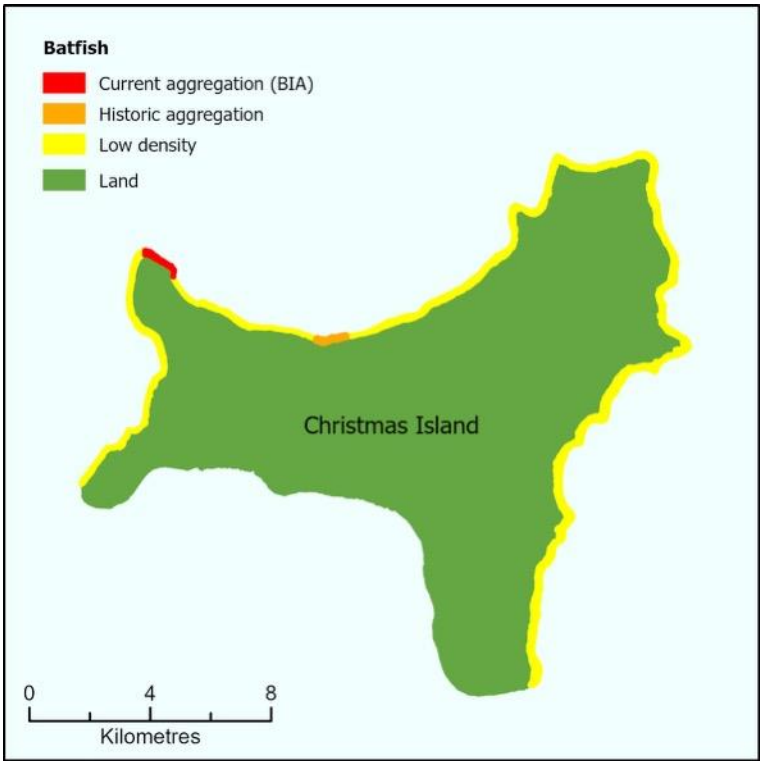


Figure 3.16. Known distribution of batfishes around Christmas Island (yellow areas), including historic (orange area) and current (red area) aggregations. The current aggregation represents a proposed BIA because this habitat is used for resting. Data from Hobbs pers. obs.; T. Hamanaka pers. comm.

Figure 3.17. A school of adult batfish (*Platax teira*) at 25 m depth on the outer reef slope at Thundercliff Cave, Christmas Island. Photograph taken in 2008 by Justin Gilligan.

3.10 Gong gong (CKI)

Gong gong, or spider conch shell (*Lambis lambis*) are an important fisheries species at CKI because they are regularly harvested for food by the local Cocos Malay population. Gong gong have been well studied at CKI (Lincoln-Smith et al.,1993; Hender et al., 2001; Konzewitsch and Evans, 2020). Based on this research, gong gong is known to occur throughout the inner lagoon flats at CKI (Figure 3.18) and this distribution has generally been consistent for the last 17 years (Hender et al., 2001; Konzewitsch and Evans, 2020). Most individuals are found in waters shallower than 2 m depth (Bellchambers et al., 2011). Adults slowly move around on top of the benthos and their abundance is positive correlated with hard macroalgae (*Acanthophora* sp.) and submassive corals, and negatively associated with seagrass and relict coral (Bellchambers et al., 2011). They reach their highest densities on flats in south-east lagoon (Figure 3.18). Juveniles have also been found embedded in the sediment in this area and in close vicinity to seagrass and *Caulerpa* beds (Hender et al., 2001). No dedicated surveys have been done on juveniles due to difficulties locating them. Thus, the distribution of juveniles and their reliance on particular nursery habitats (e.g. with seagrass and

Caulerpa sp) is unknown. Given that adult gong gong do not move far (Konzewitsch and Evans, 2020), the juveniles probably live in the sediment within the distribution of the adults. Adults mature and likely reproduce (between October and March) throughout their observed distribution on the lagoon flats (Bellchambers and Evans, 2013). Based on limited field observations, it appears that they deposit their eggs within this habitat (Bellchambers and Evans, 2013). Although the diet of gong gong at CKI is unknown, the lack of movement in the adults indicates that the habitat where they reside provides the necessary food resources. The area of highest gong gong density (south east lagoon flats, Figure 3.18) is proposed as a BIA for gong gong because the evidence indicates that this habitat supports juveniles and adults.

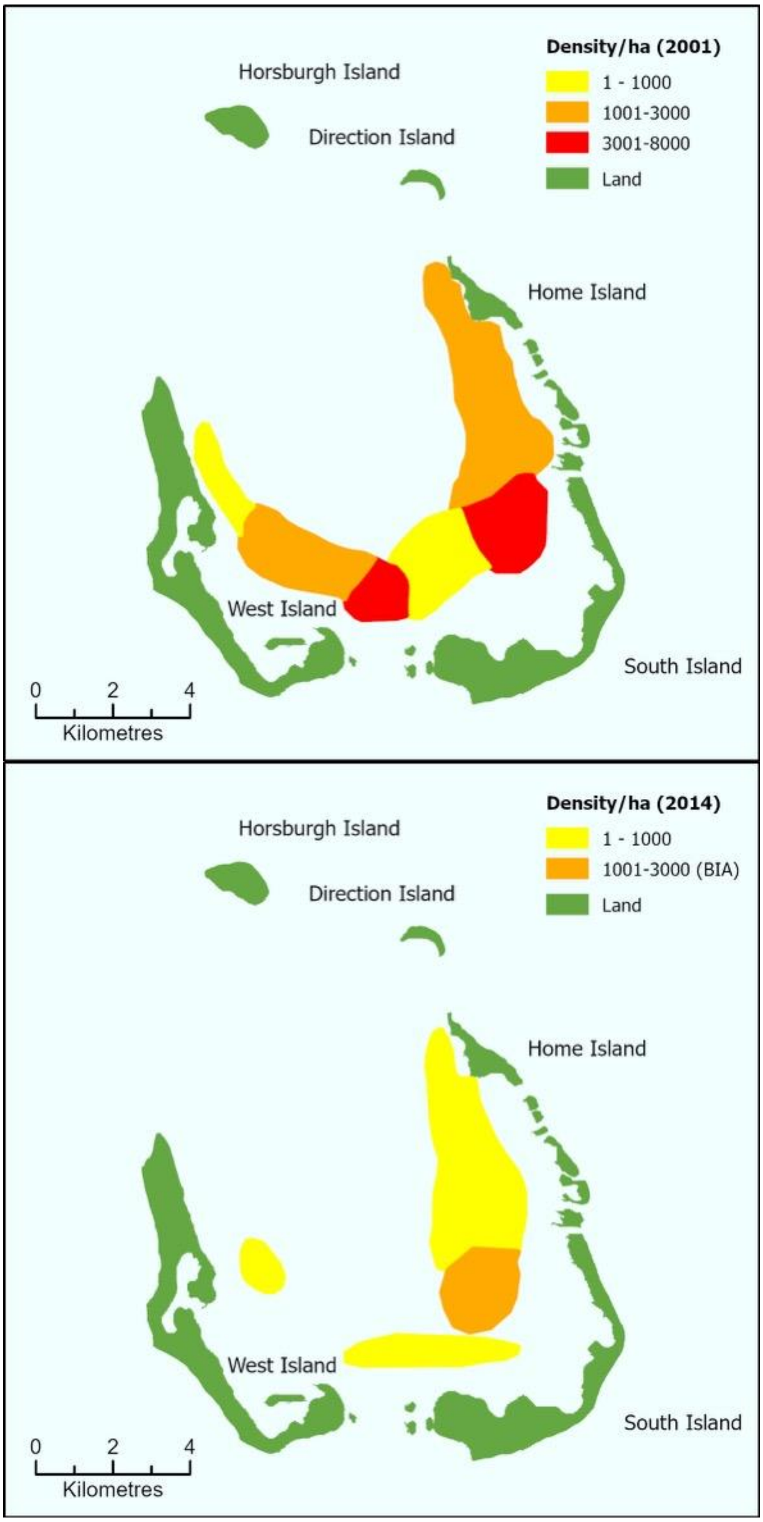


Figure 3.18. Spatial patterns in the density of gong gong (*Lambis lambis*) in the shallow lagoon and inner lagoon flats at South Keeling Island in 2001 (top) and 2014 (bottom). Data from Hender et al., 2001 and Evans et al, 2016. The proposed BIA (orange area in bottom map) supports juveniles and the highest density of adults, and is probably a significant breeding area.

3.11 Coral trout (CKI)

Coral trout (*Plectropomus* spp) are a major fisheries species throughout their range (Frisch et al., 2016). Some species of coral trout are listed as threatened by the IUCN due to overfishing. Three species of coral trout (genus) have been described from CKI (Allen and Smith-Vaniz, 1994). However, it is likely that only two species of coral trout, the squaretail coral trout (*Plectropomus aerolatus*) and bluespotted coral trout (*Plectropomus laevis*), occur at CKI, because there have been no reports of the third species (*Plectropomus maculatus*) since it was first collected in 1973. CKI is also well outside the geographic range and typical habitat of *P. maculatus*. The third species of coral trout that occurs at CKI may actually be *Plectropomus pessuliferus*, a species that was often misidentified as *P. maculatus* in the 1970s and 1980s (Heemstra and Randall, 1993). *Plectropomus pessuliferus* occurs on outer reefs in neighbouring locations (Chagos, Maldives, Sumatra), so CKI fits the habitat and range. Regardless of the identity of this species, it has not been reported since 1973.

Of the two species currently present at CKI, the squaretail coral trout (*P. aerolatus*) is common, while the bluespotted coral trout (*P. laevis*) is rare. There have only been a handful of reports of *P. laevis* being observed underwater or caught (by spear or line) over the past 20 years. From 2001 to 2017 extensive underwater surveys around CKI, and in the areas where it has been reported to occur, failed to find any individuals (Hender et al., 2001; Hobbs unpubl. data). All reports of *P. laevis* come from locals fishing or diving along the northwest outer reef, particularly around Turks Reef (Figure 3.19). This species is currently at extremely low abundance (or potentially absent) at CKI. Based on the habitat use of this species elsewhere, and the availability of this habitat at CKI, if this species was common, it would probably be distributed more broadly along the outer reef slope.

The squaretail coral trout (*P. aerolatus*) is listed as Vulnerable by the IUCN and is currently the most common coral trout species at CKI. Its abundance at CKI has fluctuated greatly through time, which was thought to be due to overfishing (Hender et al., 2001). It was originally reported as a common target species by Gibson-Hill in 1946. Local fishers remember catches of 30 a day up to the 1970s. Then its abundance declined, and it was reported at much lower numbers in 1993 by

Lincoln-Smith et al. By 2001 it was rarely seen, with extensive underwater surveys recording few individuals - all along the northwest outer reef (Hender et al, 2001). According to reports from local fishers, the decline occurred during the 1990s (Hender et al, 2001). Extensive underwater surveys throughout the northwest outer reef failed to find any coral trout in 2005, 2008 and 2010 (Hobbs unpubl. data).

In 2013, there were reports of juvenile squaretail coral trout in the southern blue holes. Underwater surveys in 2014 confirmed many juveniles were present in this location. At the same time, reports began of coral trout being caught in the northern lagoon and adjacent outer reef. By 2015, underwater surveys recorded coral trout in the southern, central and northern lagoon sites and on the outer reef at Home Island. In 2017, underwater surveys revealed that coral trout were abundant throughout the lagoon and the northern outer reefs from the middle of West Island to Home Island. Today, the known distribution of square tail coral trout at CKI is extensive. It is commonly seen and caught throughout the southern blue holes, central and northern lagoon, and along the outer reef crest and slope on the northern half of the atoll (Figure 3.20). It is unknown if its distribution extends along the outer reef to the southern half of the atoll. Juveniles are most commonly seen in the southernmost blue holes and on small patch reefs in inner lagoon, but not on the inner lagoon flats (Figure 3.20).

Based on the available data, there are two areas that are most biologically important for coral trout. The first area is the southern blue holes, which appears to be important nursery habitat for squaretail coral trout (Figure 3.20). The second area is the outer reef slope on the north-west side of the atoll (Figure 3.20), where aggregations of adult coral trout are sometimes observed (K. Willshaw pers. comm.), and may represent spawning aggregations. Throughout the Pacific, *P. aerolatus* are known to form seasonal and predictable spawning aggregations in comparable habitat as observed at CKI (Sadovy de Mitcheson et al. 2020; Hughes et al., 2020). Prohibition of fishing in areas where spawning aggregations occur is an important and effective management strategy to protect these fishes from overfishing (Sadovy de Mitcheson et al. 2020; Hughes et al., 2020).

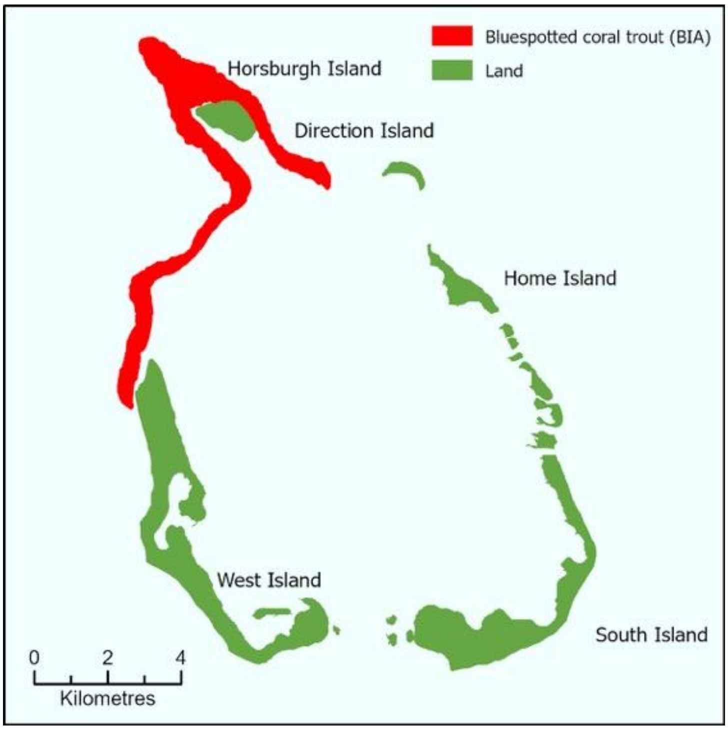


Figure 3.19. Distribution of the bluespotted coral trout (*Plectropomus laevis*) at SKI. The proposed BIA (in red) represents the most likely habitat for bluespotted coral trout. Data based on interviews with local residents.

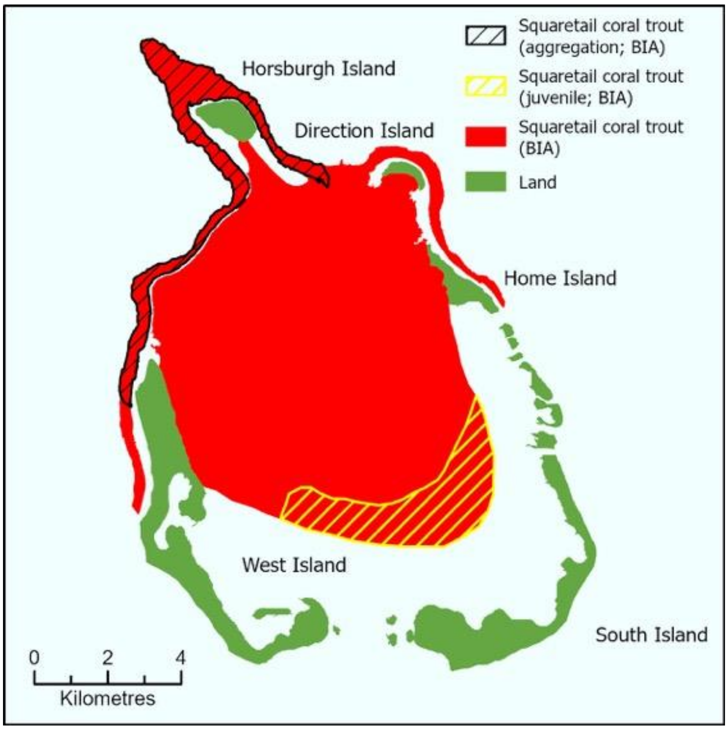


Figure 3.20. The known distribution of squaretail coral trout (*Plectropomus aerolatus*) around South Keeling Islands. The proposed BIAs (shown in red) incorporates aggregation (black) and nursery (yellow) areas. Data from Hender et al., 2001; Hobbs unpubl. data; Willshaw pers. comm.; interviews with local residents.

3.12 Significant reef species – emperors and snappers

Many reef species at CKI are considered significant due to their high fisheries and/or ecological value. In addition to coral trout, reef fishes most-commonly targeted at CKI include emperors and snappers. These species are common throughout the lagoon and on the outer reef, where they shelter in the reef matrix and feed on reef associated prey (Figure 3.21). Most emperors and snappers reach their greatest abundance on the outer reef slope on the northwest of the atoll (Hender et al., 2001; Hobbs unpubl. data). This habitat is important because it supports large schools (Figure 3.21), which may represent spawning aggregations. Most shallow-water emperor and snapper species are naturally rare at Christmas Island (Gilligan et al., 2008).

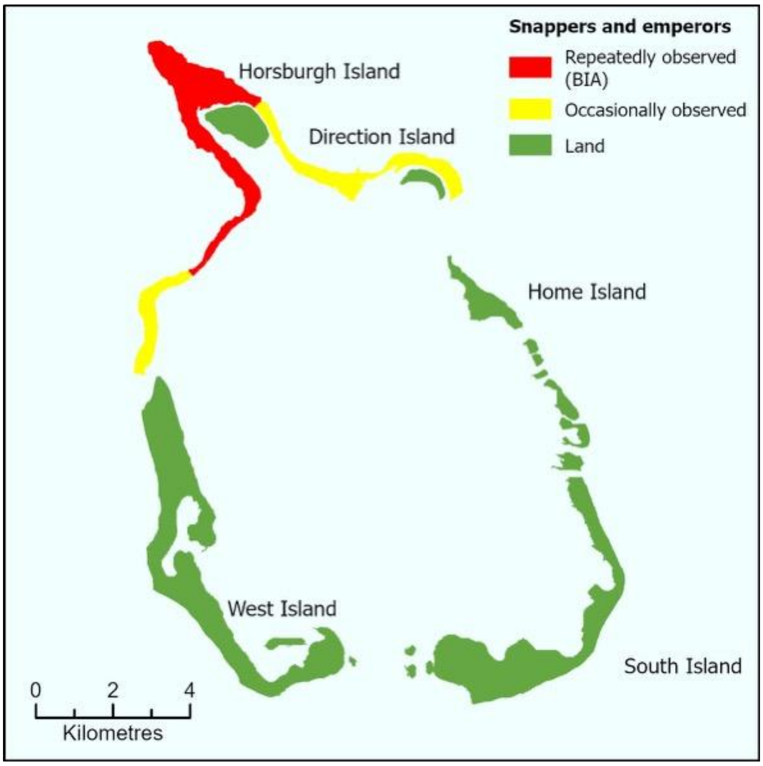


Figure 3.21. The proposed BIA for snappers and emperors (shown in red) represents the area which supports the highest densities of adults. Data based on Hender et al., 2001; Hobbs unpubl. data.

