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The status of hard coral diversity at Christmas Island and Cocos (Keeling) Islands

Zoe T. Richards[1*] & Jean-Paul A. Hobbs[2]

Abstract. Very little is known about the coral biodiversity in Australia's remote Indian Ocean Territories; hence it is not possible to detect extinctions, depletions or to quantify changes in the coral fauna. Here we document the results of rapid visual assessment surveys of hard coral biodiversity at Christmas Island. This study provides a much-needed updated species list as well as a baseline dataset on coral community composition that will enable detection of future changes in the community. From this survey, a total of 145 species of scleractinian coral and five species of non-scleractinian coral (three hydrozoans and two octocorals) from 51 genera were recorded, including 28 range extensions. When combined with existing specimen-based records, the current estimate of hard coral species richness at Christmas Island is 169, and comparable to communities at other isolated Indian Ocean localities. In conjunction with the results of a previous study at neighbouring Cocos (Keeling) Islands, the total number of hard corals recorded from Australia's Indian Ocean Territories is 197 species. The composition of the coral community is biogeographically unique and its long-term conservation is dependent on greater protection from local pollution impacts to safeguard resilience.

Key words. baseline, conservation, hermatypic, rapid visual assessment, Scleractinia

INTRODUCTION

Christmas Island lies atop of a seamount that emerged in the late Miocene and has progressed through numerous stages of sea-level change that have significantly affected its fringing coral reefs (Beeton et al., 2010). As a result of its isolation and geographic history, Christmas Island hosts a unique suite of marine flora and fauna (see Berry & Wells, 2000; Brewer et al., 2009). For example, studies of marine fishes indicate that during Pleistocene low sea-levels, species diverged into Pacific and Indian Ocean taxa and as the sea-level rose again these taxa came into secondary contact and subsequently hybridised at Christmas Island (Hobbs et al., 2009, 2012). Many other marine groups have co-occurring Indian and Pacific Ocean species in the region (Wells, 1994; Hobbs & Salmond, 2008) and similar patterns of speciation and hybridisation may also be present in hard corals.

At Christmas Island, the majority of surface rock is limestone that has accumulated over millions of years of coral growth. Despite their importance to the island's geomorphology, surprisingly little is known about the status of hermatypic scleractinian coral diversity. There has been limited taxonomic research on hard corals at Christmas Island and filling this knowledge gap has been identified as a research priority (Beeton et al., 2010). For scleractinian corals, isolated and peripheral locations represent crucial areas for conservation due to their high rates of speciation and hybridisation (Budd & Pandolfi, 2010). Christmas Island is an example of such an isolated and peripheral location; however, a lack of species-level baseline data on corals precludes our understanding of species-level patterns and processes at this location.

The investigation of corals at Christmas Island began when H. M. Bernard examined coral material collected in 1897 by C. W. Andrews from the British Museum of Natural History (Bernard, 1911). Following this, S. Slack-Smith from the Western Australian Museum collected a small number of corals in 1969 (unpublished). The most comprehensive historical coral collections were conducted by T. Done and L. Marsh in 1987 and this resulted in a preliminary scleractinian species list (Done & Marsh, 2000). Eighty-eight species of corals from 38 genera were recorded at 15 sites. From their survey, Done & Marsh (2000) concluded that the diversity of coral fauna at Christmas Island was low when compared to other islands, reefs and atolls in the NE Indian Ocean such as Ashmore Reef, Scott and Seringapatam Reefs. They attributed this to the small size of the island, its isolation from sources of planktonic larvae, the limited range of habitats present and historical disturbances. The authors surveyed less than 1% of the coral reefs at Christmas Island and acknowledged that additional species were likely to be detected with further surveying. Since their 1987 surveys, there have been no species-level coral surveys at Christmas Island.

[1]Department of Aquatic Zoology, Western Australian Museum, 49 Kew St, Welshpool Western Australia, 6106; Email: zoe.richards@museum.wa.gov.au (*corresponding author)

[2]Department of Environment and Agriculture, Curtin University, Perth, Western Australia, 6845

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While Christmas Island is remote, its coral reefs are by no means immune to impacts. During the 1982/83 El Niño event, coral bleaching led to widespread coral mortality at various depths around the entire island (Berry, 2000). Indian Ocean bleaching events in 1998 are also likely to have impacted reefs in the region (Goreau et al., 2000); however no data is available. In 2008, an outbreak of coral disease at Christmas Island selectively impacted the coral community (Hobbs & Frisch, 2010). In addition, sewerage, oil and phosphate pollution and introduced pests pose a threat to the coral communities (Hobbs, 2014).

Christmas Island (and its neighbouring Cocos Islands) is in the least protected marine bioregion in Australia, with less than 1% designated as marine protected areas (Barr & Possingham, 2013). The marine biodiversity at Christmas Island is extremely unique and warrants greater protection (Hobbs, 2014); however the significance of the marine life is likely to be underestimated because most marine groups are yet to be studied. The lack of quantitative data about the extent of coral biodiversity at Christmas Island needs to be addressed because not only is the potential loss of coral diversity and coral community health of concern, but the wider biodiversity of the coral reef may be at risk. For example, the loss of live coral cover and structural complexity has been linked to losses in fish diversity and abundance (Jones et al., 2004; Graham et al., 2006), particularly among specialist corallivores (Pratchett et al., 2004, 2006) including those at Christmas Island (Hobbs et al., 2010).

The overall purpose of this study was to conduct a comprehensive description of the coral communities at Christmas Island for the benefit of long-term conservation of coral reef biodiversity in Australia's remote Indian Ocean Territories.

This study has three key aims:

1. To update the hard coral species inventory based on new records and revised nomenclature;
2. To examine spatial patterns of species abundance and occupancy to identify dominant, rare and potentially threatened coral species;
3. To compare the coral communities of Christmas Island and Cocos (Keeling) Islands and place these communities in a regional context.

This information is crucial for three reasons. Firstly, it will enable threatened coral species to be identified; secondly, it will provide a baseline that will enable future shifts in coral biodiversity to be detected. Lastly, it will provide expert information needed to support optimal coral reef management and to develop public knowledge about these coral reef ecosystems.

METHODS

Study site. Christmas Island (10˚30'S, 105˚ 39'E) is an external Australian Territory in the eastern Indian Ocean located 2600 km northeast of Perth (Fig. 1a). The 73 km of coastline surrounding this oceanic island is made up of rock platforms and coral reef that extends 50 to 200 m out from the coast before a rapid drop in depth from approximately 12–20 m to several thousand meters (Berry & Wells, 2000; Director of National Parks, 2002). There are no lagoons and very little sand thus there is a restricted subset of habitat types. Christmas Island experiences strong south-easterly winds and large southerly swells throughout most of the year.

Taxonomy and threatened status. For the purposes of this study the following taxonomic classification schemes were used: Wallace et al. (2012) for *Acropora* and *Isopora*; Gittenberger et al. (2011) and Benzoni et al. (2012) for Fungiidae; Benzoni et al. (2010) for *Psammocora*; Budd et al. (2012) and Huang et al. (2014) for Lobophylliidae, Merulinidae, Montastraeidae and Diploastraeidae; and Veron (2000) for all taxa that have not been revised recently. The historical data for Christmas and Cocos (Keeling) Islands is summarised from Done & Marsh (2000), Veron & Marsh (1988), Veron (1994) and placed in a regional context according to the distribution records of Wallace (1999), Veron (2000) and Richards & Rosser (2012). The threatened status of each coral species at Christmas and Cocos (Keeling) Islands was determined according the IUCN red list of threatened species (Carpenter et al., 2008).

Field surveys. Coral diversity was surveyed from the 26th April – 6th May 2013 using a standard method of rapid ecological assessment (DeVantier et al., 1998; Richards et al., 2013). Scleractinian and non-scleractinian hard coral communities were documented at nine sites by the first author (ZR) whilst SCUBA diving. All sites were composed of a narrow reef top (~78 m wide, Gilligan et al., 2008), and the reef slopes steeply (at angles of 40–80°) from 12–20 m to more than 4000 m depth (for site-specific details see Table 1). All sites were surveyed using a rapid visual assessment methodology for a total of 70 min from 1 to 30 m depth (Fig. 1). The dive began at 30 m depth and the ascending dive profile generally involved surveying at 20–30 m depth for 15 min; then 30 min at 10–20 m depth and 25 min at 1–10 m depth. The majority of the searching was conducted in the 10–20 m depth zone as that is where the greatest diversity and density of coral was encountered. Sites on the southern side of the island could not be surveyed due to rough weather conditions.

Prior to this study, skeletal material collected from Christmas Island by T. Done and L. Marsh (1988) was examined to obtain a comprehensive understanding of the species known to exist at Christmas Island. Every effort was made to identify corals underwater or via photographs, however in some cases, sufficient confidence was not obtained in the identification of some individuals in situ hence skeletal material was collected to facilitate further examination in the laboratory. Skeletal (and wet) material has been registered into the Western Australian Museum Coral Collection (See Appendix 1 for accession numbers).

To determine the relative frequency of species occurrence at every site, species counts were tallied and abundance records were converted to five categories: rare (1–2 colonies);

infrequent (3–5 colonies); frequent (6–20 colonies); common (21–50 colonies); and dominant (51+ colonies). Thus, for the purposes of this study, rare species are those occurring at one site only and/or in low abundance (i.e., 1–2 colonies in total across all sites).

