TIM SKEWES CONSULTING

Coral Sea sea cucumber survey

Coral Sea, April 2017

Timothy Skewes, Sanna Persson
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Executive summary

Australia's Coral Sea Commonwealth Marine Reserve (CSCMR) is an almost 1M km^2 region off the Australian north-east coast. It contains 18 emergent coral reef systems and is recognised as a large, diverse, and globally significant coral reef domain. The CSMR currently has 2 National Nature Reserves (NNR) which were declared 1982 covering Lihou Reef, Coringa Bank and Herald Reefs.

At least 12 commercially valuable species of tropical sea cucumber have been fished on these reefs of the CSCMR for many years, by the Australian Coral Sea Sea Cucumber Fishery (CSSCF), and recently, illegally by foreign owned and crewed fishing vessels (FFV).

In April 2017, we surveyed sea cucumber populations on 8 reefs of the CSCMR, including the reefs of the NNR, with several reefs being surveyed for the first time. We visited 109 sites at 15 different locations and collected data in 28 of 105 possible reef-habitat strata combinations (excluding deep terrace and drowned bank habitats; and Cato and Mellish Reefs); which contained approximately 51% of available shallow reef habitat area within the CSCMR. The sample coverage was somewhat restricted due to depth restrictions and adverse weather and sea conditions. Important reef habitats that remained under-sampled on surveyed reefs included: forereef habitat on most reefs; reef pinnacles on Lihou Reef and Coringa Bank; and most deep lagoon habitats.

The survey was able to estimate the density and population biomass of 10 commercial species with sufficient precision to make some inferences about their biogeography and population status. Species composition was extremely variable among reefs sampled, most likely due to a combination of differences in sea cucumber biogeography and fishing pressure.

The density of most sea cucumber species, and especially high value sea cucumbers was relatively low throughout the Coral Sea survey area, but especially those reefs that have been subject to most fishing. This low density probably reflects a naturally low carrying capacity for Coral Sea reefs, but is also due to unsustainable fishing pressure by FFV in particular for high value species at least. This is especially true for the southern reefs of the Coral Sea and also for the reef pass and sheltered deeper back reef habitats that were depleted of high value species.

Holothuria atra (Lollyfish) was the most abundant species in the study area, and were super abundant at several sites on Coringa Bank, usually on the shallow reef or backreef habitats in close proximity to coral cays. *Stichopus chloronotus* (Greenfish) was the second most abundant species, and (similarly to *H. atra*) was found in a few high-density locations on the shallow reef flat in close association with reef cays, primarily on Coringa Bank and Kenn Reef.

The third highest density species was the high value species *Thelenota ananas* (Prickly redfish), which was found in the majority of habitats and on most reefs, but had its highest density in the reef passes and lagoon pinnacles; and on Lihou Reef. The population biomass estimate of *T. ananas* was 1,903 t live weight (± 624 t; 90% CI) and made up over 30% of all sea cucumbers biomass. Its fishery (landed) biomass estimate of 1,109 t (± 364 t; 90% CI) is encouraging given the modest estimate of catches for the Australian CSSCF (18 t) and observed illegal FFV catch (240 kg for one vessel).

The highly targeted high value species, *Holothuria fuscogilva* (White teatfish), was found in very low densities throughout the study area, but was particularly scarce on the southern reefs, and was not seen at all on Saumarez Reef or Wreck Reef. *H. fuscogilva* has made up the largest component of the Australian CSSCF catch and has also been the focus of recent illegal fishing by FFV, indicating a strong causal link to unsustainable fishing pressure.

However, the estimated population size for *H. fuscogilva* from this survey will be underestimated due to limitations on survey depth (generally <20 m) and sea cucumber visibility, especially of juvenile *H. fuscogilva*. It is likely that some stocks of this deep-water species still occur in deeper habitat on the southern reefs due to the predominance of *H. fuscogilva* in the recent catch of a FFV on those reefs. Most larger reef systems in the Coral Sea have extensive areas of deep lagoon habitat in the 20 to 40 m depth range that may provide suitable habitat for a deep-water species such as *H. fuscogilva*. Very little is known about these deep lagoon areas, making it difficult to assess the status of *H. fuscogilva* populations. Even so, it is likely that the shallower habitats at least have been depleted, either by the Australian CSSCF, FFV, or a combination of the two.

The density of the other high value species, *Holothuria whitmaei* (Black teatfish), was relatively low overall (1.64 per ha). Its density in the Lihou Reef NNR was only 2.6 per hectare in the present survey compared to 4.5 per ha in 2008; and 9.4 per ha in Torres Strait and 20.9 per ha on closed reefs on the GBR. The low population density and downward trend of *H. whitmaei* would appear to indicate some fishery related depletion of this species. Even so, the estimated biomass for *H. whitmaei*, 215 t (± 155 t, 90% CI) landed weight, was large in relation to the known annual catch of the Australian CSSCF of less than 2 t per year (Woodhams et al., 2015); and the estimated catch for one apprehended FFV of 0.6 t (Skewes et al., 2017). It may be that undocumented FFV catch of this specie has occurred in recent times.

The deep lagoon reef pinnacles still have high densities of high value species (38.5 per ha for *H. whitmaei* and 17.2 per ha for *H. fuscogilva*) indicating that this habitat may not have been fished to a large extent, and may provide a significant source of recruitment for these high value species. The protection afforded by the established NNR would also appear to have afforded some protection to the higher value species on these reefs, probably due to high levels of compliance by Australian CSSCF.

Low and medium value species (e.g. *H. atra* and *S. chloronotus*) have been only lightly exploited and most are likely to be at near virgin biomass levels. There is also the possibility of large populations of diurnally burying species occurring in sandy reef habitats.

While this survey provided estimates of sea cucumber population density and biomass for several important reefs in the Coral Sea territory, the sampling was not representative of all reef habitats and the number of sample sites per reef was small. Regular resurveys would provide more certainty to these estimates and provide information suitable for determining trends in sea cucumber density. Every opportunity should be taken to gather additional sea cucumber density data for the CSCMR region, particularly of un-sampled reef-habitats (forereef habitat; reef pinnacles on Lihou Reef and Coringa Bank; and deep lagoon habitats); and un-sampled reefs (e.g. Flinders Reef, Osprey Reef, Willis Islets, Diane Bank, Tregrosse Reefs). If revisiting already sampled reefs, the periodicity should be at least once every 3 years to maintain population trend connectivity regards year class strength and stock requitement considerations.