3.13 Significant reef species – humphead Maori wrasse and bumphead parrotfish

The humphead Maori wrasse is large-bodied fish targeted by local fishers, particularly due to its importance in wedding feasts. This species is listed as

Endangered by the IUCN due to its vulnerability to overfishing. Despite fishing pressure, the density of humphead (*Cheilinus undulatus*) at CKI is among the highest in the world (Hender et al., 2001; Birt et al., 2021). This species is found throughout the lagoon and outer reef, but anglers mainly target individuals on the outer reef due to their superior taste compared to lagoonal fish. The bumphead parrotfish (*Bolbometopon muricatum*) is a related species that also grows to a large size and has a similar biology and ecology to the humphead Maori wrasse. It is also listed as Endangered by the IUCN due to overfishing. Its abundance is relatively high at CKI (Choat unpubl. data; Hobbs unpubl. data), and fishing pressure has declined considerably in recent years owing to reduced use of nets. Both these species shelter and feed in many areas at CKI, and most likely spawn on the outer reef slope, while the southern blue holes in the lagoon appear to be important nursery habitat (Hamilton et al., 2017; Choat unpubl. data; Hobbs unpubl. data; Figure 3.22). In the blue holes, juveniles live in close proximity to branching coral and quickly shelter in it when scared (Figure 3.23). Humphead Maori wrasse and bumphead parrotfish are naturally rare at Christmas Island (Gilligan et al., 2008).

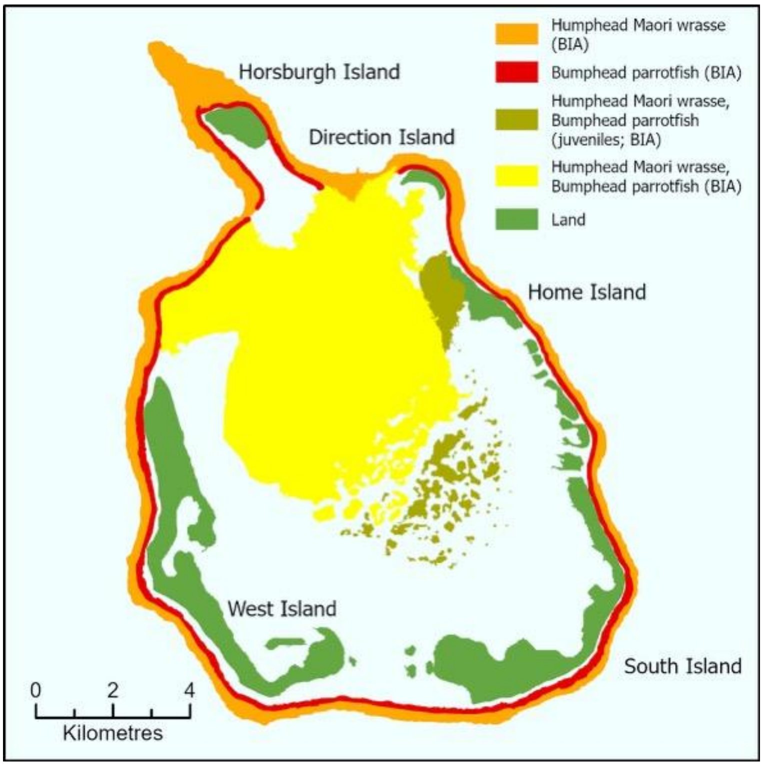


Figure 3.22. Humphead Maori wrasse (*Cheilinus undulatus*) and bumphead parrotfish (*Bolbometopon muricatum*) demonstrate biologically important behaviours throughout most areas of SKI – all shaded areas are proposed as BIAs for these species. Data based on Hender et al., 2001; Hamilton et al., 2017; Choat unpubl. data; Hobbs unpubl. data.

Figure 3.23. Juvenile humphead Maori wrasse shelter amongst branching corals in the southern blue holes nursery habitat at South Keeling Island. Photograph by Tane Sinclair-Taylor.

3.14 Significant reef species – crayfish and slipper lobsters

There are four species of crayfish at CKI and two species are commonly targeted by local fishers (Ng and Naruse, 2014; Hobbs pers. obs.). These two species, spiny crayfish (*Panulirus penicillatus*) and slipper lobster (*Parribacus antarcticus*) are abundant on the outer reef crest and play an important ecological role in this habitat (Figure 3.24). These are resident populations, that shelter, forage and breed within the reef crest habitat. There is not enough data to determine if particular sections of reef crest habitat are biologically more important than others. Four species of spiny crayfish and one (possibly two) species of slipper lobster are present (and occasionally targeted) along the foreshore and outer reef flat on the north coast of CI (Ng and Naruse, 2014; Hobbs pers. obs.). However, their distribution and abundance around CI is unknown.

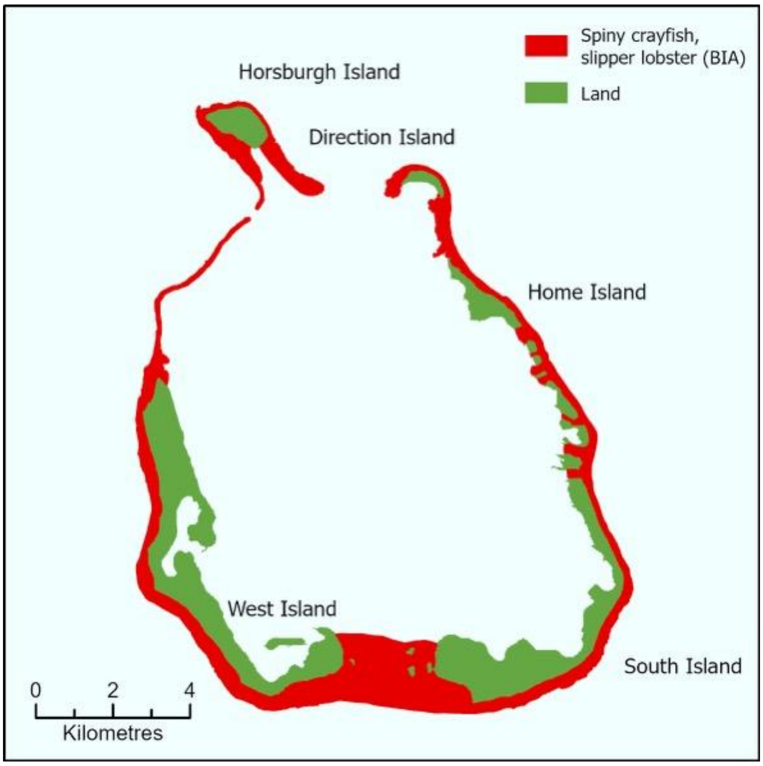


Figure 3.24. The distribution of spiny crayfish (*Panulirus penicillatus*) and slipper lobster (*Parribacus antarcticus*) along the outer reef crest and slope at South Keeling Island – because these species shelter, feed and breed across this area, it is proposed as a BIA. Distributions based on Hobbs pers obs. and interviews with local residents.

3.15 Significant reef species – deepwater fishes

Several valuable fisheries species (including deepwater cods, jobfishes and sepat) are caught by local anglers fishing the deep reef slope (150 to 500 m deep) at CI and CKI (Figure 3.25). These species are most likely resident and reliant largely on self-recruitment. They are known to shelter, feed and most likely reproduce on the deep reef slope around the islands. This deep reef slope is proposed as a BIA for these species (Figure 3.26).

Figure 3.25. Valuable fisheries species caught by local anglers from the deep reef slope (150 to 500 m deep) at CKI and includes deep-water cods and jobfishes. Photograph by JP Hobbs. Distributions based on Hobbs pers obs. and interviews with local residents.

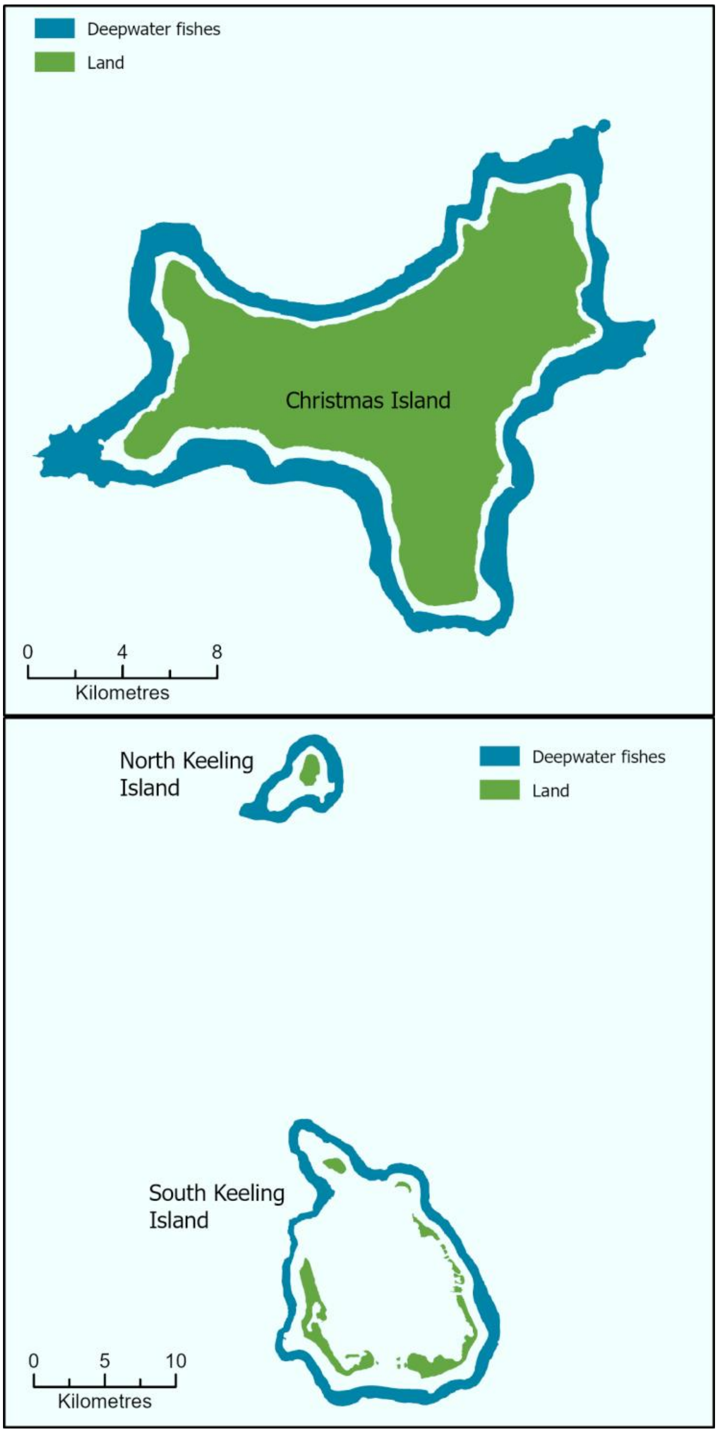


Figure 3.26. The distribution and extent of the deep reef slope around CI (top) and CKI (bottom). The proposed BIA (blue) is the extensive deep reef slope (150 to 500 m) that encircles CI, NKI and SKI.

3.16 Significant pelagic fishes

Given the close proximity of oceanic waters, several pelagic fishes are common and targeted by local anglers at CI and CKI. Reef associated pelagics, such as giant trevally and bluefin trevally, are frequently caught along the outer reef flat and crest, and in the lagoon at CKI. The outer reef crest supports the highest adult densities of both trevally species (Figure 3.27). Dogtooth tuna inhabit the outer reef slope and mesophotic reefs (Figure 3.28). All three species are also present on the outer reefs at CI and both locations probably contain resident populations that feed and breed in their respective habitats.

The three most commonly caught fishes in the pelagic waters adjacent to the reef are wahoo, sailfish and yellowfin tuna. These prized species are targeted by anglers at both island locations and are the basis of a small-scale commercial fishing operation at CI. While these three species inhabit and feed in the pelagic waters throughout the EEZs of the IOTs, there is no knowledge on their reproduction. As non-resident species that move and feed throughout the Indian Ocean, it is not clear if the waters of the IOTs are as biologically important as they are for resident pelagic species like trevallies and dogtooth tuna. For the three pelagic species mentioned above, further research is required to gain sufficient data to determine BIAs.

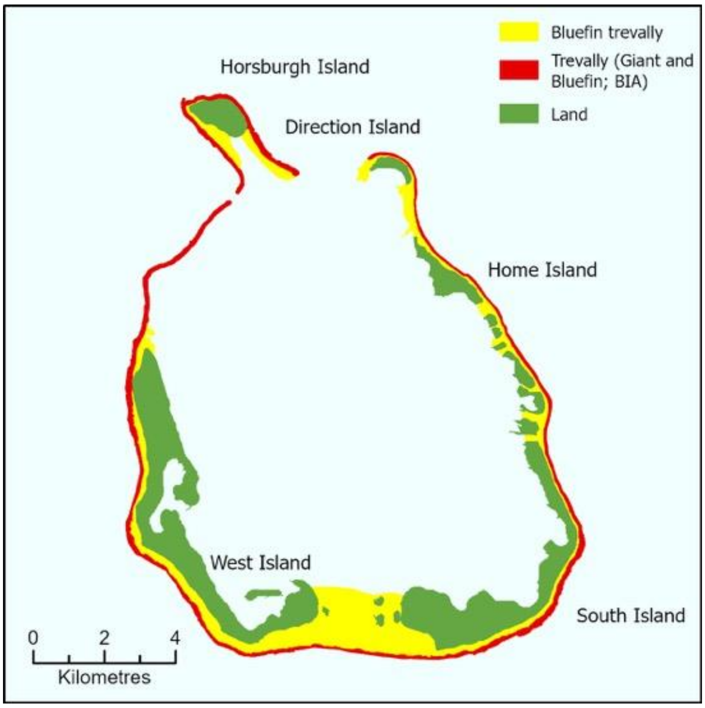


Figure 3.27. The known distribution of giant and bluefin trevally along the outer reef flat and crest slope SKI. The proposed BIA is indicated in red and represents the habitat that supports high adult densities of both species. Both species also occur in the lagoon at lower densities. Distributions based on Hender et al., 2001; Hobbs unpubl. data and interviews with local residents.

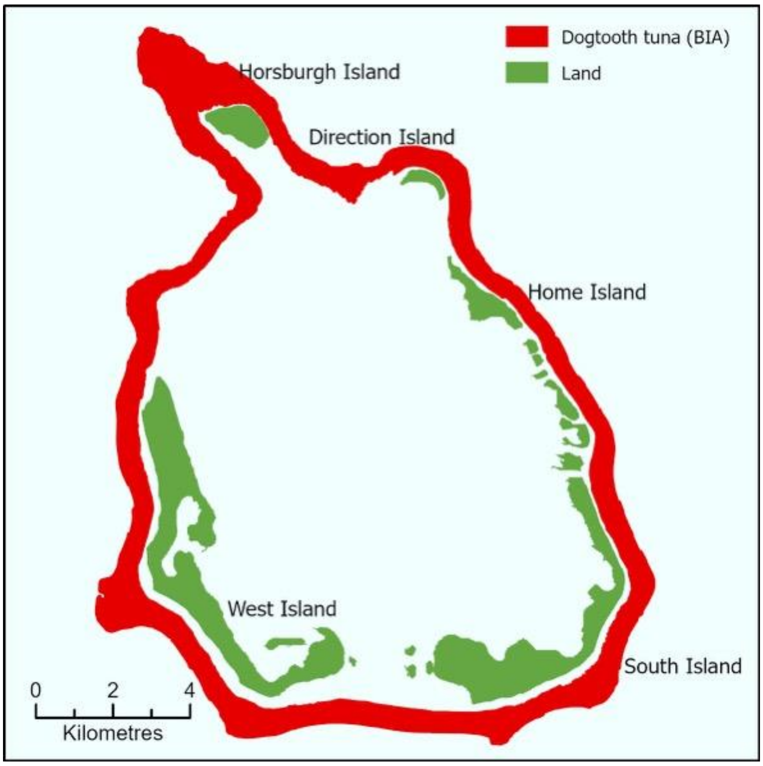


Figure 3.28. The known distribution of dogtooth tuna along the outer reef slope and mesophotic reef at SKI. The area is proposed as a BIA because this species shelters, feeds and presumably breeds in this habitat. Distributions based on Hender et al., 2001; Hobbs unpubl. data and interviews with local residents.

3.17 Endemic species

Endemics are significant species because they have high conservation value as they represent unique biodiversity that is not found anywhere else in the world. Some endemics are also important fisheries species, e.g. the Cocos angelfish supports a small commercial aquarium fishery at CKI. The evolution of endemics is facilitated by the isolation of the islands. The terrestrial ecosystem at CI is well known for its high proportion of endemic species. This appears to extend into the marine environment with CI ranked seventh in the world for the number of endemic coral reef fishes per area of habitat (Allen et al., 2007).