Analysis. Species accumulation curves were calculated for each site using the 'vegan' library in R and the function 'specaccum' with jack-knifed standard errors (Oksanen et al., 2011). This provided a graphical check of whether sampling was sufficient to detect rare members of the assemblage. To determine if coral species diversity varied between sites and depths, a range of diversity indices were calculated using PRIMER-E v6 (Clarke & Warwick, 2001). These included species richness (S), Margalef's Index (d), Pielou's evenness (J'), Shannons Diversity Index (H') to the log base e, and Simpsons Diversity (λ). A resemblance matrix based on Bray-Curtis similarities was constructed square-root transformed relative abundance data from nine sites. Agglomerative CLUSTER analysis was used to group the sites according to the similarity in the composition of the coral assemblage using group average linkage distances. We used Kruskal's non-metric multidimensional scaling (nmMDS) analysis to visualise the variation in the composition of the coral assemblage between sites as a 2-D plot.

RESULTS

A total of 3233 colonies were identified at nine sites and 96 skeletal specimens were collected pertaining to 66 species (Western Australian Museum accession numbers Z65796-Z65891). From this current survey, a total of 145 species of scleractinian coral and five species of non-scleractinian coral (three hydrozoans and two octocorals) from 51 genera were recorded (Appendix 1). The species accumulation curve approached an asymptote indicating that this dataset provides a reasonable representation of the coral diversity along the north, eastern and western sides of the island (Fig. 2).

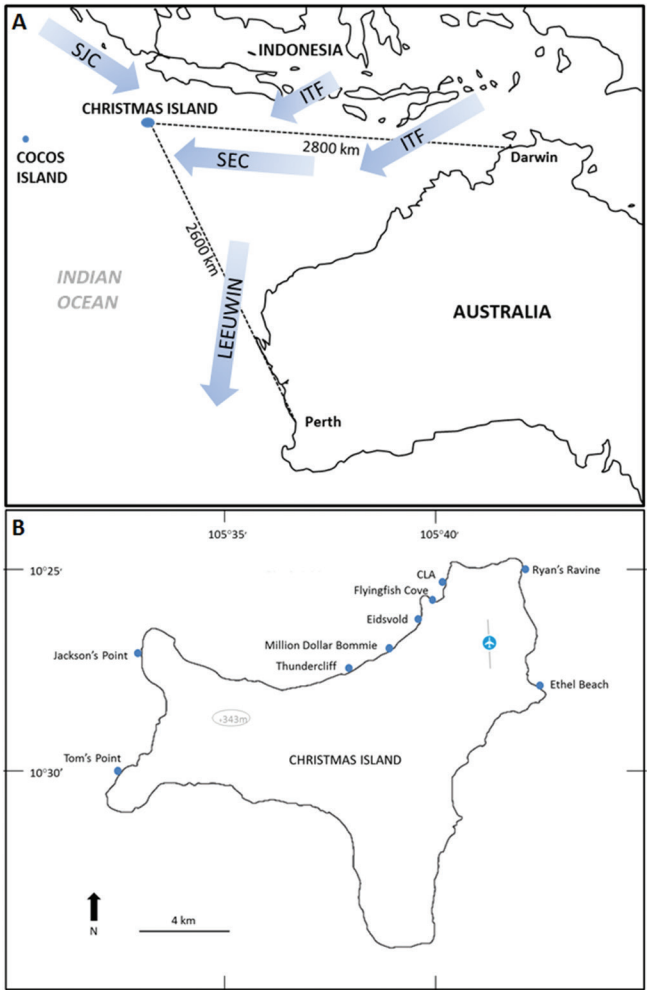

Fig. 1. Map of study sites. A, Location of Christmas and Cocos (Keeling) Islands in relation to the predominant regional currents (SJC – South Java Current; SEC – Southern Equatorial Current; ITF – Indonesian Through-Flow). B, Location of study sites at Christmas Island.

Table 1. Physical descriptions of the nine sites surveyed at Christmas Island in 2012.

Site	GPS coordinates	Coastline	Wave exposure	Reef width (m)
Tom's point	10°30.068 S, 105°32.317 E	Western	medium to large	72
Jackson's point	10°26.893 S, 105°32.829 E	Western	medium to large	118
Thundercliff	10°27.980 S, 105°36.404 E	Northern	small	31
Million Dollar Bommie	10°27.382 S, 105°38.155 E	Northern	small	126
Eidsvold	10°26.446 S, 105°39.552 E	Northern	small	130
Flyingfish Cove	10°25.720 S, 105°40.089 E	Northern	very small	62
CLA	10°24.900 S, 105°40.450 E	Northern	small	149
Ethel	10°27.832 S, 105°42.494 E	Eastern	medium	48
Ryan's Ravine	10°25.099 S, 105°42.228 E	North-Eastern	medium	53

Combining the current survey results with those of Done & Marsh (2000), the total species richness for Christmas Island is estimated to be 169. When the diversity of corals recorded from neighbouring Cocos (Keeling) Islands is included (Veron, 1994) with the corals of Christmas Island, the number of hard coral species in Australia's Indian Ocean Territories is 197 (Appendix 1). Twenty-eight species recorded at Christmas Island represent range extensions from either Southeast Asia, northwest Pacific or Indian Ocean locations (verified by skeletal specimen and/or photograph) (Table 2, Fig. 3).

Species richness was highest at Flyingfish Cove (102 species), followed by Million Dollar Bommie (73 species), Eidsvold (69 species), and lowest at Ryan's Ravine (46 species) (Fig. 4a, Table 3). This pattern of diversity was also reflected in the other diversity indices examined (Table 3). The results for Pielou's Evenness (J') however indicate fine-scale difference in the patterns of abundance within sites. The comparatively lower evenness values for Million Dollar Bommie and Thundercliff indicate that at these sites there is greater variation in the relative abundance of species (Fig. 4b).

Table 2. Range extensions for scleractinian corals recorded at Christmas Island and verified by skeletal specimen and/or photograph. Former known range from Veron (2000). Abbreviations according to compass direction (N, S, E, W); IO = Indian Ocean; IP = Indo-Pacific. IUCN classifications according to Carpenter et al. (2008).

Range Extensions	Former Known Range	IUCN Classification
Acanthastrea brevis Milne Edwards & Haime, 1849	W. IO, SE Asia, NW Pacific	Vu
Acropora austera (Dana, 1846)	IP	NT
Acropora cerealis (Dana, 1846)	IP	LC
Acropora donei Veron & Wallace, 1984	E. IO, SE Asia, NW Pacific	Vu
Acropora microclados (Ehrenberg, 1834)	Red Sea, E. IO, SE Asia, NW Pacific	Vu
Acropora papillare Latypov, 1992	E. IO, SE Asia	Vu
Acropora selago (Studer, 1878)	IP	NT
Acropora yongei Veron & Wallace, 1984	IP	LC
Echinophyllia aspera (Ellis & Solander, 1786)	IP	LC
Echinopora gemmacea Lamarck, 1816	E. IO, SE Asia	LC
Goniopora lobata Milne Edwards & Haime, 1860	IP	NT
Goniopora minor Crossland, 1952	IP	NT
Goniopora pandoraensis Veron & Pichon, 1982	E. IO, SE Asia, NW Pacific	LC
Goniopora stokesi Milne Edwards & Haime, 1851	IP	NT
Leptastrea purpurea (Dana, 1846)	IP	LC
Leptoseris foliosa Dinesen, 1980	IO, SE Asia, NW Pacific	LC
Leptoseris hawaiiensis Vaughan, 1907	IP	LC
Leptoseris solida (Quelch, 1886)	W. IO, SE Asia, Pacific	LC
Lobophyllia flabelliformis Veron, 2000	SE Asia, W. Pacific	Vu
Merulina scabricula Dana, 1846	IP	LC
Micromussa minuta (Moll & Borel-Best, 1984)	SE Asia, N. IO	NT
Montipora crassituberculata Bernard, 1897	IP	Vu
Montipora hoffmeisteri Wells, 1954	E.IO, SE Asia, Pacific	LC
Montipora turtlensis Veron & Wallace, 1984	SE Asia, E and W Australia	Vu
Montipora undata Bernard, 1897	IP	NT
Pavona bipartita Nemenzo, 1980	IP (not Australia)	Vu
Platygyra ryukyuensis Yabe & Sugiyama, 1936	IP	NT
Cycloseris explanulata (Van der Horst, 1922)	IP	LC

Table 3. Comparison of the number of species, diversity indices and indicators of evenness (see text) for the stony coral fauna at 9 sites at Christmas Island.

Site	Species Richness	Margalef's Index (d)	Pielou's Evenness (J')	Shannon's Diversity Index {H'(log e)}	Simpson's Diversity Index (1-Lambda')
Flyingfish Cove	102	19.367	0.974	4.504	0.993
Million Dollar Bommie	73	14.937	0.966	4.146	0.990
Eidsvold	69	13.926	0.972	4.114	0.989
Jackson's Point	68	14.044	0.970	4.093	0.990
Tom's Point	68	13.765	0.971	4.098	0.989
CLA	60	12.552	0.970	3.970	0.988
Thundercliff	59	12.488	0.962	3.922	0.987
Ethol	57	12.269	0.966	3.906	0.987
Ryan's Ravine	46	10.212	0.960	3.675	0.983

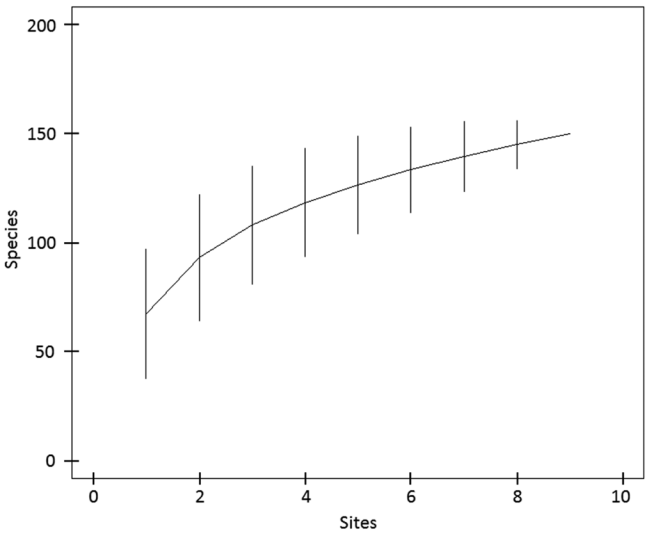

Fig. 2. Species accumulation curve for scleractinian corals surveyed at nine sites around the east, west and north coasts of Christmas Island.