Sea cucumber fisheries globally have been overexploited, highlighting the need for careful and responsive management. Australian fisheries are among the few tropical shallow water sea cucumber fisheries globally to have continued viability, especially for high value species. However, controlling illegal FFV activity is a high priority if the Coral Sea populations are to remain viable. The collection and analysis of fishery dependent data from the CSSCF, together with periodic surveys, should provide the basis for informed management decisions to promote sustainable utilisation and protect the values of the Coral Sea Commonwealth Marine Reserve.

1.1 Sea cucumbers as ecological indicators

Sea cucumbers are an appropriate ecological indicator species due to their important role in ecosystem functioning, and their risk from a range of threats, including fishing and climate change. However, the extremely patchy distribution of some high-density species (e.g. *H. atra* and *S. chloronotus*) means there could be large changes in density and distribution due to natural environmental and recruitment related factors and the drivers of their distribution is poorly understood.

Additional surveys of sea cucumber density will be required in un-sampled reefs and some reef-habitat combinations before a there is a sufficient understanding of sea cucumber biogeography to make totally informed decisions about future monitoring strategies, especially if a Coral Sea wide assessment is the goal. However, if the existing NNRs of Lihou Reef, Coringa Bank and Herald Cays is the focus, then the 3 known surveys carried out so far in those locations should provide enough information to formulate a survey approach suitable for monitoring sea cucumbers in those locations. We make a series of recommendations on the design and implementation of monitoring strategies for sea cucumbers in the Coral Sea.

2 Introduction

Australia's Coral Sea Commonwealth Marine Reserve (CSMR) is an almost 1M km^2 region off the Australian north-east coast adjacent to the Great Barrier Reef to the limit of Australia's EEZ. It contains 18 emergent coral reef systems located on offshore plateaux or the tops of seamounts, many with multiple smaller reefs forming their perimeter (Figure 2-1) (Ceccarelli et al., 2013). It is recognised as a large, diverse, and globally significant reef domain (Ceccarelli et al., 2013; McKinnon et al., 2014).

A new management plan is currently being implemented for the CSMR. Until it is implemented, transitional arrangements apply, including the current protection form fishing for Lihou Reef, Coringa Bank and Herald Reefs which were declared National Nature Reserves (NNR) in 1982.

The reefs of the CSMR are impacted by a range of pressures including fishing and climate change. At least 12 commercially valuable species of tropical sea cucumber are documented to occur on reefs of the CSMR and are found in all reef habitats from the shallow reef flat to depths of 50 m or more (Woodhams et al., 2015; Purcell et al., 2012). Sea cucumbers have been fished on these reefs for many years, and since the early 1990s by the Australian Coral Sea Sea Cucumber Fishery (CSSCF), though effort in the fishery has been relatively low since about 2010. Sea cucumbers have also recently been fished illegally by foreign owned and crewed fishing vessels (FFV), with recent activity predominantly by Vietnamese based fishing vessels (blue boats).

2.1 The Coral Sea Sea Cucumber Fishery

The AFMA managed Coral Sea Sea Cucumber Fishery (CSSCF) includes most of the reefs in the CSMR apart from Saumarez and Marion Reefs, which are part of the Queensland East Coast Sea Cucumber (Beche-de-mer) Fishery (Figure 2-1). Sea cucumbers have been fished from most reefs in the CSMR apart from the NNRs (Hunter et al., 2002; Woodhams et al., 2015). Fishery logbook data indicates that over 70% of sea cucumber catch in the CSSCF since 1997 has been taken off one reef (Woodhams et al., 2015) (data confidentiality prevents identification of that reef).

The total catch for the CSSCF for the period 1997 to 2009 was 143 t (Woodhams et al., 2015), with the peak annual catch of 49 t in 2000–01. Annual catches since 2007–08 have generally been less than 3 t, but increased to 8.2 t in 2013–14. There has been no fishing since 2013-14 (AFMA, unpublished data; AFMA, 2015).

The primary target species in the catch up to 2009-10 (Woodhams et al., 2016) included:

- *Holothuria fuscogilva* (White teatfish) — 58 t
- *Holothuria whitmaei* (Black teatfish) — 23 t
- *Thelenota ananas* (Prickly redfish) — 18 t
- *Actinopyga mauritiana* (Surf redfish) — 16 t

These 4 species make up over 80% of the catch. At least another 9 species have been recorded in the catch.