Some species, such as the Island Gregory, are likely to be endemic subspecies that are evolving into their own species because they have long been isolated from any other population. One such species, the lemonpeel angelfish, was recently renamed as a new endemic species, *Centropyge cocosensis* (Figure 3.29). The Christmas blenny was thought to be endemic to CI (Allen et al 2007), but its distribution is unclear given there are three apparent records from distant locations in the Pacific Ocean (James et al., 2019). Although the distribution of some endemics encompasses both CI and CKI, endemism appears to higher at CI than CKI, possibly because the CKI system is much younger. Ongoing discovery of endemic marine species at CI is expected given that new discoveries of terrestrial endemics show no signs of slowing (James et al, 2019) and marine research lags considerably behind terrestrial research. Based on available data, the outer reef slope on the north coast of CI and CKI support the highest densities of endemic angelfishes (Figures 3.30 and 3.31). These fish are known to use this area to feed, shelter and breed (Hobbs et al, 2010b). For the same reasons, the outer reef habitat on the west coast of CI is the most important for the Island Gregory (Figure 3.32).

Deepwater habitats (> 50 m depth) will probably contribute a high proportion of the endemic species discoveries in future years. This is because deep, isolated, oceanic habitats (e.g. seamounts) are renowned for high levels of endemicity. Furthermore, there has been little to no research of the marine communities in deep water habitats (Brewer et al., 2009). These habitats most likely support unique communities that are of high importance to the biodiversity and ecology of the region. There is also likely to be notable differences in the marine communities among deep water habitats in the IOTs due to the variation in the location, isolation and physical characteristics of these habitats (Brewer et al., 2009).

The information provided here on endemic species is very limited in taxonomic scope. We have focussed on fishes, not because this group is of greater significance, but because it is the best studied group and has a bipartite life history typical of most coral reef species. Therefore, the documented patterns in fishes (Hobbs et al., 2014b,c) are likely to be representative of the coral reef species in general. The accuracy of this proxy will be determined by future research. Comprehensive biodiversity surveys (across taxa and into deep water habitats) will be required to gain an accurate estimate of the number species endemic to the IOTs, or not found anywhere else in Australia. Even though the IOTs have received less research effort than most other marine systems in Australia, its marine biodiversity is clearly unique. An understanding of the level of uniqueness and its conservation value will increase with research effort and will likely be comparable or surpass most other marine systems with similar sized habitats.

Figure 3.29. A) Cocos angelfish (*Centropyge joculator*) and B) lemonpeel angelfish (*Centropyge cocosensis*). Both species are endemic to Christmas Island and Cocos Keeling Islands. Photographs by Tane Sinclair-Taylor.

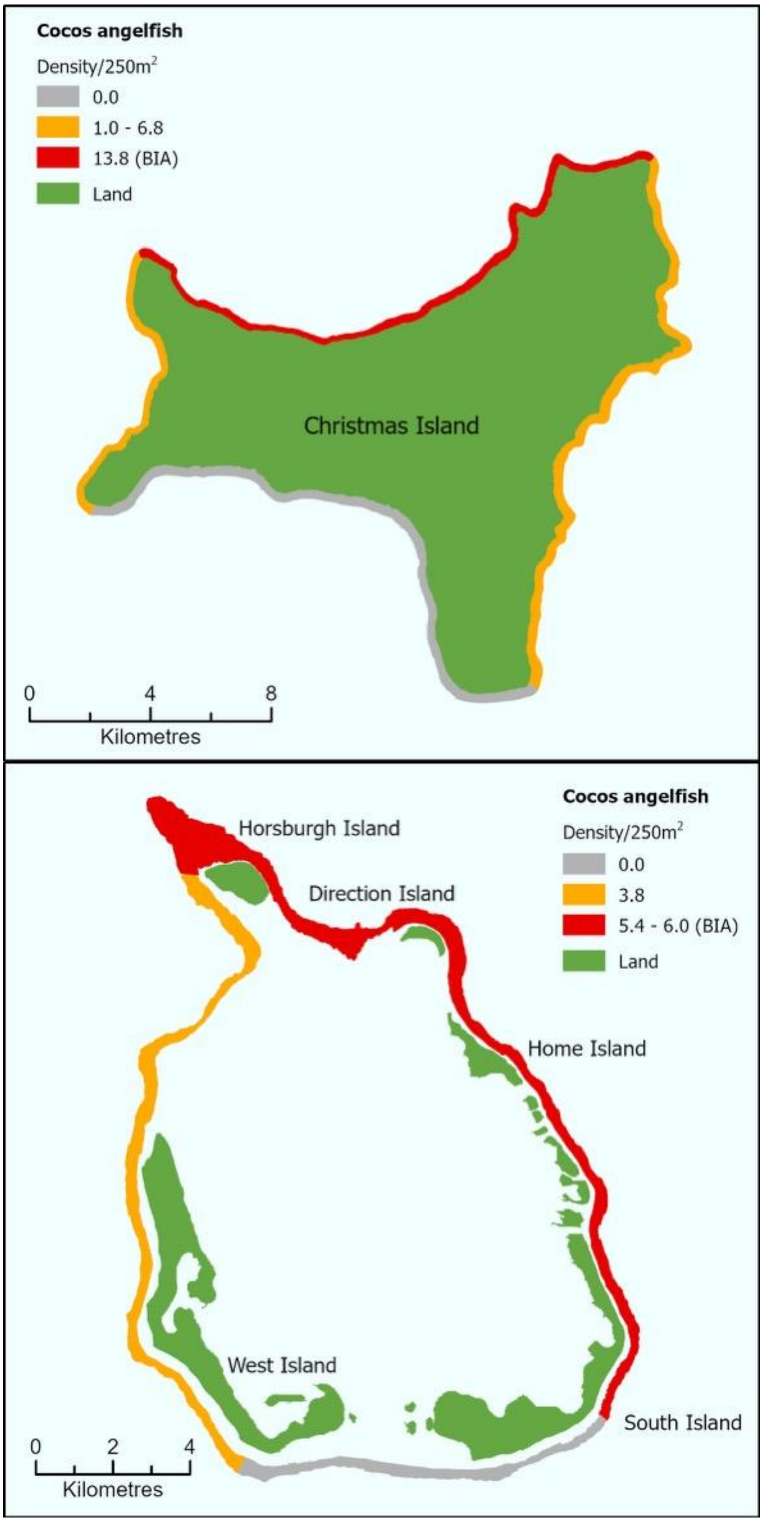


Figure 3.30. The distribution and abundance of the Cocos angelfish (*Centropyge joculator*) around CI (top) and CKI (bottom). The proposed BIA (red) is the outer reef slope along the north coast of CI and CKI because this habitat supports the highest densities. Data from Hobbs et al., 2010b; 2012; Hobbs unpubl. data.

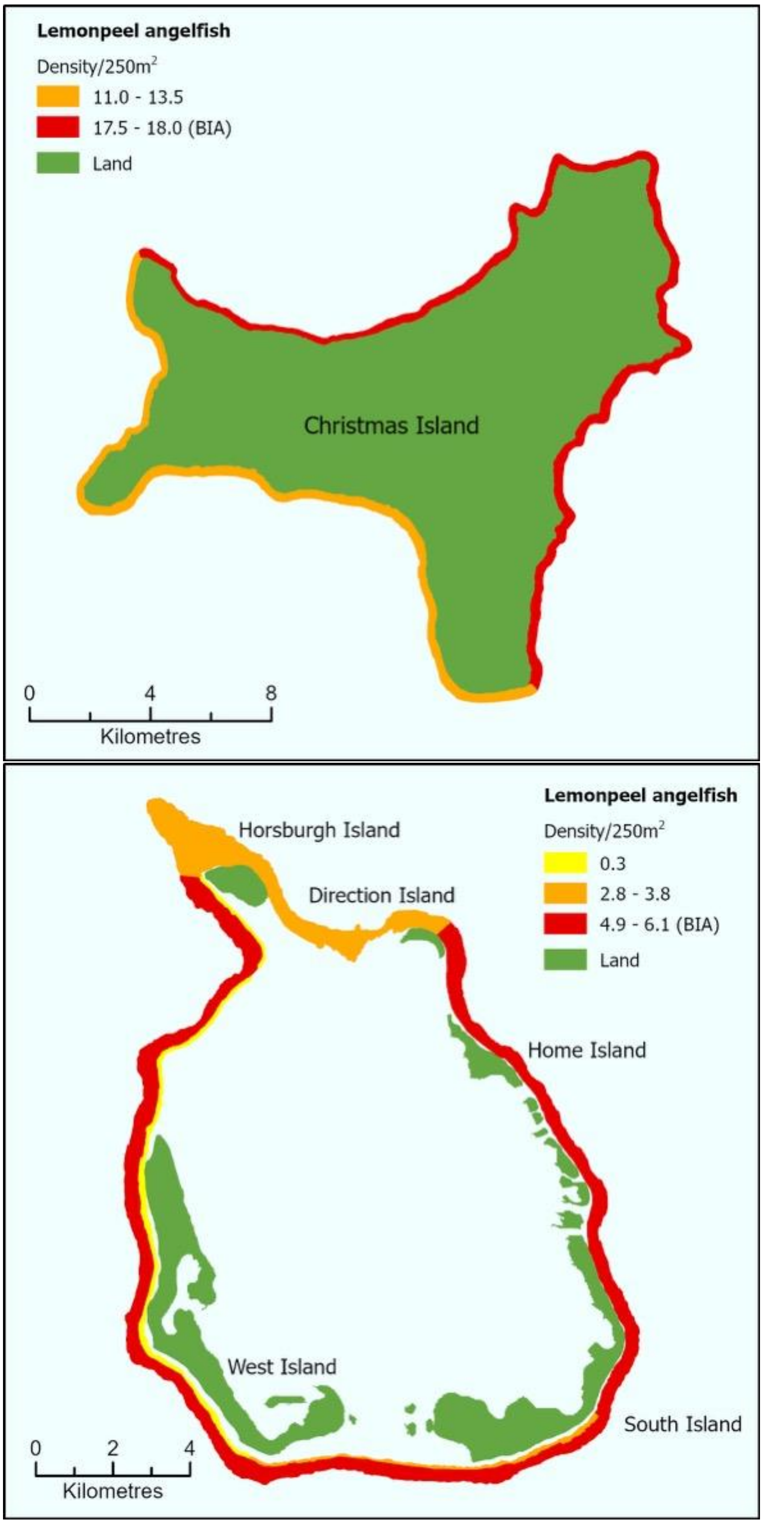


Figure 3.31. The distribution and abundance of the lemonpeel angelfish (*Centropyge cocosensis*) around CI (top) and CKI (bottom). The proposed BIAs are indicated in red and represent sections of outer reef slope that support the highest densities of lemonpeel angelfish. Data from Hobbs et al., 2010b; 2012; Hobbs unpubl. data.

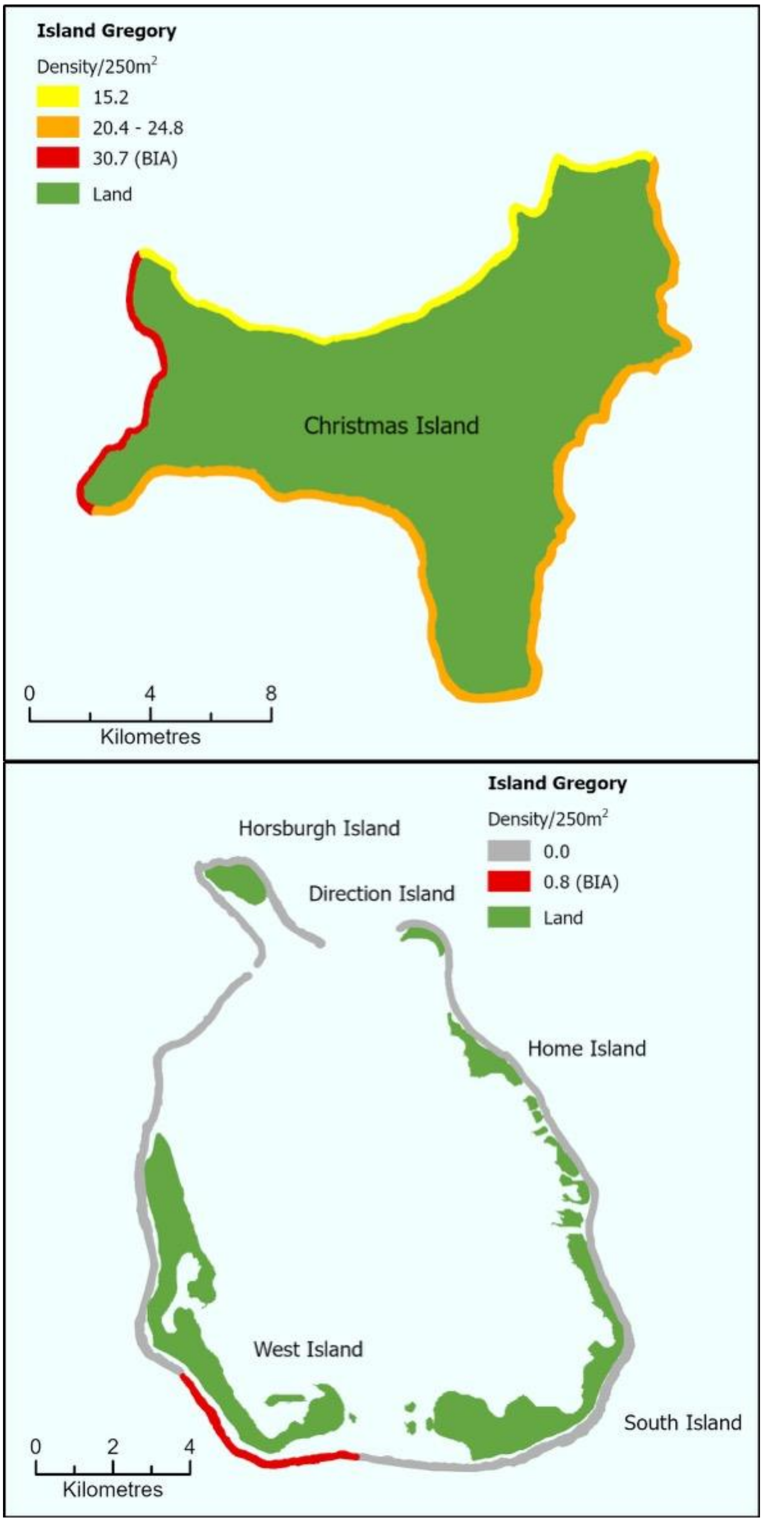


Figure 3.32. The distribution and abundance of the Island Gregory (*Stegastes insularis*) around CI (top) and CKI (bottom). The proposed BIAs (red) represent outer reef habitats that support the highest densities. Data from Hobbs et al., 2010b; 2012; Hobbs unpubl. data.

Table 3.4. The status, distribution and abundance of fishes endemic to the IOTs, based on average abundance recorded during dives of approximately 60 minutes and encompassing approximate 5000 m^2 (Common = > 5 per dive; moderately common = 2–5 per dive; uncommon = 0.5–2 per dive; occasionally seen = 0.2–0.5 per dive; seldom seen = 0.1–0.2 per dive; rare = <0.1 per dive). Sources: Allen et al., 2007, Hobbs et al., 2014b,c; Froese and Pauly, 2021; Hobbs unpubl. data.

Species	Status	CI	CKI
Lemonpeel angelfish, *Centropyge cocosensis*	Endemic to CI, CKI, NKI	Common	Common
Cocos angelfish, *Centropyge joculator*	Endemic to CI, CKI, NKI	Common	Common
Christmas dottyback, *Pseudochromis viridis*	Endemic to CI	Unknown	Not recorded
Christmas blenny, *Praealticus natalis*	Thought to be endemic to CI but may be more widespread	Common	Not recorded
Christmas eviota, *Eviota natalis*	Endemic to CI	Moderately common	Not recorded
Mottled sole, *Aseraggodes crypticus*	Endemic to CI	Unknown	Not recorded
Island Gregory, *Stegastes insularis*	Probably an endemic subspecies	Common	Rare at CKI and NKI
Anderson's Viviparous Brotula, *Microbrotula andersoni*	Endemic to CI	Unknown	Not recorded
Christmas viviparous brotula, *Paradiancistrus christmasensis*	Endemic to CI	Unknown	Not recorded

3.18 Other vulnerable and significant marine species

The IOTs support many listed species that have high significance due to their conservation importance. For example, 27 species of coral at CI are listed as *Vulnerable* by the IUCN and another 54 are classified as *Near Threatened* (Richards and Hobbs, 2014). The area that supports the greatest number of

Vulnerable and *Near Threatened* coral species at CI is in Flying Fish Cove (Figure 3.33, Richards and Hobbs, 2014). The same area in Flying Fish Cove also appears to be the most important for regionally unique fish species that are not found anywhere elsewhere in Australian waters, including species listed as *Vulnerable* by the IUCN (Hobbs et al., 2010b, Hobbs et al., 2014b,c). The reason Flying Fish Cove contains the highest number of unique species on CI is probably because the necessary resources and conditions to support the colonisation and persistence of these species (Hobbs et al., 2010; Richards and Hobbs, 2014). Compared to elsewhere on CI, Flying Fish Cove is the largest sheltered bay, contains the most sandy habitat and the most protected reef flat.

Due to its unique biogeographic location, the composition of reef fishes in the IOTs contains a unique mix of Indian and Pacific Ocean species that are of national and international significance (Hobbs et al., 2012; Bennett et al., 2018). The IOTs also represent the most north-western territory in Australia and consequently there are many species that are regionally unique in that they do not occur anywhere else in Australian waters. For example, more than 50 fish species in the IOTs are not found anywhere else in Australian waters (Allen et al., 2007; Hobbs et al., 2014 b,c). Species with similar geographic distributions are present in other groups (e.g. corals, molluscs, crustaceans: Morgan, 1994; Richards and Hobbs, 2014) and thus these species will also not be protected by management practices in other parts of Australia. Some deepwater reef fish (e.g. Yamakawai anthias and Russell's wrasse) at CI represent the only known populations in the Indian Ocean and are likely to be separate to the Pacific Ocean populations. Future genetic research may confirm they these unique populations are endemic species.