Based on the rapid visual assessment surveys, the majority of species (31%, n = 47) were recorded at a single site only (Fig. 5a). Of the species that were only recorded at a single site, 20 were observed at Flyingfish Cove (see Appendix 2). However single species-site observation records were obtained from all other sites, i.e., six species were recorded only at Million Dollar Bommie; five species at Tom's Point, four species at Eidsvold, four species at Ethel, three species at Jackson's Point, two species at CLA, two species at Thundercliff, and one species at Ryan's Ravine.

Based on the relative abundance categories used in this study, the highest proportion of species (0.53) were rare, indicating that one or two colonies were recorded per site occupied (Fig. 5b). Conversely, a surprisingly low proportion of species (0.007) dominated the coral community. Of the few dominate species, *Porites lobata* was found to dominate three sites (CLA, Million Dollar Bommie, Thundercliff) and *Galaxea astreata* dominated at Ethel. A larger proportion of species (0.22 and 0.2 respectively) was found either frequently or commonly (i.e. 6–20 colonies per site or 21–50 colonies per site). Only eight species were recorded at all nine sites (*Porites lobata*, *Porites rus*, *Acropora clathrata*, *Montipora informis*, *Leptastrea pruinosa*, *Cyphastrea microphthalma*, *Astreopora myriophthalma*, *Gardinoseris planulata*) (Appendix 1).

Sites along the northern side of the island (Million Dollar Bommie, Eidsvold, Thundercliff) were similar in their coral composition and this was reflected in the 2D nm-MDS plot where these sites cluster with 60% similarity (Fig. 6). The two west coast sites (Tom's Point, Jackson's Point) and CLA (north coast) also grouped together with 60% similarity in the coral communities. The MDS also revealed that the coral communities at Flyingfish Cove, Ethel and Ryan's Ravine were considerably different to the other sites because they grouped out separately and largely driven by the abundance of *Echinopora lamellosa* and *Goniastrea retiformis* at Flyingfish Cove, *Acropora gemmifera* and *Favites pentagona* at Ryans Ravine and *Galaxea astreata* and *Hydnophora microconos* at Ethel.

The majority of coral species at Christmas and Cocos Islands are classified as Least Concern (55%, 108 species) according to global IUCN red list categories and criteria (Fig. 7; Appendix 1). 14% of the corals in the community (n = 27) are listed as Vulnerable to extinction this century (Table 4). Twenty-seven percent of the community (n = 54) are classified as Near Threatened, three species are Data Deficient and 5 species have not been assessed.

DISCUSSION

Coral diversity of Christmas Island. One hundred and fifty hard coral (scleractinian and non-scleractinian) species were recorded in the present survey. When combined with existing specimen-based records, the current estimate of hard coral

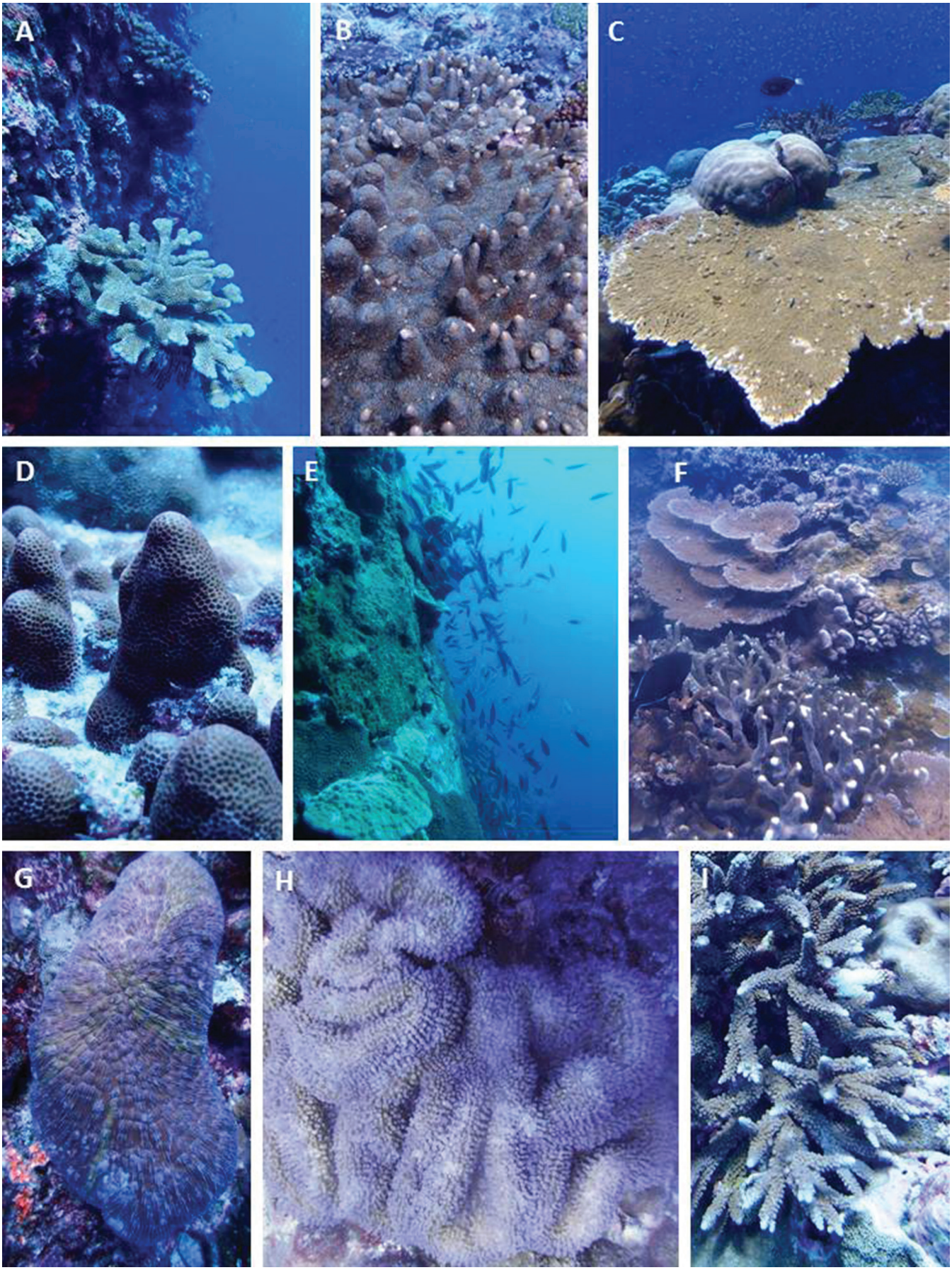

Fig. 3. Hard corals of Christmas Island: A, *Pocillopora woodjonesi* at Tom's Point; B, *Acropora papillare* at Jackson's Point; C, highly fused *Acropora clathrata* plate at Tom's Point; D, *Porites cocosensis* at Jackson's Point; E, steep wall at Thundercliff; F, mixed *Acropora* and *Pocillopora* assemblage at Million Dollar Bommie; G, *Sandalolitha dentata* at Million Dollar Bommie; H, *Lobophyllia flabelliformis* at Eidsvold; I, *Acropora austera* at Jackson's Point.

species richness at Christmas Island is 169. Currently, 328 species from 70 genera are known to occur in Western Australia (Veron & Marsh, 1988; Richards & Rosser, 2012), hence the level of diversity at Christmas Island is just over half of that known from Western Australia. While the coral community was previously considered low (Done & Marsh, 2000), the results of this survey indicate the level of diversity at Christmas Island is not dissimilar to other remote tropical Indian Ocean locations (e.g., Rowley Shoals; Veron & Marsh, 1988).

There is a high degree of similarity between coral communities on the northern coast of island, (likewise between communities on the western coast) but one site on the northern coastline is noticeably different. Flyingfish Cove was clearly separated from the other sites in multivariate analysis (Fig. 6) and this trend is most likely driven by the high species richness and large number of rare species (n = 20) at this site. Flyingfish Cove is the most sheltered site on Christmas Island hence species that are susceptible to wave damage have a greater chance of persistence at this location. Another distinctive site that was separated in multidimensional space is Ryan's Ravine, where diversity was the lowest. This site is located on the northeast extremity of the island (Northeast Point) and it is possible that the very strong currents in this area prevent larvae from being retained, or from reaching and settling at this site.

The level of coral diversity recorded at any location is generally related to the level of collecting and survey effort, hence with further surveying it is anticipated more coral species would be documented at Christmas Island. Given the southern coastline of the island was not surveyed in this study; it is possible that new records will be obtained from that section of the coastline. However, previous surveys indicate hard coral cover is low on the southern coast (i.e., 20% compared to >50% cover on the east, west and north coasts: Hobbs, unpublished data). Hence, the extreme exposure of southern coastline to persistent south swell is likely to limit the development of hard coral communities and leads us to believe that the diversity of corals on the southern coast may be low. However, soft corals (a group that has not been studied at Christmas Island) dominate the south coast (Hobbs, unpublished data) and therefore the benthic community of this coast is very different to the other coastlines and likely to support a community of species not found elsewhere at Christmas Island.