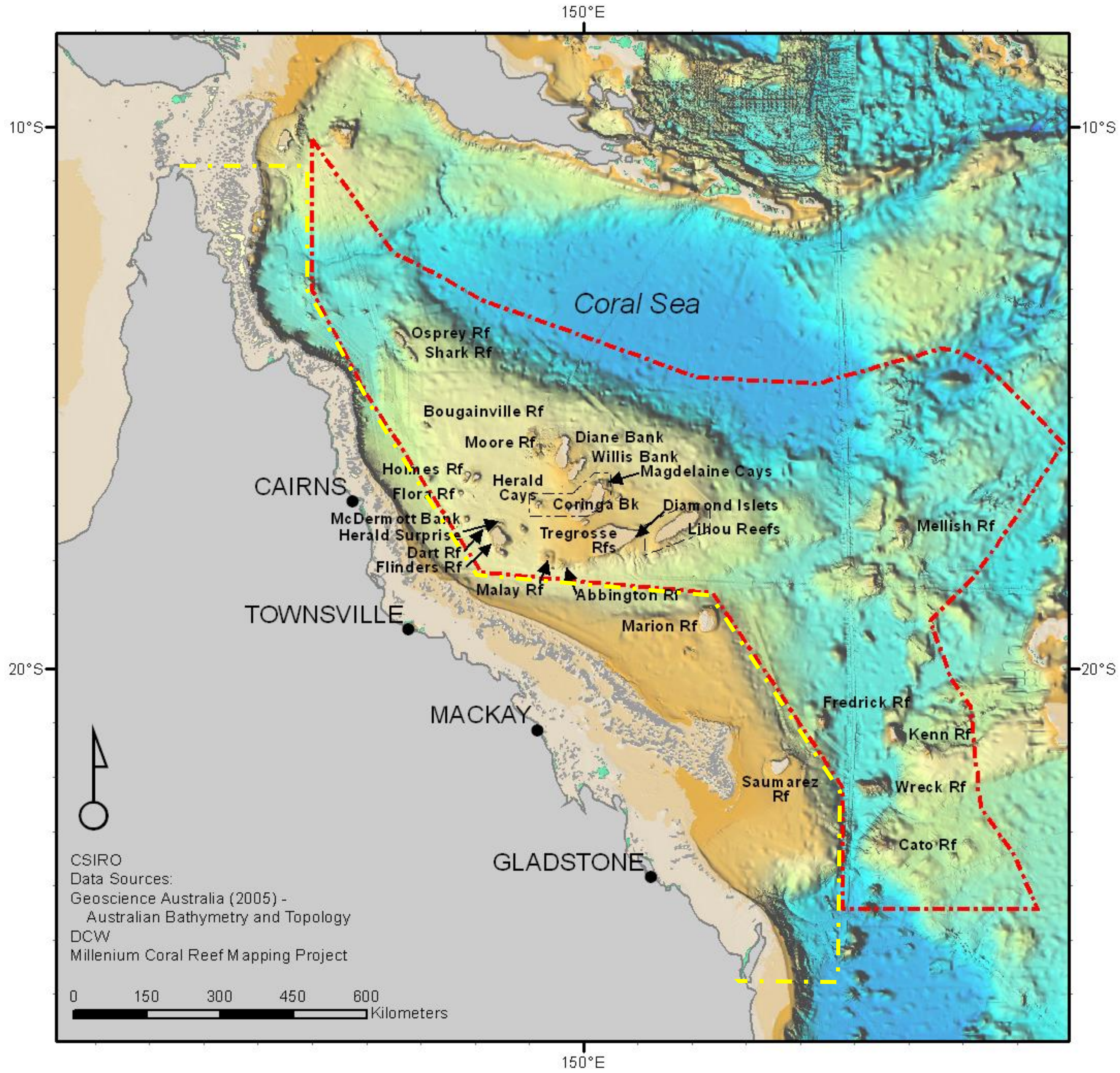


Figure 2-1. Area of the Coral Sea Sea Cucumber Fishery (red boundary) and Queensland East Coast Sea Cucumber (Beche-de-mer) Fishery (yellow boundary).

Maximum depth information is also recorded in logbooks of the Coral Sea Sea Cucumber Fishery to indicate the depth range of species in the catch (Figure 2-2) (Woodhams et al., 2015). It shows that more than 65 per cent of the *H. fuscogilva* (White teatfish) catch was taken at locations with a maximum depth recorded of between 30 and 40 metres. Similarly, the majority of the catch of *T. ananas* (Prickly redfish) was taken in waters deeper than 20 m. In contrast, more than 50 per cent of *H. whitmaei* (Black teatfish) catch was taken with an associated maximum depth of 0–10 metres. Harvesting *A. mauritiana* (Surf redfish) was mostly from locations shallower than 10 metres. These catch depth ranges are indicative of the preferred habitat for these species (Purcell et al., 2012).

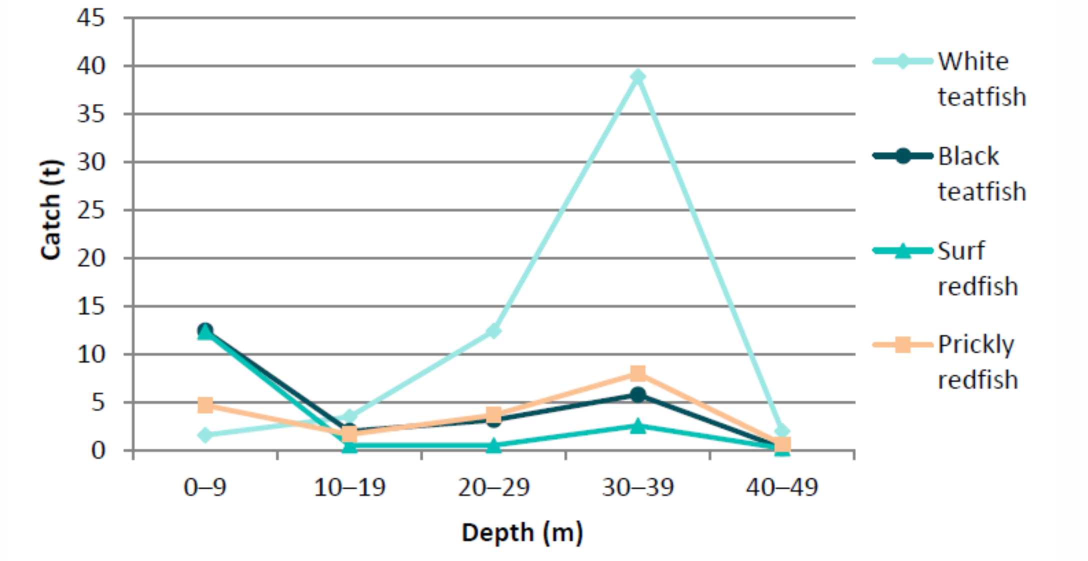


Figure 2-2. Total catch of key species of the Coral Sea Sea Cucumber Fishery by maximum depth field recorded in logbooks (Woodhams et al., 2015).

2.1.1 Management

The Coral Sea Sea Cucumber Fishery (CSSCF) is one of five Australian fishery sectors in the Coral Sea and is managed through input and output controls including limited entry, catch limits, spatial closures, move-on provisions, size limits and catch-and-effort triggers that are used to initiate further analysis and assessment. Fishers must hold permits to fish in the fishery and they can only catch species associated with the type of permit they hold. The Sea Cucumber Sector currently has 2 permits. The fishery also requires the granting of a Wildlife Trade Operation permits by the Commonwealth Environment Department based on ecological sustainability considerations. Most of the management arrangement in the CSSCF are complimentary to the adjacent Queensland East Coast Sea cucumber (beche-de-mer) Fishery.

In 2008 there was also implemented a formal Harvest Strategy (HS) as part of a rollout of Harvest Strategies in Commonwealth fisheries. This was in response to the Commonwealth Fisheries Harvest Strategy Policy 2007 (HSP) (DAFF 2007) which directed that Commonwealth fisheries should be managed to pursue 'the sustainable and profitable utilisation of Australia's Commonwealth fisheries in perpetuity through the implementation of harvest strategies that maintain key commercial stocks at ecologically sustainable levels and within this context, maximise the economic returns to the Australian community'.

The CSSCF is regarded as "low data" fishery in that there is a lack of local survey and assessment information available (Dowling et al., 2008). The basis of the HS was therefore predicated on an assumption that existing fishing effort was sustainable, and that any changes in catch and/or catch composition would result in further action. Most of the trigger limits that either control catch or initiate additional analysis and/or assessment are contained in the harvest strategies. The HS for the CSSCF were developed in collaboration with industry and were implemented in 2007.

Current management arrangements include an overarching Total Allowable Catche (TAC) of 150 t, with species specific TACs for several high and medium targeted species (Table 2-1). These species TACs have never been exceeded in the CSSCF.