Most of our knowledge on the significance of marine species in the IOTs come from research on well-studied groups (e.g. fishes and seabirds). Given the similarities between reef fishes and most other marine groups (e.g. bipartite life cycle), and the shared evolutionary conditions in the IOTs (e.g. isolation and unique biogeographic position), we can expect endemic species to be present in less-studied groups. This prediction is supported by ongoing discovery of endemic species in terrestrial environment at CI (James et al, 2019), which indicates that if the marine groups received a similar level of research effort, many more endemics would be found. Many of the unique and listed species recently documented in IOT waters are large and conspicuous (e.g. Blotched Fantail Ray, Great hammerhead, silky shark, Pelagic thresher shark, Ocean sunfish, Hobbs et al 2010; 2014b,c). Thus, research on small and/or cryptic species and those inhabiting deeper (> 50 m) waters will likely lead to discoveries of new endemic species and increased recognition of the IOTs as a location with significant levels of marine endemism. Indeed, many groups known for their high species richness have not been adequately surveyed (Hobbs et al., 2014a). Where there has been dedicated research efforts, the results are impressive. For example, 1178 species of molluscs from 165 families have been recorded at CI and CKI, of which 45 are endemic to the IOTs (Tan and Low, 2014). Therefore, dedicated biodiversity surveys are required to fill in the knowledge gaps and provide a suitable level of understanding of the Biological Important Areas and Natural Values in the IOTs.

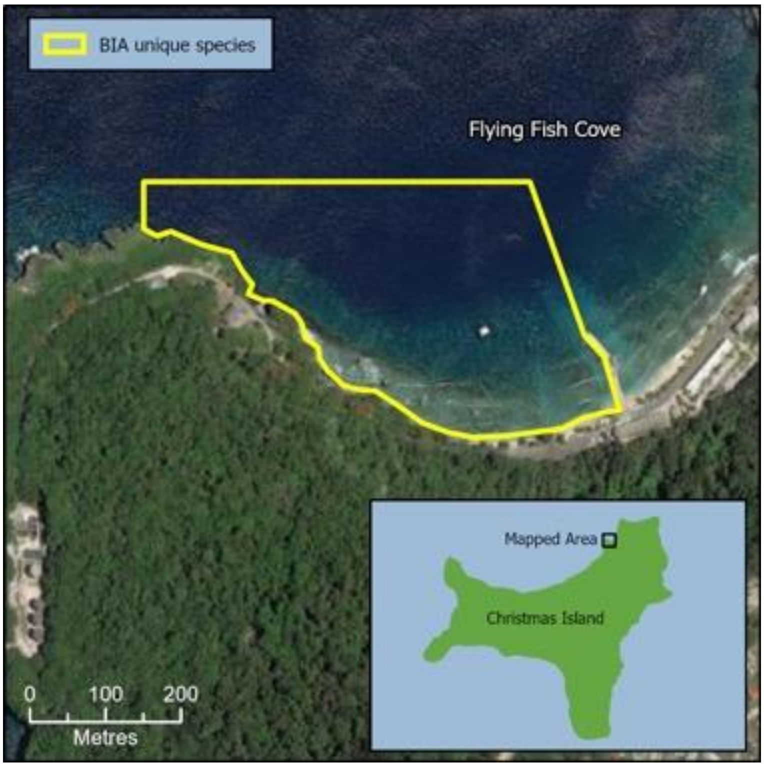


Figure 3.33. The proposed BIA (area delineated by the yellow line) for unique fish and hard coral species at CI. Of all the sites surveyed at CI, Flying Fish Cove has the highest number of coral species listed as *Vulnerable* and *Near Threatened* by the IUCN (data from Richards and Hobbs, 2014). This area also contains the highest number of unique fish species, which are not found anywhere elsewhere in Australian waters (Hobbs et al., 2010b, Hobbs et al., 2014b,c), and the highest number of hybrid fishes (Section 3.19).

3.19 Hybrid marine species

The IOTs contain the greatest number of known reef fish hybrid marine species in the world (Hobbs et al., 2009; Hobbs and Allen, 2014; Figure 3.34). This is largely due to its geographic position at the border of two marine bioregions. The coral reef communities in the IOTs represent a globally unique mix of Indian and Pacific Ocean species (Figure 3.35), and genetic studies will likely confirm many more hybrids are present in the IOTs, particularly in understudied groups. More hybrid reef fishes are seen at CI (15) compared to CKI (6) (Hobbs and Allen, 2014). At both locations, the most hybrids are observed on the north coast, and these coasts are proposed as BIAs (Figure 3.36). Within the BIAs, Flying Fish Cove at CI contains the greatest number of hybrids (15) of any location (Figure 3.35). Hybridisation is considered an important evolutionary process because it generates new genetic combinations. Some of these combinations may prove beneficial and help a species adapt. Consequently, new beneficial genotypes generated through hybridisation in the IOTs can spread (via larval dispersal) and be incorporated into populations elsewhere. Thus, it is important to conserve areas where natural hybridisation appears to be unusually prevalent.

Figure 3.34. A hybrid angelfish (*Centropyge cocosensis* x *C. eibli*). Photograph taken by Tane Sinclair-Taylor at CI.

Figure 3.35. A mixed-species breeding pair of butterflyfishes highlight the unique marine communities in the IOTs. At the top is the Pacific Ocean species (spotbanded butterflyfish, *Chaetodon punctatofasciatus*) and at the bottom is the Indian Ocean species (peppered butterflyfish, *Chaetodon guttatissimus*). These fish interbreed to produce hybrids. Photograph taken by Tane Sinclair-Taylor at CI.

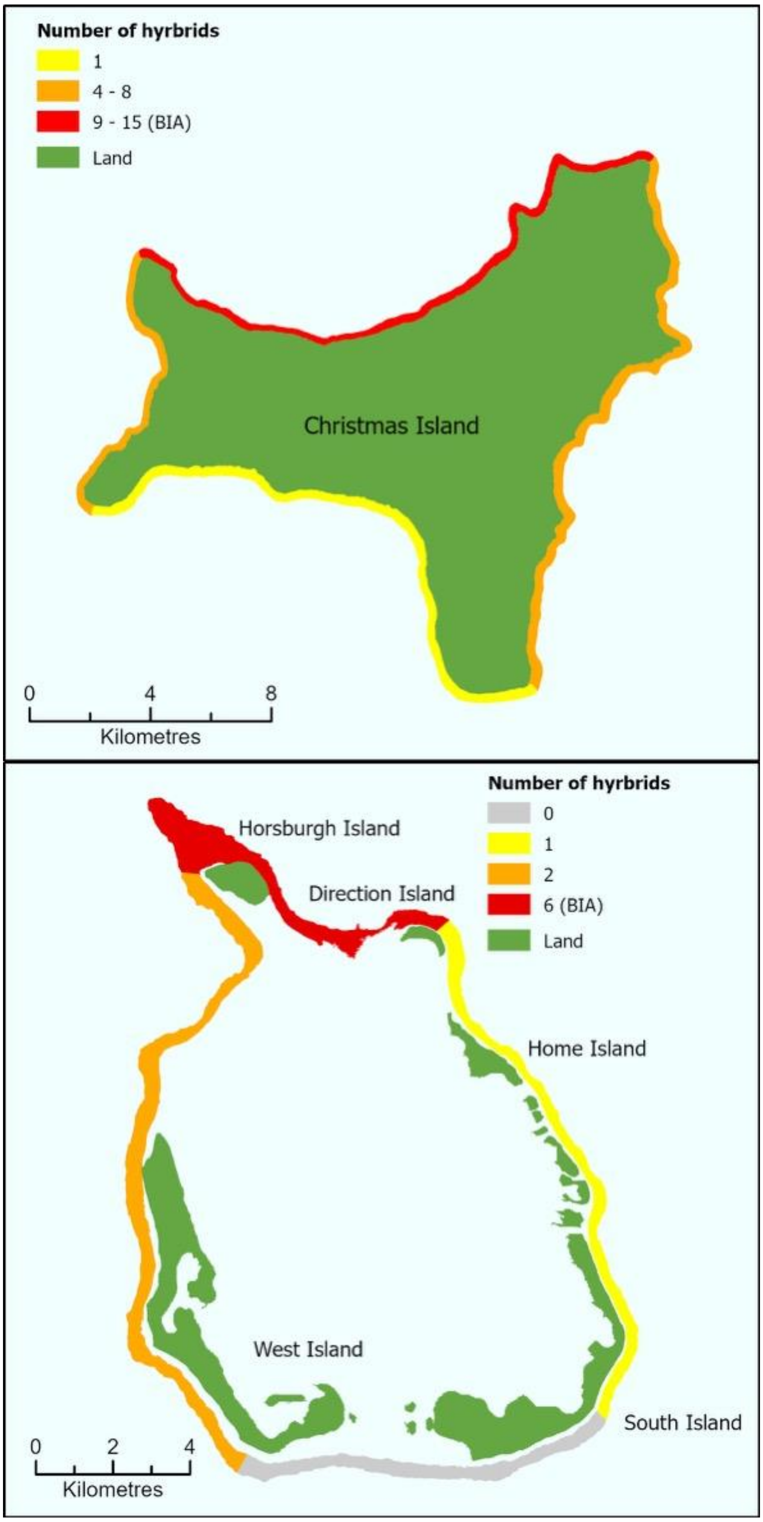


Figure 3.36. The distribution and abundance of hybrid reef fishes around Christmas Island (top) and South Keeling Island (bottom). The proposed BIAs are shown in red. Data from Hobbs et al., 2009a; Hobbs and Allen, 2014; Hobbs unpubl. data.

4. Inshore Marine Habitats and Key Natural Values

Key Natural Values (KNVs) are a concept used to support further identification of important areas, species or processes, which might ultimately establish monitoring priorities for Australian Marine Parks. KNVs are important natural features within marine parks, which also give consideration to cultural significance and social and economic benefits. They are generally identified at a finer scale than KEFs and BIAs. Given that BIAs give explicit focus to threatened species and associated habitats (Section 3), KNVs were largely identified as unique and important habitat features that are important in terms of overarching biodiversity or biomass of marine species. KNVs are not intended to necessarily represent entire habitat areas or coral reef zones. However, each of the distinct reef zones are important in their own right, such that independent inshore habitat areas are presented prior to describing the KNVs (see also Section 2). After outlining the distinct habitat types represented in inshore areas of the IOTs, two KNVs are highlighted, including the extensive fringing reef at Flying Fish Cove on CI, and extensive areas of shallow-water seagrass habitat, mainly at SKI.

Eight distinct coral reef zones are recognised from the IOTs (Table 4.1; Figures 4.1-4.3). These zones span from the intertidal to the deepest part of the mesophotic reef (150 m depth). There was a much greater diversity of reef zones at CKI (8) compared to CI (4). Furthermore, the total area between the intertidal to the deepest part of the mesophotic reef (150 m depth) at CKI (15,844 ha) was more than 5 times larger than CI (2806 ha). At CKI, the largest area was the inner lagoon flat (4819 ha) and deep lagoon (3888 ha). In contrast, the largest areas at CI were the mesophotic reef (2018 ha) and the outer reef slope (782 ha) (Figure 4.1). Similarly at NKI, the largest areas were the mesophotic reef (475 ha) and the outer reef slope (299 ha)(Figure 4.2).

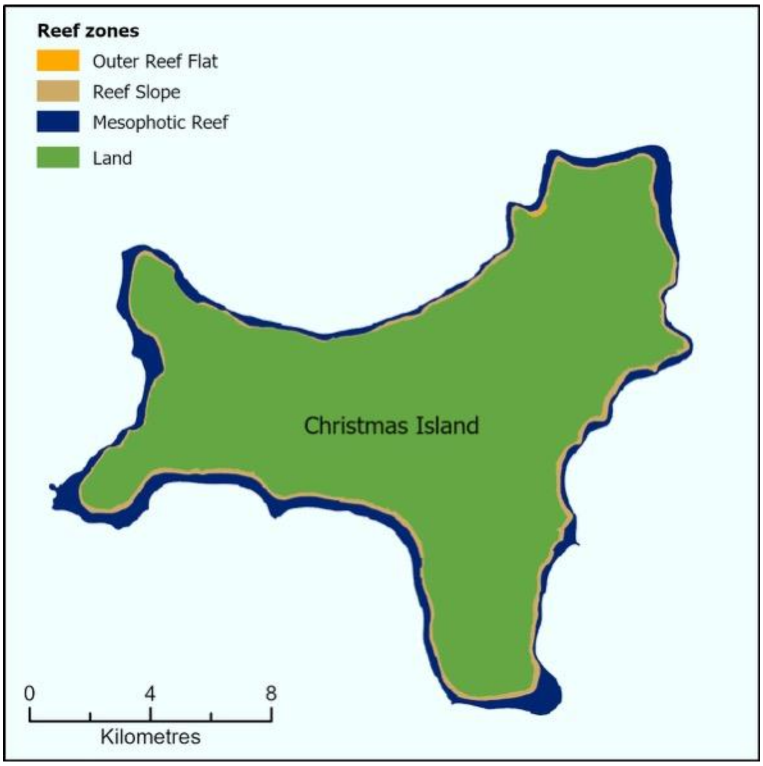


Figure 4.1. The extent of reef zones between 0 and 150 m depth at Christmas Island

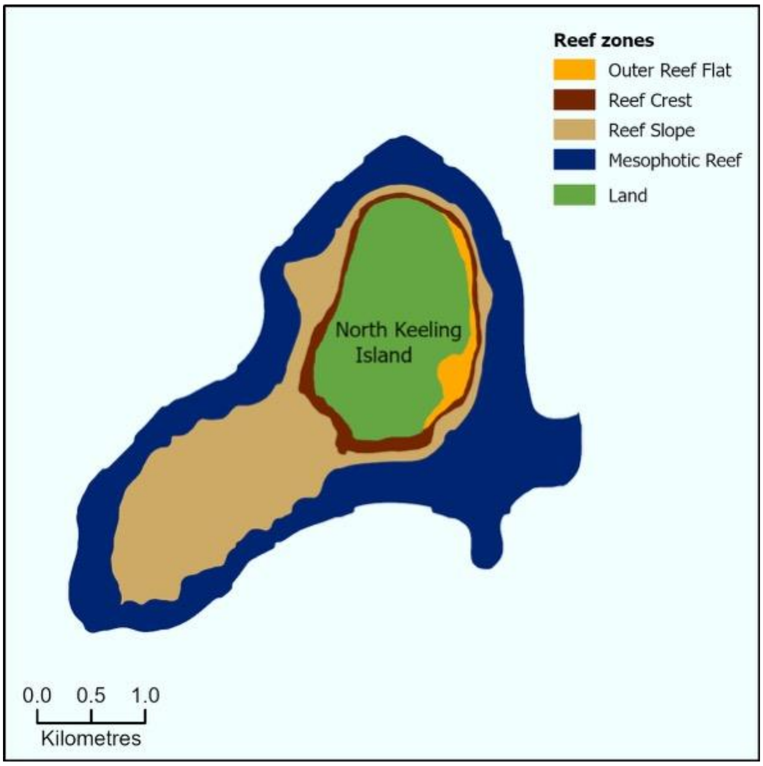


Figure 4.2. The extent of reef zones between 0 and 150 m depth at North Keeling Island

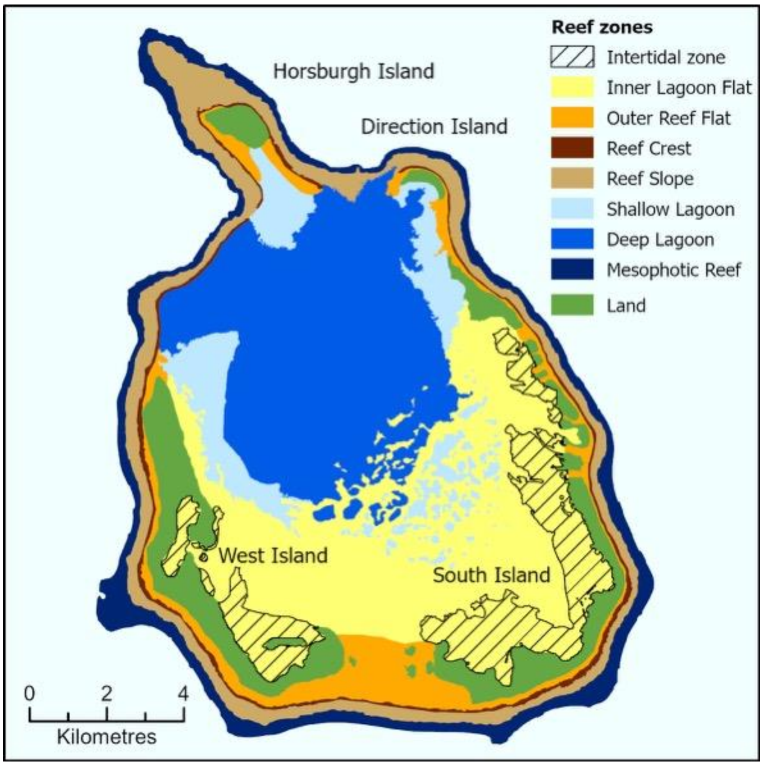


Figure 4.3. The extent of reef zones between 0 and 150 m depth at South Keeling Island

The reef zones were based on the classification scheme created for the global Allen Coral Atlas (ACA) project (Kennedy et al., 2021). The reef zones were first identified using a combination of low-tide Planet satellite imagery and bathymetric datasets. Satellite imagery and bathymetric data was used to assign zones in shallow (< 10 to 15 m) waters to ACA categories using a Random Forest classifier in Google Earth Engine. This broad-scale data was downloaded from the ACA map viewer (https://allencoralatlas.org/atlas) and used as a reference layer to create localised datasets for CKI and CI. The shallow water zones included: the inner lagoon flat (0 to 2 m depth); shallow lagoon (2 to 5 m depth); deep lagoon (> 5 m depth); outer reef flat (the area between the seaward coastline and the reef crest); the reef crest (the area seaward of the reef breaks that begins at the surf zone and extends seaward to the 5 m depth contour); and the outer reef slope (the area seaward of the reef crest from 5 to 30 m depth). These zones were then ground-truthed based on the field surveys and habitat maps (Williams, 1994; Hender et al., 2001; Gilligan et al., 2008), and through communications with local people. Bathymetric datasets were used to determine the intertidal zone (MSL to [MSL - 0.65m]) and the location and extent of the mesophotic reef (30 to 150m depth).

Table 4.1. The extent of marine zones in the IOTs. Extent is calculated as the area in hectares (ha), with percentages shown in brackets using the GDA 1994 MGA Zone 47 projection.