Based on current records, there are approximately 160 species from 24 genera that occur along the Western Australian coastline and/or on the offshore islands and atolls (Scott Reef, Rowley Shoals and Ashmore Reef) that have not been observed at Christmas Island (Richards, unpublished data). Conversely, eight species (i.e., *Acanthastrea brevis*, *Leptoseris solida*, *Pavona bipartita*, *Micromussa minuta*, *Sandalolitha dentata*, *Goniopora norfolkensis*, *Pavona frondifera*, *Coscinarea monile*) that are recorded at Christmas Island (present study; Done & Marsh, 2000) are not currently known from the Western Australian coastline, islands or offshore atolls. Furthermore, five of these

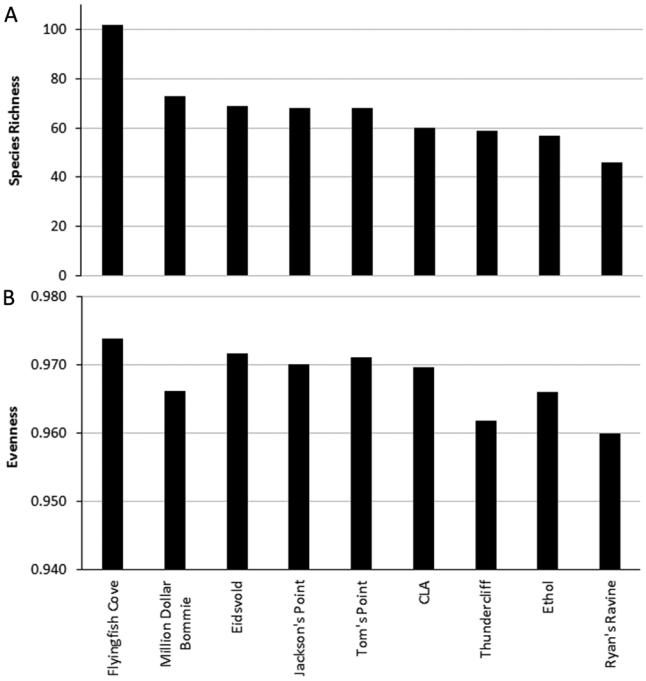

Fig. 4. Variation in: A, species richness; and B, evenness at the nine locations surveyed around Christmas Island.

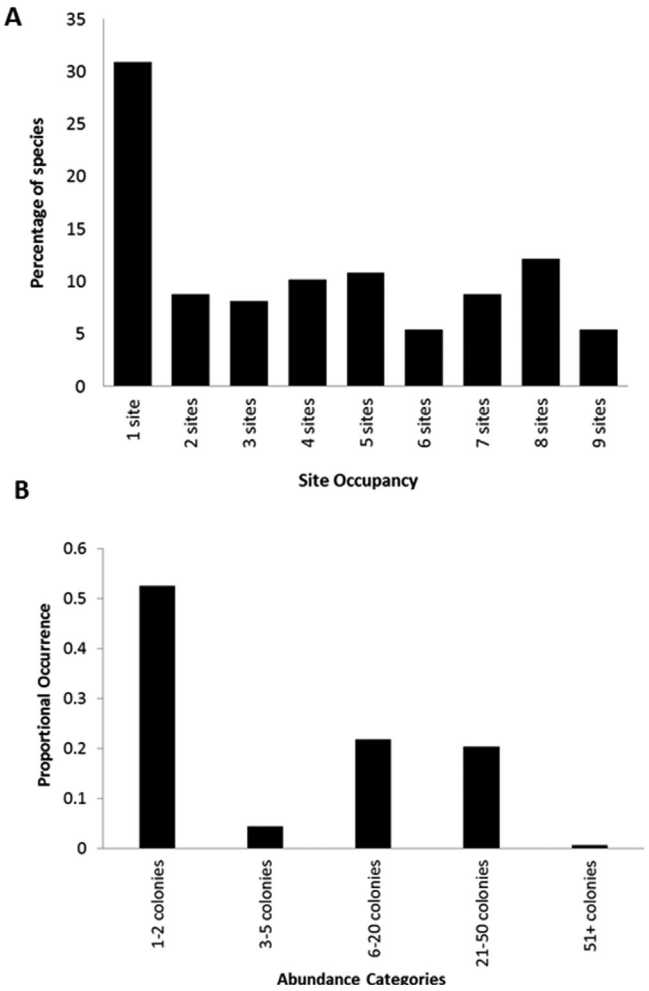

Fig. 5. Occupancy-abundance patterns in the Christmas Island coral community: A, percentage of species occupying one to nine sites; B, frequency of occurrence of species in each abundance category.

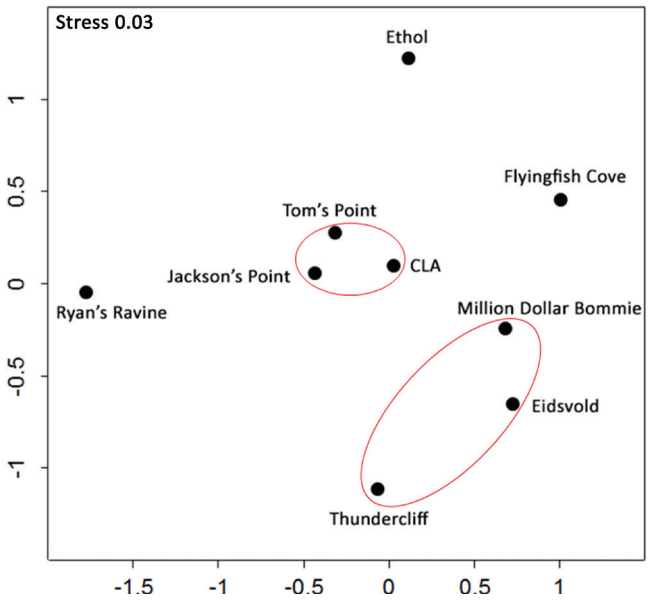

Fig. 6. Spatial variation in the composition of the coral community at Christmas Island depicted by Kruskal's non-metric multidimensional scaling (nm-MDS), using Bray-Curtis similarity index. Linkages are based on weighted pair group averages and ellipses indicate those sites with 60% similarity at $P < 0.001$.

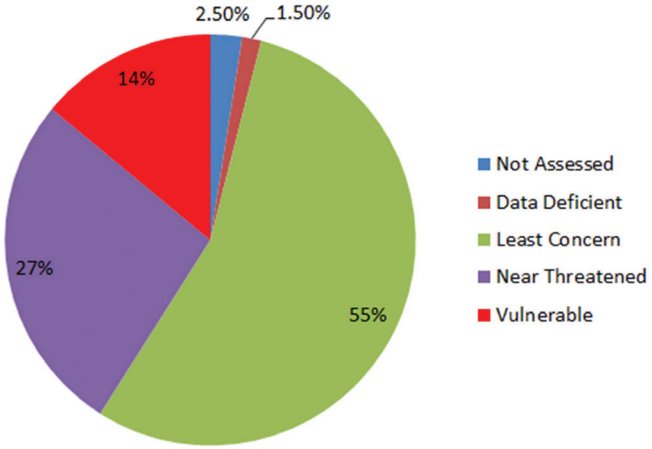

Fig. 7. Percentage of species in each IUCN category of threat at Christmas and Cocos Islands.

species (*Micromussa minuta*, *Acanthastrea brevis*, *Pavona bipartita*, *Pavona frondifera*, *Coscinarea monile*) have not previously been recorded from Australia. These species are principally known from either the Indian Ocean, Southeast Asia or northwest Pacific localities (Veron, 2000); hence the Christmas Island coral community shares affinities with regions other than Australia.

Based on current records, there is no evidence to suggest any corals are endemic to Christmas Island, however further examination with molecular techniques may reveal cryptic lineages within currently recognised species that are not apparent based on morphological features alone.

Factors affecting coral diversity. In this study, diversity indices (S, d, H', λ) were relatively similar between sites with the exception of Flyingfish Cove and Ryan's Ravine, where all diversity measures were highest and lowest (respectively). There was however, a slightly contradictory trend in evenness (J') whereby lower values at Million Dollar Bommie and Thundercliff may be indicative of a lack of historic disturbances at these sites (see the Intermediate Disturbance Hypothesis, Connell, 1978, 1997) which has led to the domination of *Porites lobata* and a different underlying pattern of community structure. The finding of high evenness at Flyingfish Cove may be a reflection that recent disturbances (see Conservation of Coral Diversity section) have impacted the locally dominant species, resulting in a more even pattern of species abundance.

Following colonisation of this oceanic island, the subsequent composition of the Christmas Island coral community has probably been strongly influenced by physical factors associated with storm events, oceanographic currents and fluctuating sea-levels. Christmas Island receives monsoonal storm and cyclonic activity and acute storm events have been observed to devastate coral communities at Christmas Island. For example, Cyclone Gillian, which passed nearby Christmas Island in March 2014 (after the current survey), devastated the *Galaxea*-dominated Ethel coral community leading to almost 100% mortality (J-P Hobbs unpublished data). Such catastrophic storm events are likely to lead to community re-assembly (Berumen & Pratchett, 2006; Pratchett et al., 2011; Graham et al., 2014) and to further explore and understand these shifts in the underlying community structure, temporal studies of coral diversity are needed.

Due to the isolation of Christmas Island and its oceanic origins, oceanographic currents are important in shaping the coral community because they determine the potential pool of species that are able to disperse to and colonise the Island. The 'Indonesian Through-flow' (ITF) current is the primary contemporary oceanographic driver in the region (Lee et al., 2002; Sprintall et al., 2009). This current is driven from the western central Pacific Ocean through deep passages in the Indonesian Archipelago into the Timor Sea and the eastern Indian Ocean (Fig. 1) (Pearce & Creswell, 1985; Wyrtki, 1987). The ITF current drives the Leeuwin Current off Western Australia and the north-eastern origin of the westward flowing Southern Equatorial Current (SEC) (Smith et al., 1991), which are hypothesized to drive the coral distribution patterns along the coast of Western Australia (Veron & Marsh, 1988; Greenstein & Pandolfi, 2008).