The management arrangements also include spatial management including move-on provisions where a fishing vessel can only catch a maximum of 5 t from any one reef annually, with no fishing within 15 n.m. once that limit is reached. It also includes a three-year rotational harvesting strategy (RHS) that was implemented in 2005 (included in permit conditions). The RHS Identifies 21 reefs in the fishery with a set number of days fishing on each reef. Each reef is only open one year in three (Table 2-2). Note that

Saumarez and Marion Reefs, as part of the Queensland East Coast Sea Cucumber Fishery, is also part of a similar RHS that is implemented in that fishery. Research on both the Coral Sea (Plaganyi et al., 2011) and GBR fisheries (Skewes et al., 2013; Plaganyi et al., 2015) have indicated that risk of overexploitation was reduced under a RHS for sea cucumbers.

There are also species-specific size limits for all species caught in the fishery (Table 2-1). They are intended to allow individuals to breed once before being fished.

Table 2-1. Management arrangements for the Coral Sea Sea Cucumber Sector in the CSF (AFMA 2015).

Common name	Species	Minimum size limit	Total Allowable Catch
Black teatfish	*Holothuria whitmaei*	25 cm	1 tonne
White teatfish	*Holothuria fuscogilva*	32 cm	4 tonnes
Prickly redfish	*Thelenota ananas*	30 cm	20 tonnes
Surf red fish	*Actinopyga mauritiana*	15 cm	10 tonnes
Greenfish and Lollyfish	*Stichopus chloronotus and Holothuria atra*	15 cm	10 tonnes
Other species		15 cm	10 tonnes
All species of the Order Aspidochirotida		15 cm	150 tonnes (including the take of the above species)

Table 2-2. Sea cucumber sector rotational zone plan (AFMA, 2015)

2016-2017		2017-2018		2018-2019	
Days permitted	Zone	Days permitted	Zone	Days permitted	Zone
15	Holmes Reef	15	Wreck Reefs	15	Flinders Reefs
15	Diamond Islets	5	Tregrosse Reefs	15	Willis Islets
10	Kenn Reefs	5	Moore Reefs	30	Osprey Reef
5	Frederick Reefs	5	Mellish Reefs	5	Diane Bank
2	Bougainville	5	Cato Island Reef	2	Malay Reef
2	Flora Reef	5	McDermott Bank	2	Abington Reef
		2	Dart Reef		
		2	Heralds Surprise		
		2	Shark Reef		

2.1.2 Stock assessments

In 2002, an assessment examining logbook data and catch rates from 2000 and 2001 for a number of target species in the Coral Sea Sea Cucumber Fishery (CSSCF) showed a decline in the number of the higher valued *H. whitmaei* (Black teatfish), *T. ananas* (Prickly redfish) and *H. fuscogilva* (White teatfish) (Hunter et al., 2002). Following the assessment results and recommendations, AFMA reduced the annual TACs for *H. whitmaei* and *H. fuscogilva* to 1 tonne and 4 tonnes respectively in 2002. While these catch quotas were considered as extremely conservative given the size of the area and likely species density in the fishery habitats, there is a global predominance of over-exploitation and slow recovery of sea cucumber fisheries illustrating the need for careful management (Purcell et al., 2012).

Reducing Uncertainty in Stock Status (RUSS) project

The status of Commonwealth fisheries has been reported in the Fishery Status Reports produced by BRS/ABARES since 1992. These document scientific and economic information for each Commonwealth fishery and they provide government, industry and the community with an independent overview of trends in the biological status of fish stocks for Commonwealth fisheries.

The Reducing Uncertainty in Stock Status (RUSS) project was a research programme to try and reduce the number of Commonwealth fish stocks that classified as uncertain. A series of stock assessments were undertaken including in the Coral Sea Fishery.

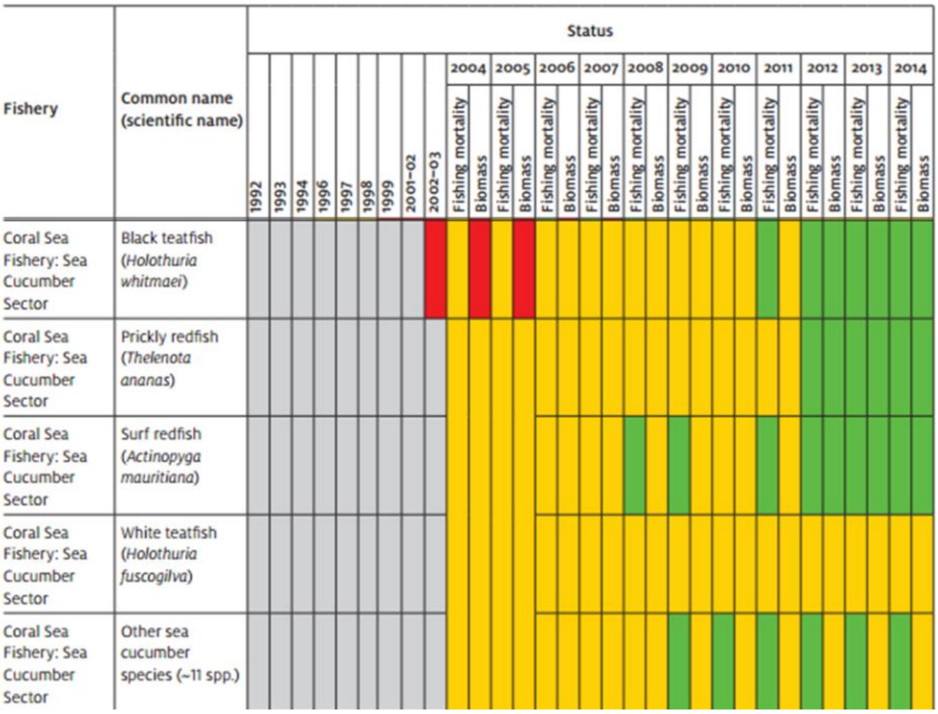
The outputs of the RUSS project have been used to modify the assessments of the status of the CSSCF in the Fishery Status Reports since about 2012, resulting in many previously uncertain stock status and fishing mortality assessments being reclassified as not overfished and not being subject to overfishing (Table 2-3). The RUSS project assessed the 4 primary target species (*H. whitmaei* (Black teatfish), *H. fuscogilva* (White teatfish), *Actinopyga mauritiana* (Surf redfish) and *T. ananas* (Prickly redfish)) (Woodhams et al., 2015).

The assessment estimated a plausible potential biomass for each species in the CSSCF. It used habitat data from satellite mapping and historical surveys of sea cucumbers in NNR, Qld (GBR) and Torres Strait. MSY was estimated using surplus production models, and fished biomass in 2010 was estimated as a proportion of biomass in 1997. Generally, the data availability was poor across all species, and was particularly poor for *H. fuscogilva* and *A. mauritiana*. Analyses was done at the reef level but status determination is undertaken at the fishery level.