Habitat	CI (ha)	NKI (ha)	SKI (ha)
Intertidal zone			1,473 (11.9)
Inner lagoon flat			4,819 (39.0)
Outer reef flat	6 (0.2)	20 (2.4)	1,051 (8.5)
Reef Crest		44 (5.3)	357 (2.9)
Reef slope	782 (27.9)	299 (35.7)	1,524 (12.3)
Shallow lagoon			1,288 (10.4)
Deep Lagoon			388 (3.1)
Mesophotic reef	2,018 (71.9)	475 (56.7)	1,444 (11.7)
Total	2,806	838	12,344

4.1 Intertidal zone (SKI)

There are approximately 1,473 hectares of intertidal habitat (forming part of the inner lagoon flat) at the SKI. The maximum tidal range at CKI is 1.3m (Harper et al 2001), which equates to 0.65m either side of the Mean Sea Level (MSL). The intertidal areas at CKI were calculated as those areas between the estimated MSL (Australian Height Datum) and 0.65m below the MSL. These are the areas that are covered by water at high tide and uncovered at low tide. Most of the intertidal area occurs in inner flats of the eastern, south-east and south-west regions of the lagoon (Figure 4.3). The areas outlined in Figures 4.1-4.3 are predictions based on bathymetric models and do not take into account local hydrodynamics that can affect which areas become dry on low tide. Local hydrodynamics (e.g. currents through the inter-island channels in the southern lagoon) can change the height of the water, the strength of the tide, and move sediments (Kench, 1994; Smithers, 1994).

Common habitats in the intertidal areas of the southern lagoon include beaches, sand flats, rubble beds, seagrass beds (*Thalassia hemprichii*) and muddy-silty areas in the inner lagoon on West Island and innermost areas of South Island.

These intertidal habitats have a highly variable physical environment with large fluctuations in factors such as temperature, salinity and dissolved oxygen. Species residing in the intertidal zone must cope with these fluctuations and avoid desiccation. This can be achieved through physiological tolerances or seeking shelter in microhabitats (e.g. burrows). Many invertebrates reside in the intertidal area, including important species consumed by the local people e.g. mud crab (*Scylla* sp.), and night octopus (*Gurita malam*). As the tide rises, a different suite of species swim into the intertidal area. Important transient species that commonly visit intertidal areas to feed include: green and hawksbill turtles; black tip reef sharks; and fisheries targets such as bonefish, silveries and mullet. As the tide falls and the intertidal areas are uncovered, some land-based species will also visit the intertidal area. These include ghost crabs and hermit crabs, which are important species that are collected for bait. Within the intertidal areas, there are some pools of deeper water, particular in the areas between islands (e.g. "The Rip", Palu Maraya). On low tides, these pools become increasingly important as fish move out of the intertidal areas and aggregate in the pools.

4.2 Inner lagoon flat (SKI)

The inner lagoon flats represent the largest zone at CKI and contain a variety of habitats including areas of dense macroalgae, seagrass beds, rubble banks, sand banks, silty-muddy bays, and small isolated coral bommies. This shallow water habitat has low habitat complexity and can be a stressful environment particularly if there are episodes of calm weather during summer. When the water stagnates, its temperature rises and dissolved oxygen plummets resulting in mass mortality of many fishes and invertebrates (Hobbs et al., 2010; Hobbs and Macrae, 2012).

Invertebrate species that are common in the inner lagoon flats include sea cucumbers (*Holothuria atra*), gong gong, night octopus and mud crabs (*Scylla* sp.). Fishes that commonly use this area include bonefish, mullet, silveries, pufferfish and blacktip sharks.

4.3 Outer reef flat

From the coastline extending seaward to the reef crest (surf zone) is the outer reef flat. At SKI, the width of this zone varies from 30 to 700 m. The zone is characterised by shallow (0 to 2 m depth) clear water and is a high sunlight environment. The water can be fast moving during high tides and large surf. These conditions help push water across the reef flat and through the channels between the southern islands (Kench, 1994). This provides the main flushing (south to north) mechanism and source of water exchange for the lagoon (Kench, 1994). On low tide (tidal range 1.3 m, Harper et al., 2001) the water movement is greatly reduced, and many areas are exposed to air.

There are limited habitats in the outer reef zone. Most of this zone is reef pavement with low coral cover (typically < 10%) and low habitat complexity. Other habitats include a small number of boulders, rubble patches, and seagrass beds (on West Island). There are also occasional deeper holes in the reef flat, which often contain high concentrations of fish that are avoiding the strong currents or low tide. Species that are common on the reef flat include mobile predators (e.g. blacktip reef sharks, giant and bluefin trevally) and target species such as tridacnid clams, silveries, and emperors. On the inner and calmer sections, day octopus are common, while slipper lobsters and spiny crayfish are common on the outer sections where there is strong water movement.

4.4 Reef crest

Seaward of the outer reef flat is the reef crest, which is the area from the surf zone to the 5 m depth contour. This zone has the highest wave energy and water movement and is also a high light environment. The zone is primarily reef pavement and includes spur and groove formations in the sections exposed to a lot of swell (south and west coasts). The shallows parts are normally dominated by turfing and coralline algae, while the deeper sections can have moderate to high cover of soft and hard corals. While the reef matrix may contain many small holes, the overall complexity of the habitat is low.

Common mobile species in this zone include spiny crayfish (see Section 3.14), giant and bluefin trevally (Section 3.16), and parrotfish (particularly schools of adult bumphead parrotfish; Section 3.13). The endemic lemonpeel angelfish also occurs in this habitat. The Island Gregory, a damselfish endemic to Christmas Island (and Marcus Island), is rare at CKI, and the only place it has been recorded is in the reef crest zone on south-western corner of CKI (Hobbs unpubl. data).

4.5 Reef slope

Extending seaward from the reef crest is the reef slope which spans the depths of 5 to 30 m. This zone generally contains much less wave energy and water movement and sunlight is increasingly filtered out. The less extreme physical conditions allow for the development of a wide range of habitat forming organisms and greater habitat complexity. This zone usually supports a moderate cover and high diversity of scleractinian corals and high cover of soft corals (particularly on the south coast) (Hender et al., 2001; Bellchambers and Evans, 2013; Hobbs, unpubl. data).

This zone usually has the highest diversity of reef fishes. Common groups are damselfishes, butterflyfishes, angelfishes (including the endemic Cocos angelfish and lemonpeel angelfish), surgeonfishes, snappers, emperors, grey reef sharks, dogtooth tuna, and resting green and hawksbill turtles. Within this reef zone, the highest number of reef fish species occurs in the northwest region of the atoll (Figure 4.4, Hobbs et al., 2010, 2012; Hobbs unpubl. data). This area also supports the greatest biomass of fishes and large aggregations of trevally, snappers, emperors and coral trout (Hender et al, 2001; Hobbs, unpubl. data), which may represent spawning aggregations for at least some species.

Corals are the key habitat forming organism at CI and CKI, and seagrass also forms important habitat at CKI. Both these habitats are sensitive to changes in the condition and abundance of the key habitat-forming organisms (namely, seagrass and reef-building corals) and changes in the location, extent and composition of these habitats will impact other species that depend on these habitats for food, shelter or breeding. Given differences in the nature and extent of species' dependence on coral or seagrass (e.g., Pratchett et al., 2008) it is difficult to accurately predict which species will be most affected by changes in these habitats. Studies of species' responses to past mortality events (in the IOTs or elsewhere) are useful for identifying the species most dependent on coral and seagrass.

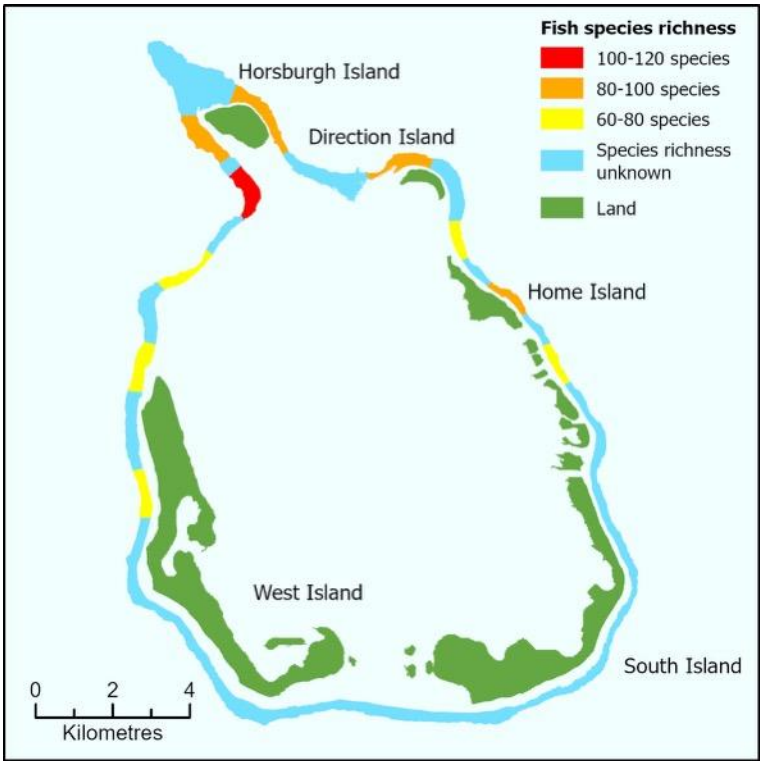


Figure 4.4. Patterns of species richness for reef fishes surveyed on the outer reef at CKI. Data is total number of species from well-studied groups: angelfishes, butterflyfishes, damselfishes, surgeonfishes, triggerfishes and wrasses (based on Hobbs et al., 2010, 2012; Hobbs unpubl. data).

Most of our knowledge of species' dependence on live corals comes from research on coral reef fishes. On the Great Barrier Reef (GBR), it estimated that 9% of reef fishes are directly dependent on live coral for food or habitat (Munday et al., 2007), though the proportion of species that are affected by broad-scale coral loss may be much greater, often approaching 60% (Pratchett et al., 2017). There is no reason to suggest that the reef fish communities in the IOTs are any more, or less, dependent on corals than in other coral reef regions. Previous research at CI shows that declines in live coral cover have led to population declines of coral gobies and corallivorous butterflyfishes, as well as local extinctions of the highly specialist coral-feeding harlequin filefish (Hobbs et al., 2010b; Hobbs, unpubl. data). These species are primarily dependent on live corals for shelter and/or food and have suffered the same fate elsewhere following coral mortality events (Munday 2004; Pratchett et al., 2008). These groups can be expected to decline the most following coral mortality events (e.g. coral bleaching). The endemic Cocos angelfish, lemonpeel angelfish, and Island Gregory are herbivores and do not rely directly on live coral, but do shelter within the 3-dimensional shelter provided by the reef matrix (Hobbs et al, 2010). Studies elsewhere show that declines in topographic complexity resulting from widespread coral loss affects many reef fish species (Pratchett et al. 2008, 2017), which could impact on many reef-associated endemic fishes that occur at CI and CKI (Allen et al., 2007).

4.6 Shallow lagoon (SKI)

In the southern lagoon is a large shallow area (1-5 m depth) that contains a mixture of habitats including sand flats, live coral bommies, dead coral patches, algae patches, coral rubble beds, and the southern-most blue holes (inner lagoon flat and shallow lagoon zones; Figure 4.3). This area supports a wide range of species, including fisheries target species (such as gong gong, mud crabs, painted crayfish, bonefish, emperors). Common invertebrates in the shallow lagoon include sea cucumbers (e.g. *Holothuria atra*) on the sandy areas and painted crayfish are often found under large *Porites* bommies. Important fisheries species also include invertebrates such as gong gong and tridacnid clams. Common fish species include blacktip reef sharks, emperors and coral trout. This area appears to be a nursery area for many fish species, particularly humphead Maori wrasse, bumphead parrotfish and squaretail coral trout.

The shallow lagoon area at SKI is reliant on periodic flushing (Kench, 1994) and is heavily impacted by changes in environmental conditions during prolonged periods of limited flushing. Notably, this was the worst affected area during mass mortality events (Hobbs and McDonald, 2010, Hobbs and Macrae, 2012), and has seen rapid and catastrophic loss of live coral habitat in recent years (see Section 5.1). The area is also subject to lagoonal infilling (Smithers, 1994), a process that caused major loss of habitat and mobile species at NKI (Section 4.10). This area is important due to its uniqueness, the provision of nursery habitat for many species, and its vulnerability to changes in hydrology and climate.

The shallow lagoon includes the small blue holes in the southern lagoon. The waters in this habitat are usually calm, but turbid. Typically, these blue holes have extensive coral growth around the margins and coral rubble and silt in the centre. Historically, live coral cover was high (>40%, Hender et al., 2001; Evans et al., 2016). However, around 2012-13 there was a significant coral mortality event and coral cover decreased to almost 0% (Evans et al., 2016). The cause was not able to be determined but may have been related to freshwater input from a heavy rainfall event (Evans et al., 2016).

4.7 Deep lagoon (SKI)

The deep lagoon includes the deeper “blue holes” in the centre of the lagoon and the deep habitats in the northern lagoon. The water here is less turbid than the shallow lagoon and was not affected as much by the 2012-13 coral die-off that impacted the shallow lagoon (Evans et al., 2016; Hobbs unpubl. data). Areas of seagrass (*Thalassodendron ciliatum* and *Syringodium isoetifolium*) are present in the far northern lagoon (Williams, 1994). Tridacnid clams are common in this reef zone (Hender et al., 2001). For fishes, grey reef sharks are very common in this area, as are a range of target fishes including squaretail coral trout, humphead Maori wrasse, emperors, and snappers (Hender et al, 2001; Hobbs unpubl. data).

4.8 Mesophotic reefs

Extending further down the outer reef slope is the mesophotic zone from 30 to 150 m. This environment is characterised by very low light, and consequently many scleractinian corals and algae cannot persist is these conditions. With increasing depth, the habitat becomes dominated by seawhips and gorgonians (Figure 4.5), which support unique communities of fishes. Common species in this habitat include deepwater angelfishes and butterflyflshes and predatory fishes like cods and coronation trout. The endemic Cocos angelfish extends to 70m depth, but the lemonpeel angelfish usually occurs in reef habitats above 50m depth (Hobbs, unpubl. data).

Beyond the mesophotic zone the reef slope continues into an environment that lacks light. Little is known about the habitat in this zone. However, local fishers have caught a wide range of interesting fishes from the deep reef slope between 150 to 500 m deep. These include deepwater cods, jobfishes and sepat, which are species that form the basis of valuable fisheries in other locations. Thresher sharks have also been caught at this depth.

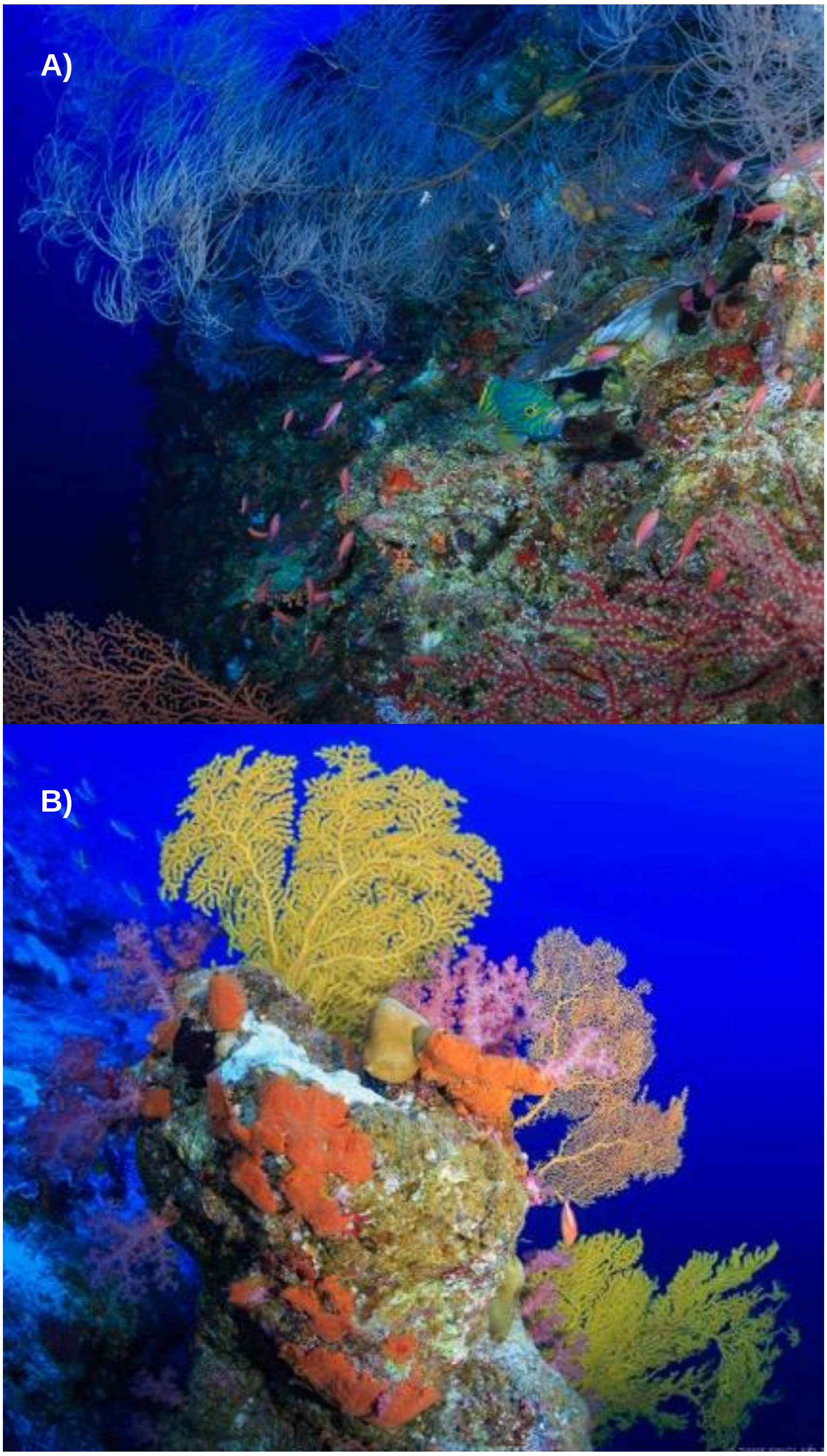


Figure 4.5. Mesophotic reefs at A) Christmas Island, 60 m depth and B) Cocos Keeling Islands, 50 m depth. Photographs by Tane Sinclair-Taylor.