Surface circulation maps (Tchernia, 1980) indicate that Christmas Island lies in the path of the easterly flowing Southern Java Current, however as it reaches the Timor Sea this current is overpowered by the westerly flowing ITF and SEC, hence regional migration in the vicinity of Christmas Island is determinate (in westerly and southerly directions). In the Pleistocene however, sea-levels were approximately 120 m lower than they are now, therefore land bridges halted the flow of the ITF, and the SEC would not have flowed as it does today. With different current patterns in operation, it is possible that during low sea-level stands, eastward flowing currents brought propagules from the western Indian Ocean to the eastern Indian Ocean. Nevertheless, Christmas Island

Table 4. Coral species at Christmas and Cocos Islands that are listed as Vulnerable to extinction this century on the IUCN Red List of threatened species.

List of Vulnerable to extinction coral species	
Acanthastrea brevis	*Montipora capricornis*
Acropora anthocercis	*Montipora crassituberculata*
Acropora aspera	*Montipora lobulata*
Acropora donei	*Montipora turtlensis*
Acropora listeri	*Pavona bipartita*
Acropora microclados	*Pavona cactus*
Acropora paniculata	*Pavona decussata*
Acropora papillare	*Pavona venosa*
Alveopora allingi	*Porites cocosensis*
Cyphastrea agassizi	*Stylocoeniella cocosensis*
Galaxea astreata	*Turbinaria retiformis*
Isopora crateriformis	*Turbinaria stellulata*
Lobophyllia flabelliformis	*Heliopora coerulea*
Montipora angulata	

has always been isolated and therefore colonisation of the island is most likely for species with good dispersal ability, i.e., broadcast spawners with long-lived larvae. Such a pattern is evident in the fish community at Christmas Island, which is dominated by species with a long pelagic larval duration (Hobbs et al., 2012). Further research into the larval ecology of the corals at Christmas Island would aid in determining if the coral community is comprised primarily of good dispersers. Similarly, future research into population genetics of corals would help determine whether the populations wholly rely on self-replenishment or whether distant source populations play a role in sustaining the Christmas Island coral community.

A comparison of the corals of Christmas Island and Cocos (Keeling) Islands. The coral reef communities of the Cocos Islands have been researched more thoroughly than those of Christmas Island. From 1879–1994 there have been four major studies of corals. Veron (1994) summarises the historical surveys and when combined with his own collections, the total number of scleractinian coral species is 99 (Veron, 1990, 1994). In his account, Veron lists five species as *sp.* and suggests another two (*Montipora spumosa* and *Anacropora forbesi*) may be extinct. Given that Cocos Islands is the type locality for *Anacropora forbesi* (Ridley, 1884), a species with a broad geographic distribution (Veron, 2000), the loss of this species at its type location would be significant.

A synopsis of the species recorded at Christmas Island and Cocos (Keeling) Atoll is provided in Appendix 1 based on updated taxonomy. Veron (1994) previously compared the coral fauna of Cocos and Christmas, and found the principal difference is the much greater number of *Montipora* species at Cocos and the greater generic richness at Christmas. However, our survey has raised the number of *Montipora* spp. at Christmas Island from two to 15, which is equivalent to that known from Cocos. We find the main points of difference between the two locations include twice as many *Acropora* and *Leptoseris* species at Christmas than Cocos (Appendix 1). Also, no records of *Galaxea*, *Goniastrea*, *Goniopora*, *Platygyra* or *Symphyllia* species are known from Cocos, whereas two, three, nine, six and four species (respectively) have been recorded at Christmas. Furthermore, species from the genera *Coeloseris*, *Coscinaraea*, *Ctenactis*, *Diploastrea*, *Echinophyllia*, *Merulina*, *Mycedium*, *Micromussa*, *Heliopora*, *Plerogyra*, *Scapophyllia* and *Tubipora* have not been recorded at Cocos; however, all these genera are represented at Christmas Island.

There are an additional 23 species belonging to the genera *Echinopora*, *Favia*, *Favites*, *Fungia*, *Hydnophora*, *Isopora*, *Leptastrea*, *Lobophyllia*, *Pavona*, *Porites*, *Sandalolitha* and *Psammocora* that are recorded at Christmas but not at Cocos. Conversely, 11 species are recorded at Cocos but not at Christmas Island *(Barabattoia amicorum*, *Fungia concinna*, *Heroplitha limax*, *Leptastrea bottae*, *Leptoseris papyracea*, *Pavona cactus*, *Plesiastrea versiopora*, *Porites cylindrica*, *Porites evermanni*, *Porites somaliensis*, *Sandalolitha robusta*).

Although Christmas Island is considered the only 'stepping-stone' for westerly movement of propagules from Australia, Veron (1994) concluded that there is no clear evidence that Christmas Island has acted as a 'stepping stone' for the dispersal of corals to the Cocos Islands. While regional differences in species composition are apparent, there is a large subset of shared fauna and the extent of regional connectivity remains to be resolved in a molecular framework.

Conservation of coral biodiversity. The provinces of Christmas and Cocos Islands are among the most unique and threatened marine bioregions in Australia, yet receive no protection from Australia's National Representative System of Marine Protected Areas (Hobbs, 2014). For corals in these isolated provinces, there is likely to be a low capacity for larval recruitment from neighboring reefs, as demonstrated in other isolated systems (Ayre & Hughes, 2004; Gilmour et al., 2013), and this can impede coral reef recovery after disturbances (Graham et al., 2006). If however, the coral community is healthy and reproductively viable, self-recruitment and seeding could maintain a stable supply of propagules within this isolated location. Recent studies on isolated oceanic reefs in northwest Australia demonstrated this capacity for rapid self-replenishment following mass coral bleaching events (Ceccarelli et al., 2011; Gilmour et al., 2013). However, both of these studies clearly highlight that local anthropogenic impacts must be minimised to ensure recovery following disturbances. Hence at Christmas and Cocos Islands, the reproductive success of surviving mature colonies must be protected and this will be achieved through appropriate management of the fringing reef habitat and water quality.

Coral disease, crown- of-thorns starfish, and coral bleaching have significantly affected corals reefs in the Christmas and Cocos region (Colin, 1977; Berry, 2000; Hobbs & Frisch, 2010; Hobbs et al., 2013). Furthermore, phosphate pollution arising from ongoing mining operations and other environmental disasters such as the 2012 grounding of the MV Tycoon, which resulted in hundreds of tonnes of oil, diesel and phosphate being spilt onto reefs in Flying Fish Cove (Hobbs, 2014) further threaten the survival of coral reefs. Reducing local impacts, such as pollution, at Christmas Island should be a conservation priority.

Because Christmas Island has a restricted range of reef habitats (primarily consisting of steep walled habitats with high exposure to waves and currents) (Fig. 3a, e) and lacks sheltered habitats, species capable of dispersing to Christmas Island may not be able to persist due to the lack of sheltered habitat. The only semi-sheltered habitat (Flyingfish Cove) supports many locally rare coral species that are found nowhere else on Christmas Island (for example *Acanthastrea echinata*, *Acropora yongei*, *Echinopora gemmacea*, *Favites stylifera*, *Goniopora pandoraensis*) a pattern that is echoed in reef fishes (Hobbs et al., 2010). Therefore, Flyingfish Cove appears to be a critical refuge for coral reef biodiversity at Christmas Island and worthy of additional protection measures, especially given its close proximity to pollution sources.

CONCLUSION

This study has found that the coral community of Christmas Island is not species depauperate; but rather, it has a comparative level of diversity to that recorded in other isolated Eastern Indian Ocean locations. Furthermore, the Christmas Island coral community is characterised by affinity with other locations in the Indian Ocean, Southeast Asia and northwest Pacific faunas rather than solely with the Australian coral fauna. Conserving this unique coral community should be a management priority. The long-term fate of isolated reefs in Australia's Indian Ocean Territories (and the threatened species within) will depend on the recurrence and severity of future impacts (e.g., bleaching, storm damage, pollution events) relative to rates of recovery. To maximise the possibility of recovery, local disturbances must be kept to a minimum and this involves not only increasing the level of marine conservation effort but also improving the management and mitigation of pollution risks.

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Appendix 1. Coral species of Christmas and Cocos (Keeling) Islands summarised from the current and historical studies. Abbreviations for IUCN classification are as follows: NA = Not Assessed, DD = Data Deficient, LC = Least Concern, NT = Near Threatened, V = Vulnerable.