The principal finding of the RUSS analysis (Woodhams et al., 2015) were:

- *H. whitmaei* (Black teatfish) and *T. ananas* (Prickly redfish) median biomass was greater than 99% of 1997 biomass.
  - classified as not overfished and not subject to overfishing.
- *A. mauritiana* (Surf redfish) median biomass was between 70 % and 91 % of 1997 biomass.
  - *A. mauritiana* (Surf redfish) catch was greater than the median MSY for 3 of 14 years since 1997.
  - Recent catches for surf redfish have been less than the median MSY.
  - classified as unlikely to be overfished and not subject to overfishing.
- *H. fuscogilva* (White teatfish) biomass could not be established.
  - *H. fuscogilva* (White teatfish) catches in recent years well below the historical peak of 19.7 t.
  - *H. fuscogilva* (White teatfish) stock remains uncertain with respect to being overfished and overfishing.
- No stock assessments of the group of other sea cucumber species.
  - Catch has recently been very low.
  - Classified as uncertain with respect to being overfished and not subject to overfishing.

Table 2-3. Biological stock status of stocks in the Coral Sea Sea Cucumber Fishery, assessed in 2014, and their status since 1992. As reported in the 2015 Fishery Status Reports (Patterson et al., 2016) as Fishing mortality status (is it being overfished or not); and Biomass status (is it overfished or not).



2.2 Illegal fishing activity

The reefs of the Coral Sea have long been subject to illegal fishing by foreign owned and crewed fishing vessels (FFV), with recent activity predominantly by Vietnamese based fishing vessels (blue boats) focused on sea cucumber. This activity has resulted in several recent apprehensions, with 13 FFV being apprehended with illegal sea cucumber product fished from the Coral Sea and Great Barrier Reef since 2016 (AFMA, unpublished data; Skewes, 2017).

Sightings and apprehensions of illegal fishing by FFV within the Coral Sea since 2016 has indicated illegal fishing effort has concentrated on Lihou Reef (45% of sightings) with Saumarez Reef second (17%) and the remainder split equally at Diane Bank, Willis Bank, Kenn Reef and Wreck Reef (AFMA, unpublished data).

The total catch of illegal fishing in the Coral Sea is unknown, however, the documented catch of one FFV apprehended at Saumarez Reef in early 2017 was 8.9 t salted weight (equivalent to 19.8 t live weight), of which 6.2 t salted weight (14 t live weight) was likely to have been sourced within Australia's Coral Sea Commonwealth Marine Reserve (Table 2-4). The catch was mostly made up of *H. fuscogilva* (White teatfish) (86%), with lesser quantities of *H. whitmaei* (Black teatfish) (10%) and *T. ananas* (Prickly redfish) (2%). It is likely that the catch was sourced from reef passes and deeper lagoon habitats of the Coral Sea reef, as indicated by ship logs and plotter information found on board (AFMA, unpublished data; Skewes, 2017).

Table 2-4. Catch estimate of a FFV apprehended at Saumarez Reef in February 2017, in tonnes salted and live weight (Skewes, 2017).

CATCH (T)	WHITE TEATFISH	BLACK TEATFISH	PRICKLY REDFISH	LEOPARD FISH	REDFISH	STONE FISH	TOTAL
Salted weight	5.32	0.61	0.12	0.05	0.05	0.05	6.19
Live weight	12.26	1.15	0.24	0.11	0.11	0.11	13.98

The illegal FFV catch of one vessel represented 133% of the *H. fuscogilva* (White teatfish), and 61% of the *H. whitmaei* (Black teatfish) annual Total Allowable Catch (TAC) for the entire Australian Coral Sea Sea Cucumber Fishery. While these TACs are considered as likely to be quite conservative, there is considerable uncertainty about the *H. fuscogilva* population, particularly in the Coral Sea (Woodhams et al., 2015), so this represents a substantial risk to the sustainability of the sea cucumber populations in the Coral Sea territory. In addition, as much as 75% of the *H. fuscogilva* catch, and almost 90% *H. whitmaei* in the catch was smaller than the minimum size limit (MSL) for the Australian CSSCF and GBR fisheries.

The provision for large numbers of simultaneous divers on the FFV indicated the likelihood of intense localised fishing effort by the FFV, and was likely to result in a marked decrease in the density of sea cucumbers in the habitats where fishing effort has occurred, such as reef passes and deeper lagoon areas. It is likely that the fishing effort would be targeted to the reef passes due to the shallower depths compared to the deep lagoon, and the presence of currents that would make a drift operation (fishing operations appear to be solely conducted from the main vessel) feasible. This mode of operation is supported by available data from logbooks and plotter information found on board the FFV (AFMA, unpublished data).

2.3 Previous surveys

The shallow reefs of the Coral Sea have largely been understudied, particularly those reefs outside the established National Nature Reserve (NNR) areas. Most of the ecological research in the region has focussed on the NNRs of Lihou Reef, Coringa bank and herald Reefs (Ceccarelli et al., 2013).

Two previous surveys of reefs in the two Coral Sea NNR (Lihou Reef NNR and Coringa-Herald NNR) have been commissioned by Commonwealth Department of the Environment of the. These surveys used several visual census sampling techniques to estimate the cover of coral, fin fishes and benthic invertebrates, including sea cucumbers. The surveys and sampling methods included (from a summary in Woodhams et al., 2016):

- Coringa-Herald NNR, March-April 2003 (Oxley et al., 2003);
  - snorkel swims of reef flat—500 metres by 5 metres transects (1–5 metres depth)
  - manta tows of back reef—~325 metres by 2 metres transects
- Lihou Reef NNR, March 2004 (Oxley et al., 2004)
  - snorkel swims of reef flat—500 metres by 10 metres transects (2–6 metres)
  - SCUBA search of reef back, front and flanks—50 metres by 5 metres transects (down to 9 metres)
- Coringa-Herald NNR, May and October 2007 (Cessarelli et al., 2008)
  - snorkel swims of reef flat—500 metres by 10 metres transects
  - SCUBA search of reef back, front and flanks—500 metres by 5 metres transects (down to 20 metres)
- Lihou Reef NNR, December 2008 (Ceccarelli et al., 2009)
  - snorkel swims of reef flat—~500 metres by 10 metres transects
  - SCUBA search of reef back, front and flanks—500 metres by 5 metres transects.