4.9 Flying Fish Cove (CI)

The extent and diversity of marine habitats is very limited at CI (especially compared to CKI), largely due to the generally narrow (< 200 m) fringing reef and steeply sloping reef slope. This limited extent of reef habitat inherently limits the abundance and biomass of reef species (Gilligan et al., 2008). However, there is extensive fringing reef at Flying Fish Cove (Figure 4.6), representing the greatest extent of shallow coral reef habitat at CI, including the only notable section of reef flat. Flying Fish Cove has highest diversity of corals recorded at CI, including many species not found elsewhere around the island (Richards and Hobbs, 2014; Figure 4.7). This unique environment and diverse coral community provides a wide range of habitats that are likely to support high diversity of other marine groups. For example, the Flying Fish Cove supports the highest number of fish species (Figure 4.8), unique and hybrid fishes at CI (see also Section 3.18).

Figure 4.6. The reef flat at Flying Fish Cove. This marine habitat is rare at Christmas Island and supports a unique community of corals and fishes.

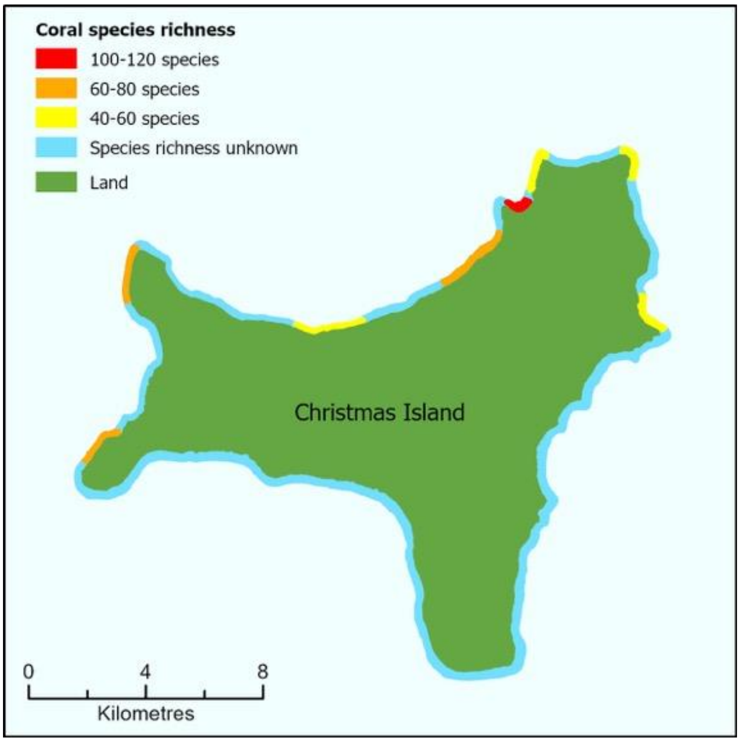


Figure 4.7. Patterns of species richness for hard corals on the outer reef at Christmas Island. Data from Richards and Hobbs (2014).

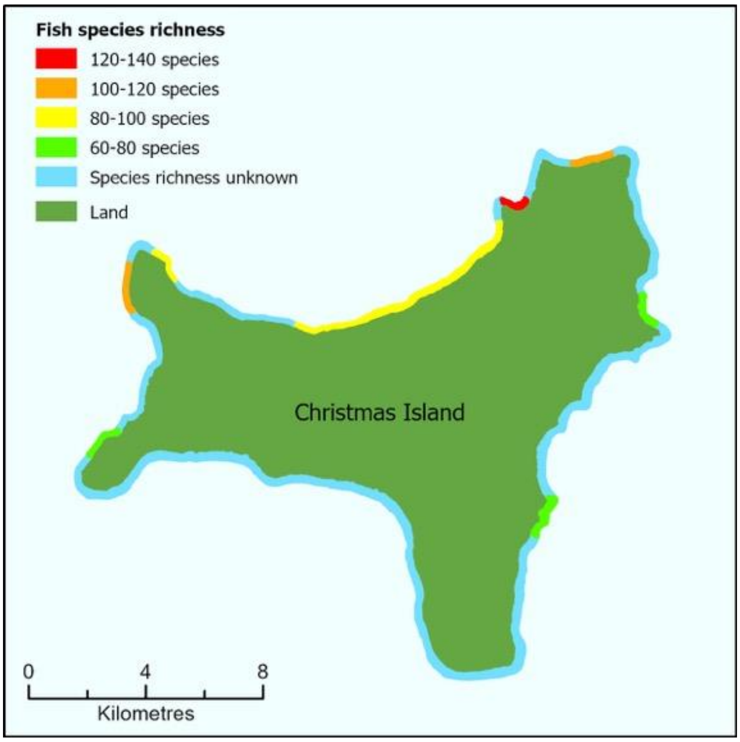


Figure 4.8. Patterns of species richness for reef fishes surveyed on the outer reef at Christmas Island. Data is total number of species from well-studied groups: angelfishes, butterflyfishes, damselfishes, surgeonfishes, triggerfishes and wrasses (based on Hobbs et al., 2010, 2012; Hobbs unpubl. data).

4.10 Seagrass habitat (SKI)

Seagrass is a key habitat because it supports many species, including listed vulnerable species (e.g. green and hawksbill turtle – Section 3.2; pipefishes – Section 3.3) and important fisheries species (see Section 2.1). Seagrass habitat is also highly vulnerable to a range of anthropogenic pressures and subject to change (Waycott et al., 2009; Buckee et al., 2021). At SKI in the 1990s, Williams (1994) and Smithers (1994) mapped approximately 1,500 hectares of seagrass comprised of three species (Buckee et al., 2021). The most abundant seagrass, *Thalassia hemprichi*, formed dense cover in the shallow (depth <2 m) inshore lagoon, particular in the southeast and western areas. It was also recorded in a narrow fringe along the outer reef flat of West Island. *Thalassodendron ciliatum* was documented in an area of the northern lagoon (depth 2-8m), while small areas of *Syringodium isoetifolium* were found near Direction and Home Islands (Figure 4.9). Macroalgae (*Caulerpa* spp.) was commonly mixed in with the seagrass, particularly the *Thalassia hemprichi* beds in the lagoon (Williams, 1994; Hender et al., 2001; Buckee et al., 2021).

Over the past 25 years there has been a marked decline in the extent and density of seagrass. Buckee et al. (2021) estimate that up to 80% (~1200 ha) of seagrass habitat has been lost in the lagoon at SKI, largely due to contractions in the areal extent of *T. hemprichi*. The loss of seagrass has been attributed to an accumulation of impacts including: episodic die-off events (due to hot calm weather in summer), sediment disturbance, and increased turbidity (Buckee et al., 2021). In addition, the loss of seagrass appears to be exacerbated by overgrazing of the remaining seagrass by the large population of turtles (Buckee et al., 2021). This overgrazing by turtles could prevent recovery of seagrass beds and lead to functional extinction, as has happened in other remote atolls (Gangal et al., 2021).

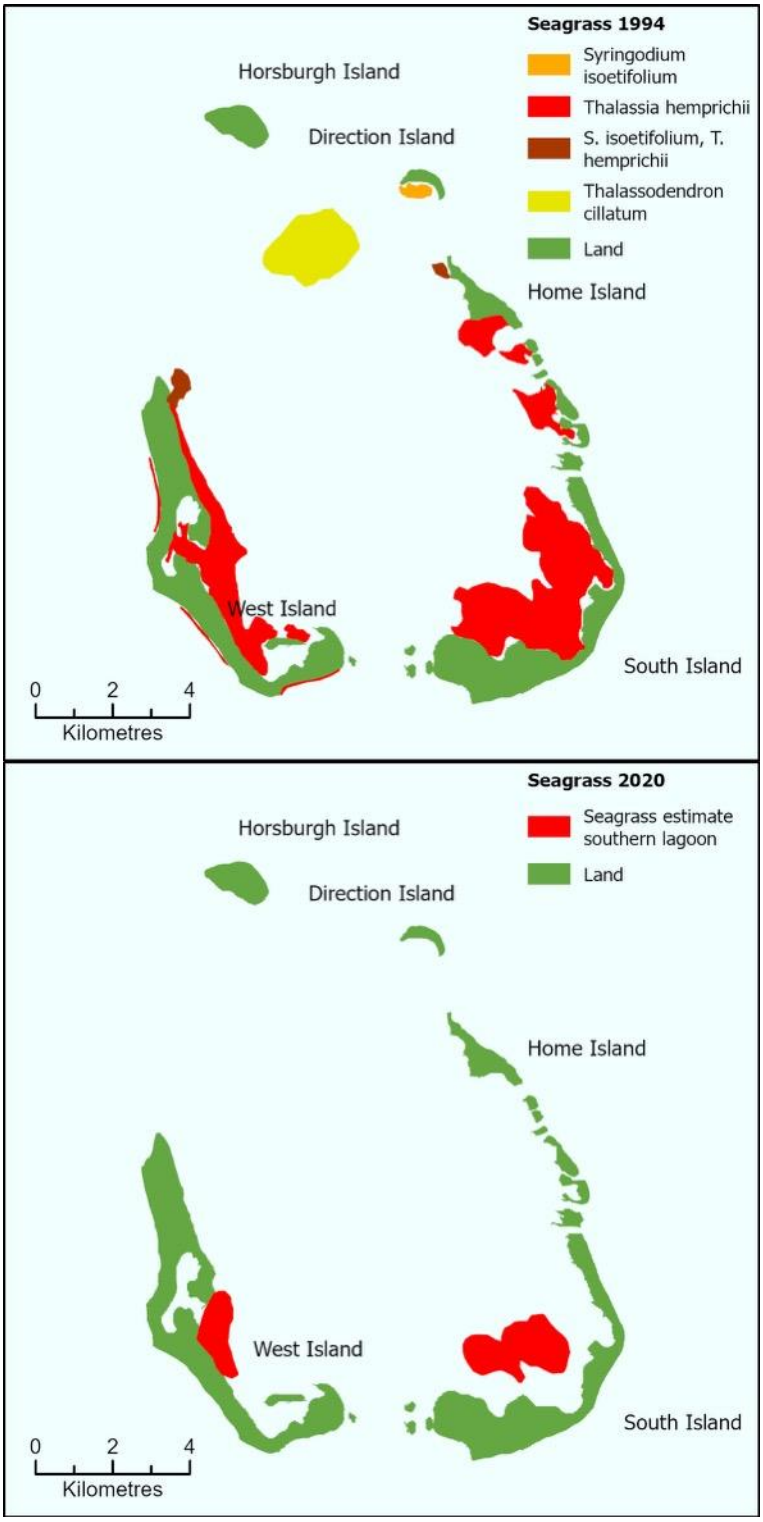


Figure 4.9. The extent and location of seagrass habitat at South Keeling Island in 1994 (Williams, 1994; Smithers, 1994) and 2020 (Buckee et al., 2021). Note that the presence and extent of seagrass patches in the northern lagoon and outer reef flat in 2020 is unknown and not mapped.

The loss of seagrass habitat will likely have important consequences. Critically, seagrass provides food and habitat for significant marine species, as well as contributing to primary production, carbon sequestration, reduced wave energy, trapping sediment, and preventing coastal erosion (Costanza, 1997; Nordlund et al., 2016). Prior to their decline, seagrass beds at CKI supported at least 70 species from 26 families of fishes (Cocos Senior High School, 1999; Buckee et al., 2021). This included listed marine species (e.g. *Micrognathus andersonii* - Anderson's pipefish) and fisheries target species (e.g. *Arothron hispidus*). The impacts of seagrass loss on other species has not yet been examined. In other coral atolls, the loss of seagrass beds and lack of recovery due to turtle overgrazing resulted in large declines in fish abundance, biomass and diversity, and in sediment-stored carbon (Gangal et al., 2021; Figure 4.10).

Thalassia seagrass is a major and important component of the diet of green turtles (*Chelonia mydas*) at CKI (Whiting et al., 2014), and its decline will impact on the resident turtle population (Buckee et al., 2021). The green turtles that nest on NKI are non-migratory and the breeding success of this discrete population is dependent on the food availability throughout the CKI (Whiting et al., 2008; Whiting et al., 2014; Buckee et al., 2021). Notably, the loss of seagrass in the southern atoll is a key threatening process to this listed species (Vulnerable – EPBC Act, Endangered - IUCN Red List).

Green turtles also fed on the seagrass (*Thalassia hemprichi*) in the lagoon at NKI. The seagrass was distributed throughout the lagoon (60 hectares) up until 2005, when the only entrance to the lagoon closed over with sand and conditions within the lagoon deteriorated (Hobbs, 2009; Hobbs and Newman, 2016). The entrance has not re-opened and the increasing build-up of sand has been colonised by plants. The NKI lagoon is recognised as a *Wetland of International Importance* under the Ramsar Convention. Most of the marine species that originally inhabited the lagoon and its seagrass beds appear to have declined in abundance or gone locally extinct (Hobbs and Newman, 2016). This includes mud crabs (*Scylla* sp.), and at least 20 other fish species such as: *Albula glossodonta*, *Crenimugil crenilabis*, *Epinephelus fuscoguttatus*, *Gerres acinaces*, *Liza vaigiensis, Lutjanus fulvus, L. monostigma* and species of trevally (Carangidae), emperor (Lethrinidae) and goatfish (Mullidae) (Hobbs, 2009; Hobbs and Newman, 2016). The endemic buff-banded rail (*Gallirallus philippensis andrewsi*), which is listed as endangered under the EPBC Act, used to forage on seagrass-associated crustacea (Cochrane, 2004). While this species appears to have adjusted its diet and its abundance seems stable despite the loss of seagrass (Director of National Parks, 2015), it is unknown what impact the lagoon closure has had on the other species (e.g. crabs, plants, seabirds) at NKI.

Figure 4.10. Short blades of seagrass (*Thalassia hemprichii*) in the shallow southwest lagoon at SKI are indicative of overgrazing by turtles. Photo JP Hobbs.

5. Important Knowledge Gaps and Future Research

While there has been significant and increasing research on shallow, nearshore marine systems within Australia's IOTs, highlighting the unique and important marine species, environments and habitats within this region (Pratchett et al. 2013; Hobbs et al. 2014a), the extent of marine research at CI and CKI lags behind that of other comparable, isolated, oceanic systems. There is also a strong taxonomic bias in existing research, whereby most published studies on the biology and ecology of marine species from CI and CKI relate to sea birds (43% of publications) and land crabs (13% of publications), while there has been very limited research on plankton or non-coral benthic invertebrates (Hobbs et al. 2014a). There is also a noticeable lack of experimental marine studies, necessary to improve understanding of the structure and function of marine communities and habitats across the IOTs. This knowledge is particularly important for addressing threats posed by increasing environmental change and other anthropogenic pressures (Hughes et al., 2017; Buckee et al., 2021).

5.1 Coral health and reef condition

Coral reefs are an important and dominant habitat in shallow marine environments across the IOTs, especially at CI. However, coral reefs are globally threatened by increasing environmental change and other anthropogenic pressures (Heron et al., 2016, Hughes et al., 2017). Despite being some of the most isolated coral reef ecosystems in the world (Evans et al., 2016), coral reefs at CI and CKI have also been exposed to significant disturbances, increasingly caused by environmental change (Hobbs and McDonald, 2010, Hobbs and Macrae, 2012, Hobbs et al., 2012; Evans et al., 2016; Hughes et al., 2017; Gilmour et al. 2019; Martinez-Escobar and Mallela, 2020). Accordingly, provisional and periodic monitoring of coral cover at various sites around CI and CKI (e.g., Hender et al., 2001; Evans et al., 2016; Mallela 2020a,b) reveals extensive coral loss in the lagoon at SKI (Figure 5.1). During the same period, high levels of coral cover (>40%) were recorded at many sites on the outer reef at CI and CKI and coral cover appears largely unchanged since 2015 (Figure 5.1). Notably, CI has high coral cover that was consistently above 50% (Davies and Hueston; 2007; Gilligan et al., 2008; Mallela 2020a). The severe bleaching event in 2016 caused significant coral bleaching

(Hughes et al., 2017); however, the coral loss was minimal and has increased since 2015 (Mallela, 2020a).

The data extracted from a combination of previous surveys of coral assemblages at CKI (e.g., Hender et al. 2001; Evans et al., 2016; Hobbs, unpubl. data; Mallela, 2020b) indicate coral cover on the outer reef has increased over the past 15 years and remains high (>30%). The 2016 mass coral bleaching event caused minor bleaching and no obvious coral mortality at CKI (Hughes et al., 2017; Gilmour et al., 2019). The monitoring surveys do reveal systematic declines in coral cover inside the lagoon at SKI in 2012-13, that has remained very low (effectively 0% coral cover) at the southern sites (Evans et al., 2016; Hobbs, unpubl. data). The cause of this decline was undetermined but may have been due to a heavy rainfall event (Evans et al., 2016). Such major declines in coral cover may have far reaching consequences for the structure of these lagoonal habitats, including shifts in the composition of coral assemblages, and potentially also lead to localised declines (or extirpation) of coral dependent species (Pratchett et al. 2008; Hobbs et al., 2010b). A key priority for future research is therefore, to build on baseline surveys of shallow reef habitats (Hender et al. 2001; Evans et al., 2016) and systematically monitor changes in the structure of reef habitats and abundance of reef-associated organisms at an increased range of fixed sites.

Routine monitoring of dominant and conspicuous coral reef fauna is fundamental in advancing knowledge of isolated coral reef environments in Australia’s Commonwealth Marine Parks (Hoey et al., 2020), but should also be complemented with experimental studies to advance understanding of key ecosystem process (e.g., coral settlement and replenishment) and more comprehensive surveys across a wide range of poorly studied taxa and habitats. There is also very limited knowledge of potential changes in seawater chemistry, and corresponding changes in the performance of calcifying organisms, which may belie important emerging effects of ocean acidification.