Family	Species (Authority)	Thus study	# Sites	Registration number of wet &/ or dry specimen or photograph	Done & Marsh (2000) Christmas Island	Veron (1994) Cocos (Keeling) Islands	IUCN Classification
Acroporidae	*Acropora abrotanoides* (Lamarck, 1816)	Yes	8	65826, 65859		Yes (as *A. danai*)	LC
Acroporidae	*Acropora anthocercis* (Brook, 1893)	Yes	1				V
Acroporidae	*Acropora aspera* (Dana, 1846)					Yes	V
Acroporidae	*Acropora austera* (Dana, 1846)	Yes	8	65825, 65860 (see Fig. 3I)			NT
Acroporidae	*Acropora cerealis* (Dana, 1846)	Yes	4	65878			LC
Acroporidae	*Acropora clathrata* (Brook, 1891)	Yes	9	65807, 65837, 65849, 65866, 65873 (see Fig. 3C)	Yes		LC
Acroporidae	*Acropora cytherea* (Dana, 1846)	Yes	8	65822, 65858	Yes	Yes	LC
Acroporidae	*Acropora digitifera* (Dana, 1846)					Yes (as *A. schmitti*)	NT
Acroporidae	*Acropora divaricata* (Dana, 1846)	Yes	1				NT
Acroporidae	*Acropora donei* Veron & Wallace, 1984	Yes	1	65870			V
Acroporidae	*Acropora exquisita* Nemenzo, 1971	Yes	1	65827		Yes	DD
Acroporidae	*Acropora gemmifera* (Brook, 1892)	Yes	6		Yes		LC
Acroporidae	*Acropora grandis* (Brook, 1892)	Yes	4	65797, 65817, 65856	Yes		LC
Acroporidae	*Acropora hyacinthus* (Dana, 1846)					Yes	NT
Acroporidae	*Acropora intermedia* (Brook, 1891)	Yes	2				LC
Acroporidae	*Acropora latistella* (Brook, 1891)	Yes	1		Yes (as cf.)	Yes	LC
Acroporidae	*Acropora listeri* (Brook, 1893)				Yes		V
Acroporidae	*Acropora lutkeni* Crossland, 1952	Yes	4			Yes (as *A. ocellata*)	NT
Acroporidae	*Acropora microclados* (Ehrenberg, 1834)	Yes	5	65843, 65865			V
Acroporidae	*Acropora microphthalma* (Verrill, 1859)					Yes	LC
Acroporidae	*Acropora millepora* (Ehrenberg, 1834)	Yes	1				NT
Acroporidae	*Acropora monticulosa* (Brüggemann, 1879)	Yes	7	65857	Yes		NT
Acroporidae	*Acropora muricata* (Linnaeus, 1758)	Yes	1			Yes (as *A. formosa*)	NT
Acroporidae	*Acropora nana* (Studer, 1878)	Yes	4	65887	Yes	Yes	NT
Acroporidae	*Acropora nasuta* (Dana, 1846)	Yes	2				NT
Acroporidae	*Acropora paniculata* Verrill, 1902	Yes	1			Yes	V

Family	Species (Authority)	Thus study	# Sites	Registration number of wet &/ or dry specimen or photograph	Done & Marsh (2000) Christmas Island	Veron (1994) Cocos (Keeling) Islands	IUCN Classification
Acroporidae	*Acropora papillare* Latypov, 1992	Yes	5	65867, 65886 (see Fig. 3B)			V
Acroporidae	*Acropora pulchra* (Brook, 1891)					Yes	LC
Acroporidae	*Acropora samoensis* (Brook, 1891)	Yes	8				LC
Acroporidae	*Acropora secale* (Studer, 1878)	Yes	1				NT
Acroporidae	*Acropora selago* (Studer, 1878)	Yes	4	65829, 65880			NT
Acroporidae	*Acropora stoddarti* Pillai & Scheer, 1976				Yes		DD
Acroporidae	*Acropora subulata* (Dana, 1846)	Yes	6			Yes	LC
Acroporidae	*Acropora tenuis* (Dana, 1846)	Yes	1				NT
Acroporidae	*Acropora valida* (Dana, 1846)	Yes	3	65831, 65861		Yes	LC
Acroporidae	*Acropora yongei* Veron & Wallace, 1984	Yes	1	65839			LC
Acroporidae	*Acroproa robusta* (Dana, 1846)					Yes	LC
Acroporidae	*Alveopora allingi* Hoffmeister, 1925				Yes		V
Acroporidae	*Astreopora gracilis* (Bernard, 1896)				Yes	Yes	LC
Acroporidae	*Astreopora listeri* Bernard, 1896	Yes	7		Yes		LC
Acroporidae	*Astreopora myriophthalma* (Lamarck, 1816)	Yes	9			Yes	LC
Acroporidae	*Isopora crateriformis* (Gardiner, 1898)	Yes	1				V
Acroporidae	*Isopora palifera* (Lamarck, 1816)	Yes	7		Yes (as *Acropora palifera*)	Yes (as *Acropora palifera*)	NT
Acroporidae	*Montipora aequituberculata* Bernard, 1897	Yes	1			Yes	LC
Acroporidae	*Montipora angulata* (Lamarck, 1816)					Yes	V
Acroporidae	*Montipora capricornis* Veron, 1985	Yes	1			Yes	V
Acroporidae	*Montipora crassituberculata* Bernard, 1897	Yes	2	65862			V
Acroporidae	*Montipora danae* (Milne Edwards & Haime, 1851)	Yes	3			Yes	LC
Acroporidae	*Montipora digitata* (Dana, 1846)					Yes	LC
Acroporidae	*Montipora efflorescens* Bernard, 1897					Yes	NT
Acroporidae	*Montipora foliosa* (Pallas, 1766)	Yes	1	65824		Yes	NT
Acroporidae	*Montipora foveolata (*Dana, 1846)	Yes	1				NT
Acroporidae	*Montipora grisea* Bernard, 1897	Yes	8	65821	Yes	Yes	LC
Acroporidae	*Montipora hoffmeisteri* Wells, 1954	Yes	2	65814, 65851, 65877			LC
Acroporidae	*Montipora informis* Bernard, 1897	Yes	9	65808	Yes	Yes	LC
Acroporidae	*Montipora lobulata* Bernard, 1897					Yes	V

Family	Species (Authority)	Thus study	# Sites	Registration number of wet &/ or dry specimen or photograph	Done & Marsh (2000) Christmas Island	Veron (1994) Cocos (Keeling) Islands	IUCN Classification
Acroporidae	*Montipora mollis* Bernard, 1897					Yes	LC
Acroporidae	*Montipora monasteriata* (Forskål, 1775)	Yes	6	65798, 65812, 65879		Yes	LC
Acroporidae	*Montipora peltiformis* Bernard, 1897	Yes	7	65820, 65876		Yes	NT
Acroporidae	*Montipora tuberculosa* (Lamarck, 1816)	Yes	5			Yes	LC
Acroporidae	*Montipora turgescens* Bernard, 1897	Yes	7				LC
Acroporidae	*Montipora turtlensis* Veron & Wallace, 1984	Yes	4	65799			V
Acroporidae	*Montipora undata* Bernard, 1897	Yes	6	65806, 65863			NT
Agariciidae	*Coeloseris mayeri* Vaughan, 1918	Yes	1				LC
Agariciidae	*Gardineroseris planulata* (Dana, 1846)	Yes	9		Yes	Yes	LC
Agariciidae	*Leptoseris explanata* Yabe & Sugiyama, 1941	Yes	1		Yes	Yes	LC
Agariciidae	*Leptoseris foliosa* Dinesen, 1980	Yes	1	65846			LC
Agariciidae	*Leptoseris hawaiiensis* Vaughan, 1907	Yes	1	65809, 65881			LC
Agariciidae	*Leptoseris mycetoseroides* Wells, 1954	Yes	7	65848	Yes	Yes	LC
Agariciidae	*Leptoseris papyracea* (Dana, 1846)					Yes	LC
Agariciidae	*Leptoseris scabra* Vaughan, 1907				Yes		LC
Agariciidae	*Leptoseris solida* (Quelch, 1886)	Yes	1	65869			LC
Agariciidae	*Pachyseris speciosa* (Dana, 1846)	Yes	5		Yes	Yes	LC
Agariciidae	*Pavona bipartita* Nemenzo, 1980	Yes	1	65838			V
Agariciidae	*Pavona cactus* (Forskål, 1775)					Yes	V
Agariciidae	*Pavona clavus* (Dana, 1846)	Yes	8		Yes		LC
Agariciidae	*Pavona decussata* (Dana, 1846)	Yes	1			Yes	V
Agariciidae	*Pavona duerdeni* Vaughan, 1907	Yes	2				LC
Agariciidae	*Pavona explanulata* (Lamarck, 1816)	Yes	5	65805	Yes	Yes	LC
Agariciidae	*Pavona frondifera* (Lamarck, 1816)				Yes	Yes	LC
Agariciidae	*Pavona maldivensis* (Gardiner, 1905)	Yes	1	65845	Yes	Yes	LC
Agariciidae	*Pavona minuta* Wells, 1954	Yes	2	65802	Yes	Yes	NT
Agariciidae	*Pavona varians* Verrill, 1864	Yes	8		Yes	Yes	LC
Agariciidae	*Pavona venosa* (Ehrenberg, 1834)	Yes	6		Yes	Yes	V
Astrocoeniidae	*Stylocoeniella armata* (Ehrenberg, 1834)	Yes	3	65850, 65888	Yes	Yes	LC
Astrocoeniidae	*Stylocoeniella cocosensis* Veron 1990					Yes	V
Astrocoeniidae	*Stylocoeniella guentheri* Bassett-Smith, 1890	Yes	7		Yes	Yes	LC
Coscinaraeidae	*Coscinaraea monile* (Forskål, 1775)				Yes		LC