The surveys produced density estimates for several sea cucumbers in several locations within the NNR. The surveys showed a high variability in habitat structure and cover live coral. Sea cucumber populations were generally lower species diversity and density than the GBR, but greater at Lihou Reef apart from several high density populations of *H. atra* (Lollyfish) on Coringa Bank. Past research has indicated that the Coral Sea reefs are subject to a high degree of disturbance, with exposure to a high frequency of tropical cyclones and coral bleaching events (Ceccarelli et al., 2013).

2.4 Project objectives and scope

This research project is based on a survey of sea cucumbers at 8 reefs of the Coral Sea Commonwealth Marine Reserve in April 2017, with several reefs being surveyed for the first time. The primary objective was to provide information to quantify and assess the status of sea cucumber populations and supporting habitats on those reefs over a broad area of the Coral Sea; as input into the effective management of the CSMR and the maintenance of its ecological values.

Outputs include:

1. Estimates of relative abundance of sea cucumbers at selected sites;
2. Comparison of relative abundance of key economic species between fished versus non-fished sites;
3. Advice on the impacts of removal of key economic species;
4. Advice on utility of holothurians as ecological indicators in the Coral Sea.

3 Methods

3.1 Coral sea reefs habitat mapping

We used available reef habitat mapping products to define the extent of several reef habitat classes relevant to sea cucumber distribution, based on: depth, slope, exposure to prevailing waves, and reef morphology (Woodhams et al., 2015; Skewes et al., 2010; Purcell et al., 2012). These were:

1. Reef flat (emergent shallow reef flat)
2. Forereef (the ocean facing edge of the reef facing the predominant SE trade winds)
3. Backreef (the ocean facing edge of the reef facing the NW monsoon winds)
4. Inner slope (sloping reef on the inside of the reef crest toward the lagoon)
5. Sub-tidal reef flat (subtidal reef flat to approximately 20 m depth)
6. Pass (deeper, high flow areas between sub-reef units)
7. Deep lagoon (>20 m deep lagoon and deep terrace associated with reef complexes)
8. Lagoon pinnacles (shallow, >5 m, coral reef structures within deep lagoons)

The primary data source was the Millennium Coral Reef Mapping Project, provided by the Institute for Marine Remote Sensing, University of South Florida (IMaRS/USF) and Institut de Recherche pour le Duveloppement (IRD, Centre de Noumua), with support from NASA (IMaRS-USF, IRD, 2005). The mapping was done using high-resolution (30 metres) multispectral satellite imagery (Landsat 7 images acquired between 1999 and 2002) that was subjected to a supervised classification (by IMaRS/USF) to generate geomorphological classes.

The following modifications were made to the Millennium Coral Reef Mapping product, based on field data, depth, slope exposure to prevailing waves and reef morphology (Oxley et al., 2003; 2004; Ceccarelli et al. 2008; 2008; this study):

- Lihou Reef, converted shallow reef flat patches within the deep lagoon to reef pinnacles;
- Holmes Reefs, added reef pass between the north and south reefs;
- Holmes Reef, defined a backreef habitat adjacent to the reef flat;
- Herald Cays, added 7 reef pinnacle habitats using information from Google earth image;
- All reefs, changed all NW facing forereef habitats to backreef;
- All reefs, changed all deep terrace to deep lagoon;
- Wreck Reef, added a reef pass habitat to the east of Porpoise Cay.

Not all reefs of the Coral Sea are covered by the Millennium Coral Reef Mapping dataset, including Saumarez, Cato and Mellish Reefs. For Saumarez Reef, we used the reef mapping products available through the 3DGBR Project (© www.deepreef.org; R. Beaman, JCU) for initial mapping of the “dry reef” (equivalent to reef flat) habitat and reef outline. Forereef and backreef habitats were then constructed from 1 km buffer of the dry-reef habitat. The remainder was designated as deep lagoon. This product is note as accurate as fully remote sensed data but is the best that we can do without more sophisticated mapping of Saumarez reef.

The resulting Coral Sea reef habitat map, for all reefs apart from Cato and Mellish Reefs, was then used in the GIS for sample design and stratified density and population size estimates. Area for all habitat polygons were calculated in the GIS and output for the population estimate analysis. Appendix B provides reef by reef area estimates for all habitat types. It includes over 1.4M ha of reef habitat in the Coral Sea region, including 202,901 ha of shallow reef habitat (less than 20 m deep). This area of shallow reef habitat compares to 242,600 ha of shallow reef habitat in Torres Strait (Long et al., 1996) and 2.6M ha of shallow reef habitat in the GBR (GBRMPA; Skewes et al., 2012).

3.2 Sample design

Each reef was divided into a 1 km^2 or 2 km^2 grid (depending on the habitat type). Sample sites were then located within the grids at random by selecting from 25 possible sites within a restricted area of the grid. The randomised site grid was allocated to reef habitat by a spatial join with the reef habitat map in a GIS. This approach meant that it would not be possible to sample all sites allocated to a reef in the time available, but allowed for sampling as many sites and habitats as possible at selected locations given the time and logistical constraints. Sites previously sampled on Lihou Reef and Coringa Back and Herald Reefs in 2008 and 2009 (Ceccarelli et al., 2007; Ceccarelli et al., 2009) were also visited where possible.

Reef locations were primarily selected to optimise the sampling of coral cover and bleaching rate at repeated sites (unrelated project – Dr Hugo Harrison, JCU). Logistical (ships path, anchorages) and safety (weather conditions) consideration also determined locations visited.

3.3 Field sampling

We sampled eight Coral Sea reefs within the CSCMR over an 18-day period from the 9th to 21st April 2017. Due to the strategy of sampling over a broad region of the Coral Sea, and the requirement to resample established coral cover sites, we sampled sites in as many habitats as possible in the vicinity of the coral sample locations. This was usually carried out between 1 and 6 locations at each reef that was visited (Table 3-1, Figure 3-1).

The selection of sample sites at each location was based on four considerations: 1) logistic constraints with respect to the amount of sampling that could be done in one day from the support vessel; 2) exclusion of sites with unsuitable habitat sites (e.g. >20m depth); 3) optimal allocation of sampling effort to the habitat strata based on the expected density of higher value species (e.g. *H. whitmaei* (Black teatfish) and *H. fuscogilva* (White teatfish)); and 4) weather and sea conditions.

In all, we sampled 109 sites on 8 reefs during the survey (Table 3-1, Figure 3-1), including 17 repeated sites. This included 3 reefs that were declared National Nature Reserves (NNR) in 1982, and therefore have been protected from fishing (by the Australian fishery at least). In all, we were able to sample in 28 of 105 possible reef-habitat strata combinations in the Coral Sea (excluding deep lagoon, deep terrace and drowned bank habitats; and Cato and Mellish Reefs); which contained approximately 51% of shallow reef habitats area in the Coral Sea Marine Reserve (Table 3-3, Appendix B).