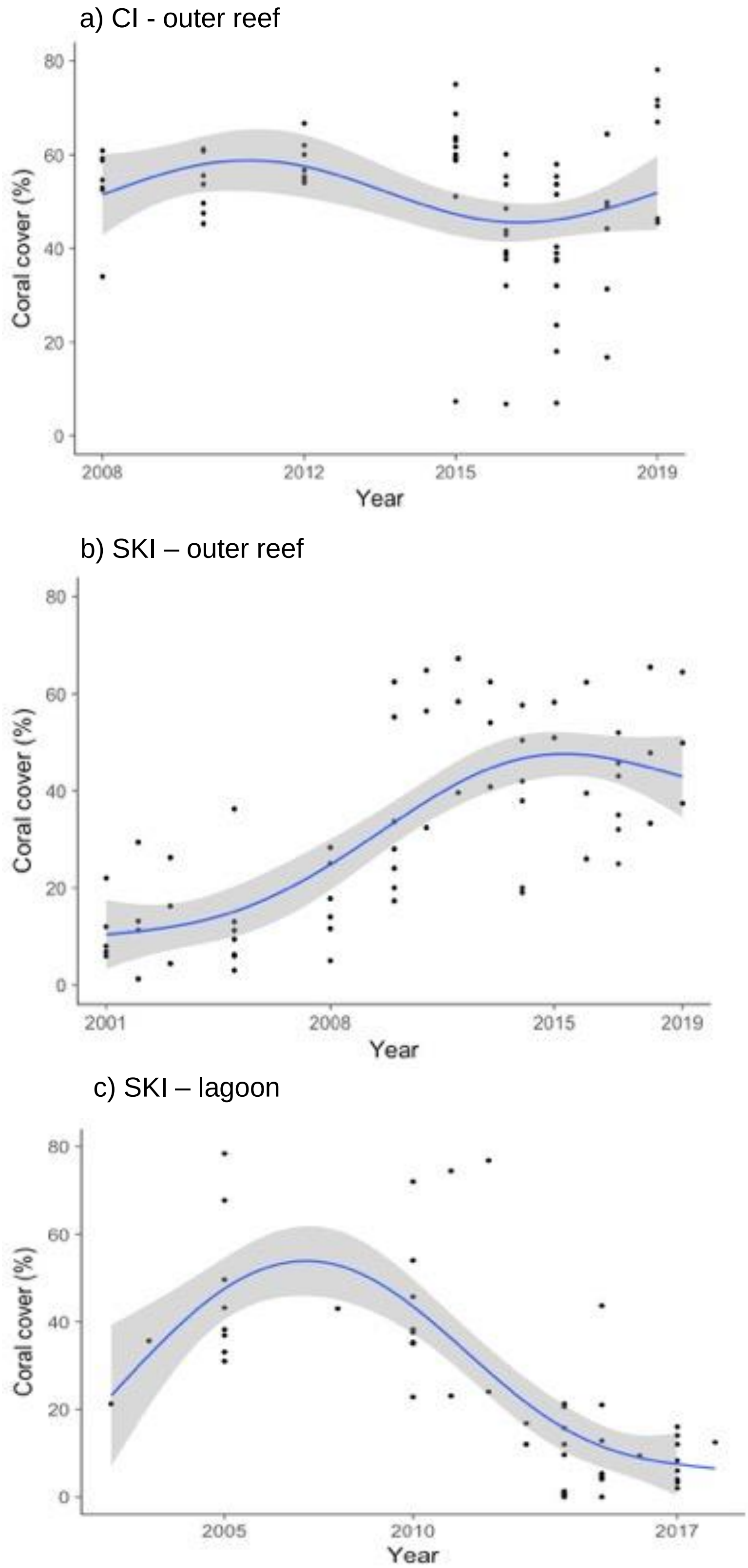


Figure 5.1. Temporal changes in coral cover (%) for a) outer reef slope at CI, b) the outer reef at SKI, and c) inside the lagoon at SKI. Data sources: Hender et al. 2001; Evans et al., 2016; Hobbs, unpubl. data; Mallela, 2020a,b.

5.2 Ecology and structure of mesophotic coral reefs

While research on coral reefs is traditionally focussed in areas of relatively shallow habitat (for practical and logistical reasons) mesophotic coral reefs (reefs at depths of 30 m to 150 m) are receiving increasing scientific attention (Lesser et al., 2009; Bridge et al., 2013), because they may represent vast areas of coral reef habitat. At CI and CKI, for example, the area of mesophotic reef habitat is equivalent (and in some cases much greater) than the overall extent of shallow reef habitats (Table 4.1). These deep reef areas, and surrounding seamounts (e.g. Muirfield), are likely to support many endemic species (Brewer et al., 2009). Mesophotic reefs may also provide refuge for shallow reef species to increasing temperatures under climate change, and a potential source of larvae to repopulate shallow habitats following disturbances (e.g., coral bleaching). Given that virtually nothing is known about the mesophotic reefs throughout the Indo-west Pacific (Kahng et al., 2010), this serves as a potentially fruitful area of future research at the IOTs and would complement similar research being undertaken in the Coral Sea. Notably, improved performance and increased availability of remote operate vehicles (ROVs) allow for efficient and effective monitoring of coral reef environments to a depth of >100 m. Extending surveys of coral reef habitats beyond the normal safe diving limits will provide much greater appreciation of the diversity and structure of coral reef habitats on oceanic seamounts.

5.3 Improved taxonomic resolution of marine species

Despite their isolation, the oceanic islands of CI and CKI are traditionally reported to have relatively low levels of endemism (e.g., Woodroffe and Berry, 1994; Brewer et al., 2009), possibly due to their relatively recent emergence and highly disturbed history. However, there have been sustained increases in the discovery and recognition of endemic species at CI throughout the last century (James et al. 2019), suggesting the levels of island endemism may have been grossly underestimated. Similarly, it is likely that more detailed surveys of marine habitats (e.g., across a broader range of unexplored habitats, such as the anchialine caves), and more refined assessments of taxonomic identity (e.g., molecular sampling of local populations and at other nearby locations) are likely to reveal more endemic species (Table 3.4), which make the IOTs a regionally significant area of unique marine biodiversity. Critically, many of the recently discovered and rediscovered terrestrial endemics at CI are threatened species (James et al., 2019), by virtue of their limited geographic range and increasing threats to natural habitats. Many endemic and threatened terrestrial species (e.g. seabirds and land crabs) rely on the marine environment; however, the nature of this dependence and the interactions with marine species are largely unknown. For example, there is no data on the spatial and temporal distribution of land crab larvae in the waters around CI, despite the potential importance of this seasonal influx to the marine ecosystem (Davies and Beckley, 2010), and the importance of larval survivorship for land crab populations and the critical functions they play in the terrestrial ecosystem on CI. Therefore, developing larval identification guides and designing a suitable marine survey method will be required to fill this knowledge gap. Effectively documenting the full range marine endemic species is important to understand the unique marine biodiversity in the IOTs and what is at risk with environmental change and habitat degradation.

5.4 Revised analyses of sediment composition and dynamics in the SKI lagoon

Given its' regional significance and apparent changes in habitat structure, renewed analyses of the geomorphic structure and dynamics of the lagoon at South Keeling (Cocos) Islands needs to be a key priority of future research. Importantly, comprehensive sampling of sediment composition (e.g., Smithers et al., 1992) provide a very useful baseline for assessing subsequent changes in sediment composition and dynamics, which may have played a part in the apparent declines in the areal extent of seagrass habitats within the SKI lagoon (Buckee et al. 2021). Determining how changes in sediment dynamics affect shallow lagoonal habitats is also important to understanding threats and population viability of species that rely on these habitats (e.g. turtles, gong gong, coral trout, reef sharks, parrotfish). Notable changes in sediment dynamics at NKI have caused significant changes in populations of lagoonal species, including local extinctions (Hobbs 2009; Hobbs and Newman, 2016). Changes in sediment dynamics have also affected the distribution and extent of habitats and islands at SKI (e.g. the loss of Prison Island). There are now much more advanced methods that will allow for a greater understanding of the current status and potential vulnerabilities of this important area, and the diversity of habitats and biological important species that it supports.

6. References

Adamczewska AM, Morris S (2001) Ecology and behavior of *Gecarcoidea natalis*, the Christmas Island red crab, during the annual breeding migration. *The Biological Bulletin* 200(3):305-320.

Alder J, Hilliard R, Hipkins M & Pobar G (1996) Christmas Island: draft integrated marine management plan. Report for the Australian Nature Conservancy Agency, LeProvost Dames and Moore and Whelans, Mount Hawthorn, Western Australia.

Ali JR, Aitchison JC (2020) Time of re-emergence of Christmas Island and its biogeographical significance. *Palaeogeography, Palaeoclimatology, Palaeoecology* 537:109396.

Allen GR (2000) The fishes of Christmas Island, Indian Ocean. *Records of the Western Australian Museum* Supplement No. 59: 83-95.

Allen GR, Smith-Vaniz WF (1994). Fishes of the Cocos (Keeling) Islands. Atoll Research Bulletin 1994:412.

Allen GR, Steene RC, Orchard M (2007) *Fishes of Christmas Island*. Second Edition. Christmas Island Natural History Association, Christmas Island, Australia.

Armstrong, AJ, Armstrong, AO, Bennett, MB, McGregor F, Abrantes KG, Barnett A, Richardson AJ, Townsend KA, Dudgeon CL (2020). The geographic distribution of reef and oceanic manta rays (*Mobula alfredi* and *Mobula birostris*) in Australian coastal waters. *J Fish Biol*. 96: 835–840.

Australian Fisheries Management Authority (2019) Reassessment Southern Bluefin Tuna Fishery July 2019. Australian Fisheries Management Authority (AFMA) Submission - Environment Protection and Biodiversity Conservation Act 1999. Australian Government, Canberra.

Australian State of the Environment Committee (2001) Australia State of the Environment 2001, Independent Report to the Commonwealth Minister for the Environment and Heritage. Department of the Environment and Heritage, Canberra.

Bellchambers LM, Evans SN (2013) A Summary of the Department of Fisheries, Western Australia Invertebrate Research at Cocos (Keeling) Islands, 2006-2011. Fisheries Research Division, Western Australian Fisheries and Marine Research Laboratories.

Bellchambers LM, Meeuwig JJ, Evans SN, Legendre P (2011)Modelling habitat associations of the common spider conch in the Cocos (Keeling) Islands. *Marine Ecology Progress Series* 432:83-90.

Bellwood DR, Hughes TP, Folke C, Nyström M (2004) Confronting the coral reef crisis. Nature 429(6994):827-833.

Bellwood DR, Hughes TP, Hoey AS (2006) Sleeping functional group drives coral-reef recovery. *Current Biology* 16(24):2434-2439.

Bennett S, Halford AR, Choat JH, Hobbs JPA, Santana-Garcon J, Ayling AM, Harvey ES, Newman SJ (2018) Geography and island geomorphology shape fish assemblage structure on isolated coral reef systems. *Ecology and Evolution* 8:6242–6252.

Birt, MJ, Cure, K, Wilson, S, Newman SJ, Harvey ES, Meekan M, Speed C, Heyward A, Goetze J, Gilmour J (2021) Isolated reefs support stable fish communities with high abundances of regionally fished species. *Ecology and Evolution* 11:4701– 4718.

Boehlert GW (1988) Current-topography interactions at mid-ocean seamounts and the impact on pelagic ecosystems. *GeoJournal* 16(1):45-52.

Brewer DT, Potter A, Skewes TD, Lyne V, Andersen J, Davies C, Taranto T, Heap AD, Murphy NE, Rochester WA, Fuller M, Donovan A (2009) Conservation values in Commonwealth waters of the Christmas and Cocos (Keeling) Islands remote Australian Territories. Report to Department of Environment and Water Resources. CSIRO, Cleveland. 216 pp.

Bridge TC, Hughes TP, Guinotte JM, Bongaerts P (2013) Call to protect all coral reefs. *Nature Climate Change* 3(6):528-530.

Brown BE, Dunne RP, Somerfield PJ, Edwards AJ, Simons WJ, Phongsuwan N, Putchim L, Anderson L, Naeije MC (2019) Long-term impacts of rising sea temperature and sea level on shallow water coral communities over a~ 40 year period. *Scientific Reports* 9(1): 8826.

Buckee J, Hetzel Y, Nyegaard M, Evans S, Whiting S, Scott S, Ayvazian S, van Keulen M, Verduin J (2021) Catastrophic loss of tropical seagrass habitats at the Cocos (Keeling) Islands due to multiple stressors. *Marine Pollution Bulletin* doi: 10.1016/j.marpolbul.2021.112602

Bunce P (1988) The Cocos (Keeling) Islands: Australian atolls in the Indian Ocean. Jacaranda Press, Milton, Queensland.

Butcher R, Hale J (2010) Ecological character description for The Dales Ramsar Site. Report to the Department of Sustainability, Environment, Water, Population and Communities, Canberra.

Carvalho KS, Wang S (2019) Characterizing the Indian Ocean sea level changes and potential coastal flooding impacts under global warming. *Journal of Hydrology* 569:373-86.

Choukroun S, Harrison HB, Hoey As, Pratchett MS (2021) Coral Sea - Coral Reef Health Project: *In situ* measurements of water temperature and current flow. Report to the Director of National Parks. Australian Government, Canberra.

Cochrane P (2004) Pulu Keeling National Park management plan. Australian Government Department of Environment and Heritage, Canberra

Cocos Senior High School (1999) Berapa banyak anak ikan? (How many young fish?) Natural Heritage Trust Project - Interim Report. Unpublished.

Commonwealth of Australia (2005) Status of the Coral Reefs at the Cocos (Keeling) Islands. A report on the status of the marine community at Cocos (Keeling) Islands, East Indian

Ocean, 1997–2005. Australian Government Department of the Environment and Heritage, Canberra.

Commonwealth of Australia (2012) Marine bioregional plan for the North-west Marine Region. Department of Sustainability, Environment, Water, Population and Communities, Canberra, Australia.

Commonwealth of Australia (2014) Protocol for creating and updating maps of biologically important areas of regionally significant marine species. Australian Government Department of the Environment, Canberra.

Costanza R, d'Arge R, De Groot R, Farber S, Grasso M, Hannon B, Limburg K, Naeem S, O'neill RV, Paruelo J, Raskin RG (1997) The value of the world's ecosystem services and natural capital. *Nature* 387(6630):253-260.

Dambacher JM, Hayes KR, Hosack GR, Lyne V, Clifford D, Dutra LX, Moeseneder CH, Palmer MJ, Sharples R, Rochester WA, Taranto TJ (2012) Project summary: national marine ecological indicators. A report prepared for the Australian Government Department of Sustainability, Environment, Water, Population and Communities. CSIRO Wealth from Oceans Flagship, Hobart

Davies C, Beckley LE (2010) Zooplankton from the inshore waters of Christmas Island (Indian Ocean) with reference to larvae of the red land crab, *Gecarcoidea natalis*. *Journal of the Royal Society of Western Australia* 93(1):43-50.

Davies C, Hueston J (2007) Christmas Island Reef Check Coralwatch Reef Monitoring 2007. Unpubl. report.

Dethmers KE, FitzSimmons NN (2005) Genetic composition of the green turtle population at feeding grounds of the Cocos Keeling Islands. Progress Report. Applied Ecology Research Group, University of Canberra

Dethmers KE, Jensen MP, FitzSimmons NN, Broderick D, Limpus CJ, Moritz C (2010) Migration of green turtles (*Chelonia mydas*) from Australasian feeding grounds inferred from genetic analyses. Marine and Freshwater Research 61(12):1376-1387.

Director of National Parks (2011) Pulu Keeling National Park Climate Change Strategy 2011-2016. Department of Sustainability, Environment, Water, Population and Communities. Canberra, Australia.

Director of National Parks (2014) Christmas Island National Park Management Plan 2014–2024. Director of National Parks, Canberra.

Director of National Parks (2015) Pulu Keeling National Park Management Plan 2015–2025. Director of National Parks, Canberra.

DSEWPaC (2012) Marine bioregional plan for the North Marine Region prepared under the Environment Protection and Biodiversity Conservation Act 1999. Australian Government

Department of Sustainability, Environment, Water, Population and Communities (DSEWPaC), Canberra.

Dunlop JN, Surman CA, Wooller RD (2001) The marine distribution of seabirds from Christmas Island, Indian Ocean. *Emu - Austral Ornithology* 101(1):19-24.

Duvat VK, Salvat B, Salmon C (2017) Drivers of shoreline change in atoll reef islands of the Tuamotu Archipelago, French Polynesia. *Global and Planetary Change* 158:134-154.

Martinez-Escobar DF, Mallela J (2019) Assessing the impacts of phosphate mining on coral reef communities and reef development. *Science of The Total Environment*. 692: 1257-1266.

Evans K, Patterson TA, Reid H, Harley SJ (2012) Reproductive schedules in southern bluefin tuna: are current assumptions appropriate? *PLoS One* 7(4):e34550.

Evans SN, Konzewitsch N, Bellchambers LM (2016) An update of the Department of Fisheries, Western Australia invertebrate and reef health research and monitoring at Cocos (Keeling) Islands. Perth, Australia: Fisheries Research Division, Western Australian Fisheries and Marine Research Laboratories.

Farley JH, Davis TL (1998) Reproductive dynamics of southern bluefin tuna, *Thunnus maccoyii*. *Fishery Bulletin* 96:223-236.

Farley JH, Davis TL, Bravington MV, Andamari R, Davies CR (2015) Spawning dynamics and size related trends in reproductive parameters of southern bluefin tuna, *Thunnus maccoyii*. *PLoS One* 10(5):e0125744.

FitzSimmons N (2010) Population genetic studies in support of conservation and management of hawksbill turtles in the Indian Ocean. Report to Multinational Species Conservation Fund .Marine Turtle Conservation Fund Award 98210-7-G126.

Froese R, Pauly D (2021) FishBase. World Wide Web electronic publication. www.fishbase.org.

Gangal M, Gafoor AB, D'Souza E, Kelkar N, Karkarey R, Marbà N, Arthur R, Alcoverro T (2021) Sequential overgrazing by green turtles causes archipelago-wide functional extinctions of seagrass meadows. *Biological Conservation* 260:109195.

Gilligan JJ, Hender J, Hobbs JP, Neilson J, McDonald C (2008) Coral reef surveys and stock size estimates of shallow water (0–20 m) marine resources at Christmas Island, Indian Ocean. Report to the Australian Government Department of the Environment and Water Resource, Parks Australia North.

Gilmour JP, Cook KL, Ryan NM, Puotinen ML, Green RH, Shedrawi G, Hobbs JP, Thomson DP, Babcock RC, Buckee J, Foster T (2019) The state of Western Australia's coral reefs. *Coral Reefs* 38(4):651-667.