Family	Species (Authority)	Thus study	# Sites	Registration number of wet &/ or dry specimen or photograph	Done & Marsh (2000) Christmas Island	Veron (1994) Cocos (Keeling) Islands	IUCN Classification
Dendrophylliidae	*Rhizopsammia verrillii* van der Horst, 1922				Yes		NA
Dendrophylliidae	*Tubastrea* spp.	Yes	1	65885	Yes		NA
Dendrophylliidae	*Turbinaria retiformis* Bernard, 1896	Yes	1			Yes	V
Dendrophylliidae	*Turbinaria stellulata* (Lamarck, 1816)				Yes		V
Diploastreidae	*Diploastrea heliopora* (Lamarck, 1816)	Yes	8		Yes		NT
Euphyllidae	*Euphyllia glabrescens* (Chamisso & Eysenhardt, 1821)	Yes	2				NT
Euphyllidae	*Galaxea astreata* (Lamarck, 1816)	Yes	4	65832	Yes		V
Euphyllidae	*Galaxea fascicularis* (Linnaeus, 1767)	Yes	7		Yes		NT
Euphyllidae	*Plerogyra sinuosa* (Dana, 1846)	Yes	3		Yes		NT
Fungiidae	*Ctenactis crassa* (Dana, 1846)	Yes	8				LC
Fungiidae	*Cycloseris explanulata* (van der Horst, 1922)	Yes	1	65854			LC
Fungiidae	*Fungia fungites* (Linnaeus, 1758)	Yes	5		Yes	Yes	NT
Fungiidae	*Heroplitha limax* (Houttuyn, 1772)					Yes	LC
Fungiidae	*Lithophyllon concinna* Verrill, 1864					Yes (as *Fungia concinna*)	LC
Fungiidae	*Lithophyllon repanda* (Dana, 1846)	Yes	3		Yes (as *Fungia repanda*)		LC
Fungiidae	*Lithophyllon scabra* (Döerlein, 1901)	Yes	6				LC
Fungiidae	*Lobactis scutaria* (Lamarck, 1801)	Yes	3		Yes (as *Fungia scutaria*)	Yes (as *Fungia scutaria*)	LC
Fungiidae	*Pleuractis granulosa* (Klunzinger, 1879)	Yes	4		Yes (as *Fungia granulosa*)	Yes (as *Fungia granulosa*)	LC
Fungiidae	*Sandalolitha dentata* Quelch, 1884	Yes	4	see Fig. 3G	Yes		LC
Fungiidae	*Sandalolitha robusta* Quelch, 1886					Yes	LC
Lobophylliidae	*Acanthastrea brevis* Milne Edwards & Haime, 1849	Yes	1	65796			V
Lobophylliidae	*Acanthastrea echinata* (Dana, 1846)	Yes	1		Yes		LC
Lobophylliidae	*Echinophyllia aspera* (Ellis & Solander, 1786)	Yes	5	65855			LC
Lobophylliidae	*Lobophyllia corymbosa* (Forskål, 1775)	Yes	5		Yes		LC
Lobophylliidae	*Lobophyllia flabelliformis* Veron, 2000	Yes	5	see Fig. 3H			V
Lobophylliidae	*Lobophyllia hataii* Yabe, Sugiyama & Eguchi, 1936				Yes		LC
Lobophylliidae	*Lobophyllia hemprichii* (Ehrenberg, 1834)	Yes	7		Yes	Yes	LC
Lobophylliidae	*Micromussa minuta* (Moll & Borel-Best, 1984)	Yes	4	65834			NT
Lobophylliidae	*Oxypora lacera* (Verrill, 1864)	Yes	5		Yes	Yes	LC

Family	Species (Authority)	Thus study	# Sites	Registration number of wet &/ or dry specimen or photograph	Done & Marsh (2000) Christmas Island	Veron (1994) Cocos (Keeling) Islands	IUCN Classification
Lobophylliidae	*Symphyllia radians* Milne Edwards & Haime, 1849	Yes	5		Yes		LC
Lobophylliidae	*Symphyllia recta* (Dana, 1846)	Yes	1				LC
Lobophylliidae	*Symphyllia valenciennesii* Milne Edwards & Haime, 1849	Yes	6		Yes		LC
Merulinidae	*Astrea curta* (Dana, 1846)	Yes	8	65864	Yes (as *Montastrea curta*)	Yes (as *Montastrea curta*)	LC
Merulinidae	*Barabattoia amicorum* (Milne Edwards & Haime, 1850)					Yes	LC
Merulinidae	*Cyphastrea agassizi* (Vaughan, 1907)					Yes	V
Merulinidae	*Cyphastrea microphthalma* (Lamarck, 1816)	Yes	9		Yes	Yes	LC
Merulinidae	*Cyphastrea serailia* (Forskål, 1775)	Yes	2		Yes	Yes	LC
Merulinidae	*Dipsastraea matthaii* Vaughan, 1918	Yes	4	65813	Yes (as *Favia matthaii*)	Yes (as *Favia matthaii*)	NT
Merulinidae	*Dipsastraea pallida* (Dana, 1846)	Yes	5		Yes (as *Favia pallida*)	Yes (as *Favia pallida*)	LC
Merulinidae	*Dipsastraea rotumana* (Gardiner, 1899)				Yes (as *Favia rotumana*)		LC
Merulinidae	*Echinopora gemmacea* Lamarck, 1816	Yes	1	65830			LC
Merulinidae	*Echinopora hirsutissima* Milne Edwards & Haime, 1849				Yes		LC
Merulinidae	*Echinopora horrida* Dana, 1846				Yes		NT
Merulinidae	*Echinopora lamellosa* (Esper, 1795)	Yes	7	65803, 65816		Yes	LC
Merulinidae	*Favites abdita* (Ellis & Solander, 1786)	Yes	8		Yes	Yes	NT
Merulinidae	*Favites chinensis* (Ellis & Solander, 1786)				Yes		NT
Merulinidae	*Favites complanata* (Ehrenberg, 1834)	Yes	1				NT
Merulinidae	*Favites halicora* (Ehrenberg, 1834)	Yes	1				NT
Merulinidae	*Favites pentagona* (Esper, 1794)	Yes	7	65847, 65874	Yes	Yes	LC
Merulinidae	*Favites rotundata* (Veron, Pichon & Wijsman-Best, 1977)	Yes	1				NT
Merulinidae	*Favites russeli* (Wells, 1954)				Yes		NT
Merulinidae	*Favites stylifera* (Yabe & Sugiyama, 1937)	Yes	1				NT
Merulinidae	*Goniastrea pectinata* (Ehrenberg, 1834)	Yes	2				LC
Merulinidae	*Goniastrea retiformis* (Lamarck, 1816)	Yes	5		Yes		NT
Merulinidae	*Goniastrea stelligera* (Dana, 1846)	Yes	8	65819		Yes (as *Favia stelligera*)	NT

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Merulinidae	*Hydnophora exesa* (Pallas, 1766)	Yes	4		Yes		NT
Merulinidae	*Hydnophora microconos* (Lamarck, 1816)	Yes	4		Yes	Yes	NT
Merulinidae	*Leptoria phrygia* (Ellis & Solander, 1786)	Yes	8		Yes	Yes	NT
Merulinidae	*Merulina ampliata* (Ellis & Solander, 1786)	Yes	1		Yes		LC
Merulinidae	*Merulina scabricula* Dana, 1846	Yes	1	65800			LC
Merulinidae	*Mycedium elephantotus* (Pallas, 1766)	Yes	1				LC
Merulinidae	*Platygyra daedalea* (Ellis & Solander, 1786)	Yes	2		Yes		LC
Merulinidae	*Platygyra lamellina* (Ehrenberg, 1834)				Yes		NT
Merulinidae	*Platygyra pini* Chevalier, 1975	Yes	2				LC
Merulinidae	*Platygyra ryukyuensis* Yabe & Sugiyama, 1936	Yes	1	65868			NT
Merulinidae	*Platygyra sinensis* (Milne Edwards & Haime, 1849)	Yes	3		Yes		LC
Merulinidae	*Platygyra verweyi* Wijsman-Best, 1976				Yes		NT
Merulinidae	*Scapophyllia cylindrica* Milne Edwards & Haime, 1848	Yes	4		Yes		LC
Pocilloporidae	*Pocillopora damicornis* (Linnaeus, 1758)	Yes	1		Yes	Yes	LC
Pocilloporidae	*Pocillopora eydouxi* Milne Edwards & Haime, 1860	Yes	8	65883	Yes	Yes	NT
Pocilloporidae	*Pocillopora meandrina* Dana, 1846	Yes	5	65840		Yes	LC
Pocilloporidae	*Pocillopora verrucosa* (Ellis & Solander, 1786)	Yes	8		Yes	Yes	LC
Pocilloporidae	*Pocillopora woodjonesi* Vaughan, 1918	Yes	4	65833 (see Fig. 3A)		Yes	LC
Pocilloporidae	*Seriatopora hystrix* Dana, 1846					Yes	LC
Poritidae	*Goniopora columna* Dana, 1846	Yes	2	65872	Yes		NT
Poritidae	*Goniopora djiboutiensis* Vaughan, 1907	Yes	1				LC
Poritidae	*Goniopora lobata* Milne Edwards & Haime, 1860	Yes	7	65828			NT
Poritidae	*Goniopora minor* Crossland, 1952	Yes	2	65875			NT
Poritidae	*Goniopora norfolkensis* Veron & Pichon, 1982				Yes		LC
Poritidae	*Goniopora pandoraensis* Veron & Pichon, 1982	Yes	1	65815			LC
Poritidae	*Goniopora stokesi* Milne Edwards & Haime, 1851	Yes	1	65871			NT
Poritidae	*Goniopora stutchburyi* Wells, 1955	Yes	8	65853	Yes		LC
Poritidae	*Goniopora tenuidens* Quelch, 1886				Yes		LC
Poritidae	*Porites australiensis* Vaughan, 1918	Yes	5			Yes	LC