Table 3-1. Reef visited, sample locations, number of sites surveyed, dates and fishing status of reefs during the April 2017 survey.

Reef	Locations	Sites	Dates	Fishery status
Saumarez Reefs	1	9	9/04/2017	Open
Wreck Reef	2	10	10/04/2017	Open
Kenn Reef	2	12	11/04/2017	Open
Marion Reef	3	26	13-14/04/2017	Open
Lihou Reef	6	25	15-17/04/2017	Closed
Coringa Bank	1	5	18/04/2017	Closed
Herald Cays	2	14	19-20/04/2017	Closed
Holmes Reef	2	8	21/04/2017	Open

Unfortunately, weather conditions during the survey were less than optimal for carrying out dive transects, with strong S-SE winds throughout the survey period, but particularly in the latter stages (Table 3-2). This prevented sampling most of the weather forereef, pass and reef flat survey sites.

Table 3-2. Wind data form Willis Island weather station for the period 9th April 2017 to 21st April 2017.

Date	Direction	Max (kts)	Average (kts)
9/04/2017	SE	23.2	15.9
10/04/2017	SSW	22.1	14.6
11/04/2017	SE	23.2	13.0
12/04/2017	SE	27.0	16.7
13/04/2017	SSE	31.9	23.5
14/04/2017	ESE	30.8	22.1
15/04/2017	ESE	29.2	22.1
16/04/2017	ESE	29.2	20.5
17/04/2017	ESE	32.9	21.6
18/04/2017	E	36.2	25.9
19/04/2017	SE	32.9	24.3
20/04/2017	SSE	30.2	22.4
21/04/2017	ESE	30.8	22.1

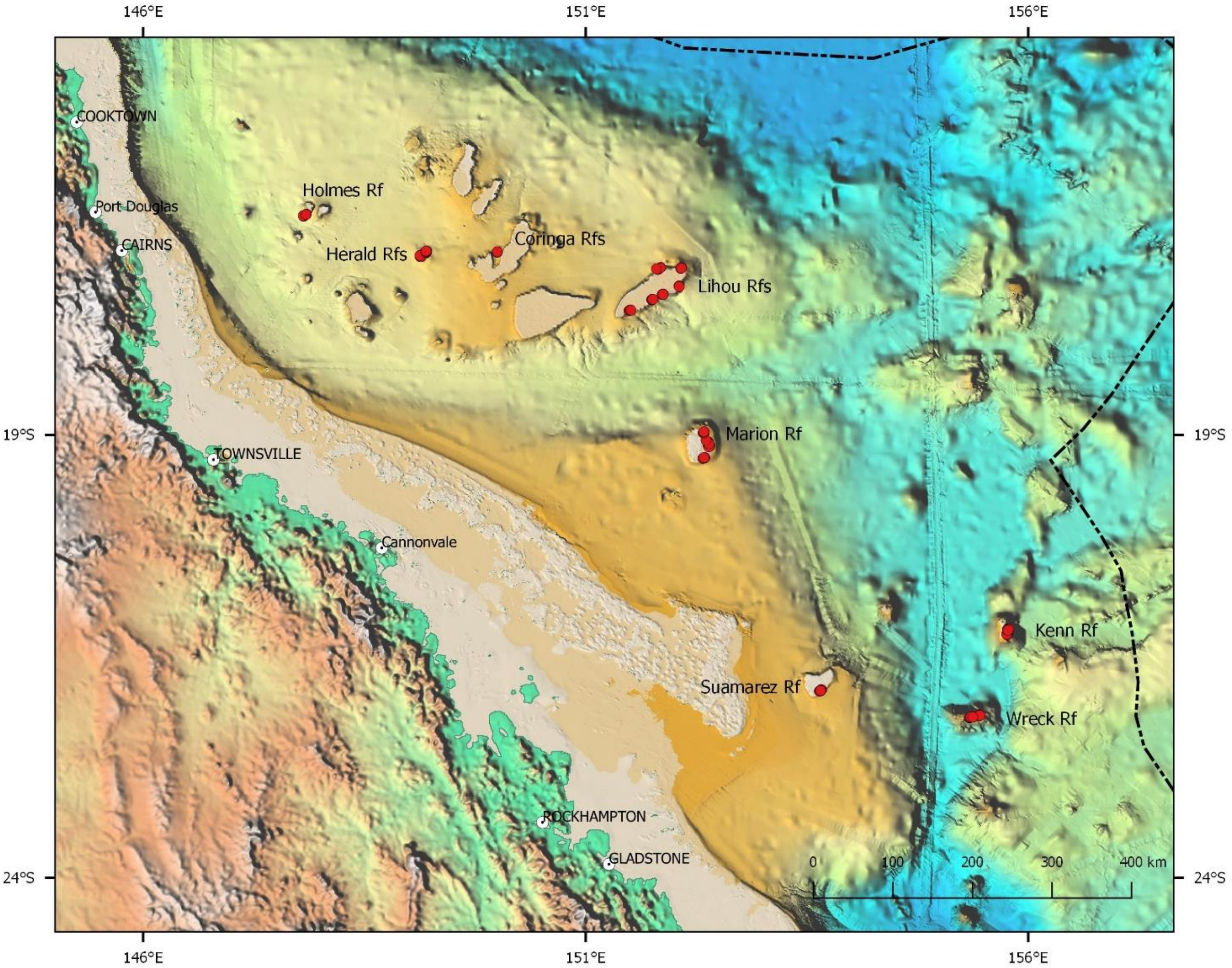


Figure 3-1. Sample sites visited during Coral Sea sea cucumber survey in April 2017.

Table 3-3. Table of reef and number of sites and habitats.