Green PT, O'Dowd DJ, Lake PS (1997) Control of seedling recruitment by land crabs in rain forest on a remote oceanic island. *Ecology* 78(8):2474-2486.

Grimes KG (2001) Karst features of Christmas Island (Indian Ocean). *Helictite* 37(2):41-58.

Hamilton RJ, Almany GR, Brown CJ, Pita J, Peterson NA, Choat JH (2017) Logging degrades nursery habitat for an iconic coral reef fish. *Biological Conservation* 210:273-280.

Hamylton SM, Mallela (2019) Reef development on a remote coral atoll before and after coral bleaching: A geospatial assessment. *Marine Geology* 418:106041.

Harper BA, Gourlay MR, Jones CM (2001) Storm tide risk assessment for the Cocos (Keeling) Islands. *Proceedings of the 15th Australasian Conference on Coastal and Ocean Engineering*. 6pps.

Harris P, Heap A, Passlow V, Sbaffi L, Fellows M, Porter-Smith R, Buchanan C, Daniell J (2005) Geomorphic Features of the Continental Margin of Australia. Geoscience Australia, Record 2003/30, 142pp.

Hayes KR, Dambacher JM, Hedge PT, Watts D, Foster SD, Thompson PA, Hosack GR, Dunstan PK, Bax NJ (2015) Towards a blueprint for monitoring key ecological features in the Commonwealth marine area. Tasmania: National Environmental Research Program Marine Biodiversity Hub.

Heemstra PC, Randall JE (1993) Groupers of the World (Family Serranidae, Subfamily Epinephelinae). An Annotated and Illustrated Catalogue of the Grouper, Rockcod, Hind, Coral Grouper, and Lyretail Species Known to Date. FAO Fisheries Synopsis. 16(125):145602.

Hender J, McDonald CA, Gilligan JJ (2001) Baseline survey of marine environments and stock size estimates of marine resources of the South Cocos (Keeling) Atoll (0-15m), Eastern Indian Ocean. Report to Fisheries Resources Research Fund (FRRF), Cocos Atoll.

Hennekam R, Zinke J, van Sebille E, ten Have M, Brummer GJ, Reichart GJ (2018) Cocos (Keeling) corals reveal 200 years of multidecadal modulation of southeast Indian Ocean hydrology by Indonesian throughflow. *Paleoceanography and Paleoclimatology* 33(1):48-60.

Hennicke JC, Weimerskirch H (2014) Coping with variable and oligotrophic tropical waters: foraging behaviour and flexibility of the Abbott’s booby *Papasula abbotti*. *Marine Ecology Progress Series* 499:259-273.

Hennicke JC, James DJ, Weimerskirch H (2015) Sex-specific habitat utilization and differential breeding investments in Christmas Island frigatebirds throughout the breeding cycle. *PloS One* 10(6):e0129437.

Heron SF, Maynard JA, Van Hooidonk R, Eakin CM (2016) Warming trends and bleaching stress of the world’s coral reefs 1985–2012. *Scientific Reports* 6:38402.

Hobbs JPA (2009) Fishes of North Keeling Island (Pulu Keeling National Park) and the impact of the lagoon closure. Report to Parks Australia, Cocos (Keeling) Islands.

Hobbs JPA, Allen GR (2014) Hybridisation among coral reef fishes at Christmas Island and the Cocos (Keeling) Islands. *Raffles Bulletin of Zoology* 30:220-226.

Hobbs JPA, Macrae H (2012) Unusual weather and trapped coral spawn lead to fish kill at a remote coral atoll. Coral Reefs. 31(4):961.

Hobbs JPA, McDonald CA (2010). Increased seawater temperature and decreased dissolved oxygen triggers fish kill at the Cocos (Keeling) Islands, Indian Ocean. *Journal of Fish Biology* 77(6):1219-1229.

Hobbs JPA, Newman SJ (2016) Darwin's atolls revisited: Lagoon infilling and closure has ecological consequences to North Keeling Atoll. *Marine Biodiversity* 46(1):21-22.

Hobbs JPA, Frisch AJ, Allen GR, van Herwerden L (2009a) Marine hybrid hotspot at Indo-Pacific biogeographic border. *Biology Letters* 5: 258–261.

Hobbs JPA, Frisch AJ, Hamanaka T, McDonald CA, Gilligan JJ, Neilson J (2009b) Seasonal aggregation of juvenile whale sharks (Rhincodon typus) at Christmas Island, Indian Ocean. *Coral Reefs* 28(3):577.

Hobbs JPA, Jones GP, Munday PL (2010a) Rarity and extinction risk in coral reef angelfishes on isolated islands: interrelationships among abundance, geographic range size and specialisation. *Coral Reefs* 29(1):1-11.

Hobbs JPA, Ayling AM, Choat JH, Gilligan JJ, McDonald CA, Neilson J, Newman SJ (2010b) New records of marine fishes illustrate the biogeographic importance of Christmas Island, Indian Ocean. *Zootaxa* 2422(1):63-68.

Hobbs JPA, Jones GP, Munday PL, Connolly SR, Srinivasan M (2012) Biogeography and the structure of coral reef fish communities on isolated islands. *Journal of Biogeography* 39(1):130-139.

Hobbs JPA, Coker D, Green P, James D, Humphreys W, McAllan I, Newman S, Pratchett M, Staeudle T, Whiting S (2014a) An annotated bibliography of the research on marine organisms and environments at Christmas Island and the Cocos (Keeling) Islands. *Raffles Bulletin of Zoology* 30:419-468.

Hobbs JPA, Newman S, Mitsopoulos G, Travers M, Skepper C, Gilligan J, Allen G, Choat H, Ayling A (2014b) Checklist and new records of Christmas Island fishes: the influence of isolation, biogeography and habitat availability on species abundance and community composition. *Raffles Bulletin of Zoology* 30:184-202.

Hobbs JPA, Newman SJ, Mitsopoulos GEA, Travers MJ, Skepper CL, Gilligan JJ, Allen GR, Choat JH, Ayling AM (2014c) Fishes of the Cocos (Keeling) Islands: new records, community composition and biogeographic significance. *Raffles Bulletin of Zoology* 30:203-219.

Hoey AS, Harrison H, Pratchett MS (2020) Coral reef health in the Coral Sea Marine Park. Report for Parks Australia. Director of National Parks, Canberra.

Hughes AR, Williams SL, Duarte CM, Heck KL, Waycott M (2009) Associations of concern: Declining seagrasses and threatened dependent species. *Frontiers in Ecology and the Environment* 7: 242–246.

Hughes AT, Hamilton RJ, Choat JH, Rhodes KL (2020) Declining grouper spawning aggregations in Western Province, Solomon Islands, signal the need for a modified management approach. *PLoS ONE* 15(3): e0230485.

Hughes TP, Kerry JT, Álvarez-Noriega M, Álvarez-Romero JG, Anderson KD, Baird AH, Babcock RC, Beger M, Bellwood DR, Berkelmans R, Bridge TC (2017) Global warming and recurrent mass bleaching of corals. *Nature* 543(7645): 373-377.

Hui TH, Naruse T, Fujita Y, Kiat TS (2014) Observations on the fauna from submarine and associated anchialine caves in Christmas Island, Indian Ocean Territory, Australia. *Raffles Bulletin of Zoology* 30: 406-418

Humphries WF (2014) Subterranean fauna of Christmas Island: habitats and salient features. *Raffles Bulletin of Zoology* 30: 29-44.

Humphreys WF, Eberhard S (2001) Subterranean fauna of Christmas Island, Indian Ocean. *Helictite* 37(2): 59-74.

James DJ, Green PT, Humphreys WF, Woinarski JC (2019) Endemic species of Christmas Island, Indian Ocean. *Records of the Western Australian Museum* 34(2): 55-114.

Jensen MP (2010) Assessing the composition of green turtle (*Chelonia Mydas*) foraging grounds in Australasia using mixed stock analyses. PhD Thesis. University of Canberra, Canberra.

Kahng SE, Garcia-Sais JR, Spalding HL, Brokovich E, Wagner D, Weil E, Hinderstein L, Toonen RJ (2010) Community ecology of mesophotic coral reef ecosystems. Coral Reefs 29(2): 255-275.

Kench P (1994) Hydrodynamic Observation of the Cocos (Keeling) Islands. *Atoll Research Bulletin* 1994: 408.

Kennedy EV, Roelfsema C, Lyons M, Kovacs E, Borrego-Acevedo R, Roe M, Phinn S, Larsen K, Murray N, Yuwono D, Wolff J, Tudman (2021) Reef Cover: a coral reef classification for global habitat mapping from remote sensing. *Scientific Data* 8: 196.

Konzewitsch N, Evans SN (2020) examining the movement of the common spider conch *Lambis lambis* in shallow water of a northeastern indian ocean atoll using passive acoustic tracking. *Journal of Shellfish Research* 39(2): 389-397.

Lesser MP, Slattery M, Leichter JJ (2009) Ecology of mesophotic coral reefs. *Journal of Experimental Marine Biology and Ecology* (1-2): 1-8.

Lincoln-Smith MP, Underwood AJ, Smith AK, Hawes PMH, Howitt L, Stark J, Skilleter GA, Chapman MG (1993) A study of the impact of harvesting marine invertebrate and fish on the marine ecosystems of Cocos (Keeling) Islands, Indian Ocean. Sydney, Australia: The Institute of Marine Ecology, The University of Sydney.

MacArthur L, Hyndes G, Babcock (2007) Western rock lobster in ecosystem processes of south-western Australia. Report 2007-12, Department of Environment, Water, Heritage and the Arts. Commonwealth of Australia, Canberra.

Mackay P, Prudent-Richard G, Hoekstra-Fokkink L (2009) Climate Change Risk Assessment for the Australian Indian Ocean Territories – Cocos (Keeling) Islands and Christmas Island. Report for Commonwealth Attorney-General's Department. Maunsell, Canberra.

Mallela, J (2020a) Coral Reef Health and Monitoring at Christmas Island: 2015-2019. A report prepared for Parks Australia. 26pp

Mallela, J (2020b) Coral Reef Health, Research and Monitoring at Cocos (Keeling) Islands: 2015-2019. A report prepared for Parks Australia. 41pp

Martinez-Escobar DF, Mallela J (2020) Assessing the impacts of phosphate mining on coral reef communities and reef development. *Science of the Total Environment* 692: 1257-1266.

Meekan MG, Jarman SN, McLean C, Schultz MB (2009) DNA evidence of whale sharks (*Rhincodon typus*) feeding on red crab (*Gecarcoidea natalis*) larvae at Christmas Island, Australia. *Marine and Freshwater Research* 60(6): 607-609.

Meekan M, Fuiman L, Davis R, Berger Y, Thums M (2015) Swimming strategy and body plan of the world's largest fish: implications for foraging efficiency and thermoregulation. *Frontiers in Marine Science* 2: 64.

Morgan, G.J., 1994. Decapod crustaceans of the Cocos (Keeling) Islands. *Atoll Research Bulletin* 41(16): 1-114:

Munday PL (2004) Habitat loss, resource specialization, and extinction on coral reefs. *Global Change Biology* 10(10): 1642-1647.

Namboothri N, Swaminathan A, Choudhury BC & Shanker K (2012) Post-nesting migratory routes of leatherback Turtles from little Andaman Island. *Indian Ocean Marine Turtle Newsletter* 16: 21-23.

Ng PKL, Naruse T (2014) The lobsters of Christmas Island and Cocos (Keeling) Islands, with new records of *Palinurellus wieneckii* (De Man, 1881) and *Enoplometopus voigtmanni* Türkay, 1989 (Crustacea: Decapoda: Palinuridae, Scyllaridae, Enoplometopidae)., *Raffles Bulletin of Zoology*, Vol. Suppl. 30: 305-312.

Nordlund L, Koch EW, Barbier EB, Creed JC (2016) Seagrass ecosystem services and their variability across genera and geographical regions. *PLoS One* 11(10):e0163091.

Orchard M (2012) Crabs of Christmas Island. Christmas Island Natural History Association. 288 pp.

Orchard M (2020) Christmas Island red crab breeding migration. Published by Max Orchard, Flagstaff Hill, SA. 164 pp.

Pratchett MS, Munday PL, Wilson SK, Graham NA, Cinner JE, Bellwood DR, Jones GP, Polunin NV, McClanahan TR (2008) Effects of climate-induced coral bleaching on coral-reef fishes—ecological and economic consequences. *Oceanography and Marine Biology: An Annual Review* 46:257-302.

Pratchett MS, Munday PL, Graham NAJ, Kronen M, Pinica S, Friedman K, Brewer T, Bell JD, Wilson SK, Cinner JE, Kinch JP, Lawton RJ, Williams AJ, Chapman L, Magron F, Webb A (2011) Vulnerability of coastal fisheries in the tropical Pacific to climate change. Pages 493-576. In: Bell JD, Johnson JE, Hobday AJ (Eds) Vulnerability of tropical Pacific Fisheries and Aquaculture to Climate Change. Secretariat for the Pacific Community, Noumea, New Caledonia.

Pratchett MS, Hobbs JPA, Davie P, Green P, Newman S, Whiting S, Pratchett DJ, Coker D (2013) An annotated bibliography of marine research at Christmas Island and Cocos (Keeling) Islands. Report to Australian Government Department of Regional Australia, Local Government, Arts and Sport (IOT Administration), Christmas Island.

Richards ZT, Hobbs JPA (2014) The status of hard coral diversity at Christmas Island and Cocos (Keeling) Islands. *Raffles Bulletin of Zoology*. 30:376-398.

Robbins WD, Hisano M, Connolly SR, Choat JH (2006) Ongoing collapse of coral-reef shark populations. *Current Biology* 16(23):2314-2319.

Rowat, D., Brooks, K.S. (2012), A review of the biology, fisheries and conservation of the whale shark *Rhincodon typus*. *Journal of Fish Biology* 80: 1019-1056.

Sadovy de Mitcheson, Y.S., Colin, P., Lindfield, S., & Bukurrou, A. (2020). A decade of monitoring an Indo-Pacific grouper spawning aggregation: Benefits of protection and importance of survey design. *Frontiers in Marine Science.* 7: 571878.

Scapin L, Cavraro F, Malavasi S, Riccato F, Zucchetta M, Franzoi P (2018) Linking pipefishes and seahorses to seagrass meadows in the Venice lagoon: Implications for conservation. Aquatic Conservation: Marine and Freshwater Ecosystems. 28(2):282-295.

Scapin L, Cavraro F, Malavasi S, Riccato F, Zucchetta M, Franzoi P (2018) Linking pipefishes and seahorses to seagrass meadows in the Venice lagoon: Implications for conservation. *Aquatic Conservation: Marine and Freshwater Ecosystems* 28(2):282-295.

Sequeira AM, Mellin C, Meekan MG, Sims DW, Bradshaw CJ (2013) Inferred global connectivity of whale shark Rhincodon typus populations. *Journal of Fish Biology* 82(2):367-389.

Smithers SG (1994) Sediment facies of the Cocos (Keeling) islands. *Atoll Research Bulletin* 1994: 407.

Smithers SG, Woodroffe CD, McLean RF, Wallensky EP (1992) Lagoonal sedimentation in the Cocos (Keeling) Islands, Indian Ocean. *Proceedings of the 7th International Coral Reef Symposium* 1: 273-288.

Speed CW, Babcock RC, Bancroft KP, Beckley LE, Bellchambers LM, Depczynski M, Field SN, Friedman KJ, Gilmour JP, Hobbs JP, Kobryn HT (2013) Dynamic stability of coral reefs on the west Australian coast. *PLoS One* 8(7): e69863.

Stoddart DR (1968) Catastrophic human interference with coral atoll ecosystems. *Geography* 53(1): 25-40.

Tan SK, Low ME (2014) Checklist of the Mollusca of Cocos (Keeling)/Christmas Island ecoregion. *Raffles Bulletin of Zoology* 30: 313-375.

Waycott M, Duarte CM, Carruthers TJ, Orth RJ, Dennison WC, Olyarnik S, Calladine A, Fourqurean JW, Heck KL, Hughes AR, Kendrick GA (2009) Accelerating loss of seagrasses across the globe threatens coastal ecosystems. *Proceedings of the National Academy of Sciences, USA* 106(30): 12377-12381.

West KM, Richards ZT, Harvey ES, Susac R, Grealy A, Bunce M (2020) Under the karst: detecting hidden subterranean assemblages using eDNA metabarcoding in the caves of Christmas Island, Australia. *Scientific Reports* 10(1): 1-5.

Whiting SD, Koch AU (2006) Oceanic movement of a benthic foraging juvenile hawksbill turtle from the Cocos (Keeling) Islands. *Marine Turtle Newsletter* 2006(112): 16.

Whiting SD, Murray W, Macrae I, Thorn R, Chongkin M, Koch AU (2008) Non-migratory breeding by isolated green sea turtles (*Chelonia mydas*) in the Indian Ocean: biological and conservation implications. *Naturwissenschaften* 95(4): 355-360.

Whiting SD, Macrae I, Murray W, Thorn R, Flores T, Joynson-Hicks C, Hashim S (2010) Indian Ocean crossing by a juvenile hawksbill turtle. *Marine Turtle Newsletter* 2010(129): 16.

Whiting SD, Macrae I, Thorn R, Murray W, Whiting AU (2014) Sea turtles of the Cocos (Keeling) Islands, Indian Ocean. *Raffles Bulletin of Zoology* 30: 168-183.

Williams DG (1994) Marine habitats of the Cocos (Keeling) Islands. *Atoll Research Bulletin* 1994: 406.

Woodroffe CD (1988) Relict mangrove stand on last interglacial terrace, Christmas Island, Indian Ocean. *Journal of Tropical Ecology* 4(1):1-7.

Woodroffe CD, Berry PF (1994) Scientific studies in the Cocos (Keeling) Islands: an introduction. *Atoll Research Bulletin* 1994:399.

Woddroffe CD, McLean RF, Wallensky E (1994) Geomorphology of the Cocos (Keeling) Islands. *Atoll Research Bulletin* 1994:402.

Woodroffe CD, McLean RF, Smithers SG, Lawson EM (1999) Atoll reef-island formation and response to sea-level change: West Island, Cocos (Keeling) Islands. *Marine Geology* 160(1-2):85-104.