Family	Species (Authority)	Thus study	# Sites	Registration number of wet &/ or dry specimen or photograph	Done & Marsh (2000) Christmas Island	Veron (1994) Cocos (Keeling) Islands	IUCN Classification
Poritidae	*Porites cocosensis* Wells, 1950	Yes	3	65844 (see Fig. 3D)		Yes	V
Poritidae	*Porites cylindrica* Dana, 1846					Yes	NT
Poritidae	*Porites evermanni* Vaughan, 1907					Yes (as cf.)	DD
Poritidae	*Porites lichen* Dana, 1846	Yes	5			Yes	LC
Poritidae	*Porites lobata* Dana, 1846	Yes	9	65810	Yes	Yes	NT
Poritidae	*Porites lutea* Milne Edwards & Haime, 1851	Yes	7	65801	Yes		LC
Poritidae	*Porites rus* (Forskål, 1775)	Yes	9	65804, 65841	Yes	Yes	LC
Poritidae	*Porites solida* (Forskål, 1775)	Yes	1	65818		Yes	LC
Poritidae	*Porites somaliensis* Gravier, 1911					Yes	NT
Poritidae	*Porites vaughani* Crossland, 1952	Yes	3		Yes		LC
Psammocoridae	*Psammocora digitata* Milne Edwards & Haime, 1851					Yes	NT
Psammocoridae	*Psammocora haimiana* Milne Edwards & Haime, 1851	Yes	8				LC
Psammocoridae	*Psammocora nierstraszi* Horst, 1921	Yes	3		Yes		LC
Psammocoridae	*Psammocora profundacella* Gardiner, 1898	Yes	3	65811	Yes (as *Psammocora superficialis*)	Yes (as *Psammocora superficialis*)	LC
Scleractinia incertae sedis	*Leptastrea bottae* (Milne Edwards & Haime, 1849)					Yes	NT
Scleractinia incertae sedis	*Leptastrea pruinosa* Crossland, 1952	Yes	9	65823, 65835, 65842, 65852	Yes	Yes	LC
Scleractinia incertae sedis	*Leptastrea purpurea* (Dana, 1846)	Yes	8	65836			LC
Scleractinia incertae sedis	*Leptastrea transversa* Klynzinger, 1879				Yes	Yes	LC
Scleractinia incertae sedis	*Plesiastrea versipora* (Lamarck, 1816)					Yes	LC
Hydrozoa - Stylasterina	*Distichopora* spp.	Yes	3	65889, 65890			NA
Octocorallia - Alcyonacea	*Tubipora musica*	Yes	1				NT
Octocorallia - Helioporacea	*Heliopora coerulea*	Yes	6	65884			V
Hydrozoa - Milleporina	*Millepora* spp.	Yes	1				NA
Hydrozoa - Stylasterina	*Stylaster* spp.	Yes	1	65891			NA

Appendix 2. Relative abundance of individual coral species at each of nine survey sites at Christmas Island. Category 1 = rare (1–2 colonies); category 2 = infrequent (3–5 colonies); category 3 = frequent (6–20 colonies); category 4 = common (21–50 colonies); and category 5 = dominant (51+ colonies).

Species	Flying Fish Cove	Eisvold	Ethol	CLA	NW Point	Tom's Point	Ryan's Ravine	Million Dollar Bommie	Thundercliff
Acanthastrea brevis								1	
Acanthastrea echinata	1								
Acropora abrotanoides	3	1	2	2	3	4	4	2	
Acropora anthocercis									1
Acropora austera	3	1	1		3	1	1	2	1
Acropora cerealis					1	2	1	1	
Acropora clathrata	3	3	3	3	4	2	3	3	3
Acropora cytherea	1	3	3	1	2		1	2	3
Acropora divaricata		1							
Acropora donei						1			
Acropora exquisita			1						
Acropora gemmifera	2		2	1		1	3	1	
Acropora grandis	2		2	2				3	
Acropora intermedia	1			1					
Acropora latistella								1	
Acropora lutkeni	1	1		2		2			
Acropora microclados	1	1		1	1	2			
Acropora millepora				1					
Acropora monticulosa	3	1	1	2	2	2	1		
Acropora muricata	1								
Acropora nana	1	1	1		1				
Acropora nasuta					3	1			
Acropora paniculata	1								
Acropora papillare	3		1		3	2		2	
Acropora samoensis	2	1	1	1	3	3		1	1
Acropora secale	1								
Acropora selago		1			1		1		1
Acropora subulata			1	1	1	3	3		1
Acropora tenuis								1	
Acropora valida	1		1						1
Acropora yongei	1								
Astrea curta	1		1	2	3	3	3	1	1
Astreopora listeri	2	3		1	2		1	2	3
Astreopora myriophthalma	2	3	1	3	3	3	2	3	1
Coeloseris mayeri	1								

Species	Flying Fish Cove	Eisvold	Ethol	CLA	NW Point	Tom's Point	Ryan's Ravine	Million Dollar Bommie	Thundercliff
Ctenactis crassa	2	2	1	1	2	2	1		1
Cycloseris explanulata	3			2	1	1		1	
Cyphastrea microphthalma	3	3	3	2	1	3	2	3	3
Cyphastrea serailia	1							1	
Diploastrea heliopora	3	3	1	3	1	2		2	1
Dipsastraea matthaii	1	2		1	1				
Dipsastraea pallida		2		2	1		1		1
Distichopora spp.	3					2			2
Echinophyllia aspera	3	1		1	1		1		
Echinopora gemmacea	1								
Echinopora lamellosa	4	1	2	1	2	1		2	
Euphyllia glabrescens	2							1	
Favites abdita	2	2	1		3	3	1	1	1
Favites complanata	1								
Favites halicora	2								
Favites pentagona	2	1		2	3	3	4	2	
Favites rotundata			1						
Favites stylifera	1								
Fungia fungites	3	3	1		1			1	
Galaxea astreata	2		5	2	2				1
Galaxea fascicularis	3	3	2		2	2	2		1
Gardineroseris planulata	3	3	3	2	1	3	2	3	2
Goniastrea pectinata		2		1					
Goniastrea retiformis	3	1	1	1				1	
Goniastrea stelligera	1	1	1	1	2	3		1	3
Goniopora columna			2			1			
Goniopora djiboutiensis								1	
Goniopora lobata	1	3	2	2		2		1	2
Goniopora minor	1	1							
Goniopora pandoraensis	1								
Goniopora stokesi						1			
Goniopora stutchburyi	2	2	1	2	2	1		1	1
Heliopora coercula	1		3	4	1	3	2		
Hydnophora exesa	1	1			1			1	
Hydnophora microconos	1		3		1		1		
Isopora crateriformis					1				
Isopora palifera	3	3		2	1	4		4	4

Species	Flying Fish Cove	Eisvold	Ethol	CLA	NW Point	Tom's Point	Ryan's Ravine	Million Dollar Bommie	Thundercliff
Leptastrea pruinosa	2	3	1	3	3	3	1	2	3
Leptastrea purpurea		3	2	3	1	2	1	3	2
Leptoria phrygia	2	2	2	2	2	2		1	2
Leptoseris explanata	1								
Leptoseris foliosa					1				
Leptoseris hawaiiensis		1							
Leptoseris mycetoseroides	2	2		1		1	1	1	1
Leptoseris solida						1			
Lithophyllon repanda		1				1			1
Lithophyllon scabra	1	1	1				1	1	2
Lobactis scutaria	1				1				1
Lobophyllia corymbosa	3	2		1				1	2
Lobophyllia flabelliformis		2		1	2			1	2
Lobophyllia hemprichii	3	3	1	3		3		3	3
Merulina ampliata	1								
Merulina scabricula	2								
Micromussa minuta					2		1	1	1
Millepora spp.						2			
Montipora aequituberculata								1	
Montipora capricornis								1	
Montipora crassituberculata					1	1			
Montipora danae		1						1	1
Montipora foliosa	1								
Montipora foveolata	1								
Montipora grisea	1	3		3	3	1	1	2	1
Montipora hoffmeisteri	1								1
Montipora informis	3	3	1	2	1	3	3	4	4
Montipora monasteriata	2	1				1	1	2	2
Montipora peltiformis	1	2	1	1	1			1	1
Montipora tuberculosa		1		1	1	1		3	
Montipora turgescens	2	1		1	1	1	2	1	
Montipora turtlensis	1	1		1				2	
Montipora undata	1	1		1	1	1			1
Mycedium elephantotus		1							
Oxypora lacera	2	3	1			1			1
Pachyseris speciosa	2	1	1			1	1		
Pavona bipartita			1						

Species	Flying Fish Cove	Eisvold	Ethol	CLA	NW Point	Tom's Point	Ryan's Ravine	Million Dollar Bommie	Thundercliff
Pavona clavus	1		2	1	1	3	1	1	1
Pavona decussata	1								
Pavona duerdeni					1		1		
Pavona maldivensis			1						
Pavona minuta	1					1			
Pavona varians	3	3	3	2	2	3		3	4
Pavona venosa	1		2	1	1	1		2	
Platygyra daedalea	1					1			
Platygyra pini	1							1	
Platygyra ryukyuensis					1				
Platygyra sinensis			1		1			1	
Plerogyra sinuosa		2				1			1
Pleuractis granulosa	1	3	1					1	
Pocillopora damicornis	1								
Pocillopora eydouxi	4		3	3	3	3	4	1	1
Pocillopora meandrina	2				1		2	1	1
Pocillopora verrucosa	3	4	3	4	3	3	4	3	
Pocillopora woodjonesi	1		1	1		1			
Porites australiensis		2		3		1	1	2	
Porites cocosensis					1	1		1	
Porites lichen	3	2					1	1	1
Porites lobata	4	4	3	5	4	3	3	5	5
Porites lutea	3			3	3	3	4	4	3
Porites rus	4	4	4	3	3	4	2	3	4
Porites solida	2								
Porites vaughani	1	1						1	
Psammocora explanulata		1							
Psammocora nierstraszi	1					1		1	
Psammocora profundacella	2		2	2	1	2	2	3	2
Sandalolitha dentata	1	2						1	1
Scapophyllia cylindrica	2		1	1					1
Stylaster spp.									3
Stylocoeniella armata		1						1	1
Stylocoeniella guentheri	1	2	1		2		1	1	2
Symphyllia radians	2				1	1	1		1
Symphyllia recta	2								
Symphyllia valenciennesii	1	1	1		1	1		1	

Species	Flying Fish Cove	Eisvold	Ethol	CLA	NW Point	Tom's Point	Ryan's Ravine	Million Dollar Bommie	Thundercliff
Tubastrea spp.							1		
Tubipora musica						1			
Turbinaria reniformis				1					