Reef	Habitat	Sites	Area (Ha)
Coringa Bank	backreef	4	905.9
Coringa Bank	reef flat	1	432.4
Herald Cays	backreef	8	116.6
Herald Cays	lagoon pinnacle	2	22.6
Herald Cays	reef flat	4	1486.6
Holmes Reef	backreef	3	1149.1
Holmes Reef	pass	2	59.8
Holmes Reef	reef flat	3	5671.4
Kenn Reef	forereef	1	2150.2
Kenn Reef	inner slope	7	4983.3
Kenn Reef	reef flat	4	1730.2
Lihou Reef	backreef	6	4814.9
Lihou Reef	forereef	1	4680.0
Lihou Reef	inner slope	5	11243.9
Lihou Reef	pass	5	7446.6
Lihou Reef	reef flat	6	6109.0
Lihou Reef	subtidal reef flat	2	4242.0
Marion Reef	forereef	1	2557.9
Marion Reef	inner slope	15	10785.2
Marion Reef	lagoon pinnacle	1	67.9
Marion Reef	reef flat	5	4317.7
Marion Reef	subtidal reef flat	4	781.8
Saumarez Reefs	inner slope	5	5569.9
Saumarez Reefs	reef flat	4	2295.5
Wreck Reef	backreef	5	627.0
Wreck Reef	deep lagoon	2	16969.0
Wreck Reef	pass	1	681.3
Wreck Reef	reef flat	2	1657.8

Un-sampled reef-strata within the sampled reefs that would be expected to hold significant populations of sea cucumbers includes: forereef habitat on most reefs (due to strong winds); and reef pinnacles on Lihou Reef and Coringa Bank. Major un-sampled reefs in the Coral Sea included Willis and Dianne Banks, Tregrosse Reef, Osprey Reef and Flinders Reef.

Rapid marine assessment techniques used during previous surveys for reef resource and habitat surveys in the Timor MOU Box (e.g. Ashmore Reef - Skewes et al., 1999), Torres Strait (Skewes et al., 2010) and the GBR were used (Leeworthy, 2007; Leeworthy and Skewes, 2007).

Field work was undertaken by a small team of 2 divers operating from a dinghy and locating sample sites using hand-held GPS. On the shallow reef top, 2 divers swam along a 100m transect and recorded resource and habitat information 1-2 m either side of the transect line. In deeper habitats (max dive depth 20 m), a SCUBA diver swam along a 100 m transect and recorded resource and habitat information 2 m either side of the transect line. Sea cucumbers, trochus and other benthic fauna of commercial or ecological interest were counted.

Substrate was described in terms of the percentage of sand, rubble, boulders, consolidated rubble, pavement and live coral. The percentage cover of all other conspicuous biota such as algae was also recorded. Sea cucumbers found along the survey were returned to the dinghy and their length measured to the nearest 5 mm before being returned to the area of the transect.

3.4 Data analysis

Transect and sample data collected during the field survey was entered into an Access database on board the vessel to reduce transcription errors and clarify uncertainties.

Area estimates of the reef habitats were output from the GIS based on a spatial join of the satellite derived habitat map and zone map. Estimates of mean density (count per hectare) were derived using a stratified analysis of transect counts based on reef habitat strata. This takes into account the heterogeneity in the variance of observed counts and is representative of the physical size differences of the varying habitats in the surveys.

Though the survey was only designed as a relative density survey, we were still able to produce estimates of population standing stock. Population stock estimates were calculated as the product of estimates of density, reef area and average weight from size frequency data collected during the survey. Live length was converted to live weight using established conversion factors (CSIRO, unpublished data). All conversion factors were available except for *Thelenota anax* (used *T. ananas*); *Bohadschia argus* (used *T. ananas*); and *Actinopyga mauritiana* (used *A. echinites*). As the fishery catch is recorded as (mostly) landed (gutted salted) weight, we converted live weight estimates to landed (gutted salted) weight for comparison to catch data, using conversion factors for each species from fishery derived information from Torres Strait and the GBR (Skewes et al., 2004), or from the literature (Purcell et al., 2009).

4 Results

In all, 10 species of sea cucumber were observed during the 2017 survey; plus 2 additional species were observed off transect: *Stichopus herrmanni* and *Bohadschia ocellata* (the latter being a relatively uncommon species) (Table 4-1). Two other species that have been observed during previous surveys were not seen during this survey: *Holothuria leaucospilota* and *Actinopyga miliaris* (Ceccarelli et al., 2009; Oxley et al., 2004). All species in the Australian Coral Sea Sea Cucumber Fishery (AFMA; Woodhams et al., 2015) and the illegal FFV fishery take (Skewes, 2017) were observed during the survey.

Table 4-1. Commercial sea cucumber species observed on the reefs of Australia's Coral Sea Commonwealth Marine Reserve.

Species	Common name	Occurrence
Holothuria atra	Lollyfish	This survey
Holothuria whitmaei	Black teatfish	This survey
Holothuria fuscogilva	White teatfish	This survey
Thelenota ananas	Prickly redfish	This survey
Thelenota anax	Amberfish	This survey
Stichopus chloronotus	Greenfish	This survey
Actinopyga echinites	Redfish	This survey
Actinopyga mauritiana	Surf redfish	This survey
Bohadschia argus	Leopardfish	This survey
Holothuria fuscopunctata	Elephant trunkfish	This survey
Bohadschia ocellata	Tigerfish	This survey (off transect)
Stichopus herrmanni	Curryfish	This survey (off transect)
Holothuria leaucospilota	Snakefish	Previous surveys (Oxley *et al.*, 2003)
Actinopyga miliaris	Hairy blackfish	Previous surveys (Oxley *et al.*, 2003)

4.1 Species density

The species with the highest average density in the sampled habitats was *H. atra* (Lollyfish), and was about an order of magnitude greater than the next highest density species, *S. chloronotus* (Greenfish) (Figure 4-1, Table 4-2). Although *H. atra* was found on most reefs, it was found at several extremely high-density sites on Coringa Bank that contributed the bulk of the density estimate (Figure 4-2). This was true for *S. chloronotus* as well, though it also occurred at high density sites on Kenn Reef as well (Figure 4-2).

The next most abundant species surveyed was *T. ananas* (Prickly redfish), a high value species, with an overall density of 6.3 per ha (Figure 4-1). It was found on every reef apart from Wreck Reef, and was particularly abundant on Lihou Reef (Figure 4-2) which had an average density of 14.4 per ha. The two other high value species, *H. whitmaei* (Black teatfish) and *H. fuscogilva* (White teatfish) had very low overall densities of 1.6 and 0.8 per ha respectively. Both were surveyed on 5 of the 8 reefs sampled. All other species averaged below 2 individuals per ha.

Lihou Reef had the highest density of high value species (*H. whitmaei, H. fuscogilva and T. ananas*) at 18.6 per ha (Figure 4-2, Figure 4-3). No high value species were observed at the 10 sites surveyed at Wreck Reef that included deep lagoon and reef pass habitats. Coringa Bank and Kenn Reef had high densities of medium value species, at 473 and 45 per ha respectively, mostly attributable to high densities of *S. chloronotus* (Figure 4-2, Figure 4-3).

Species composition was extremely variable among reefs sampled (Figure 4-2), and even for the same apparent habitat (e.g. reef flat adjacent to a coral cays), species counts varied markedly.

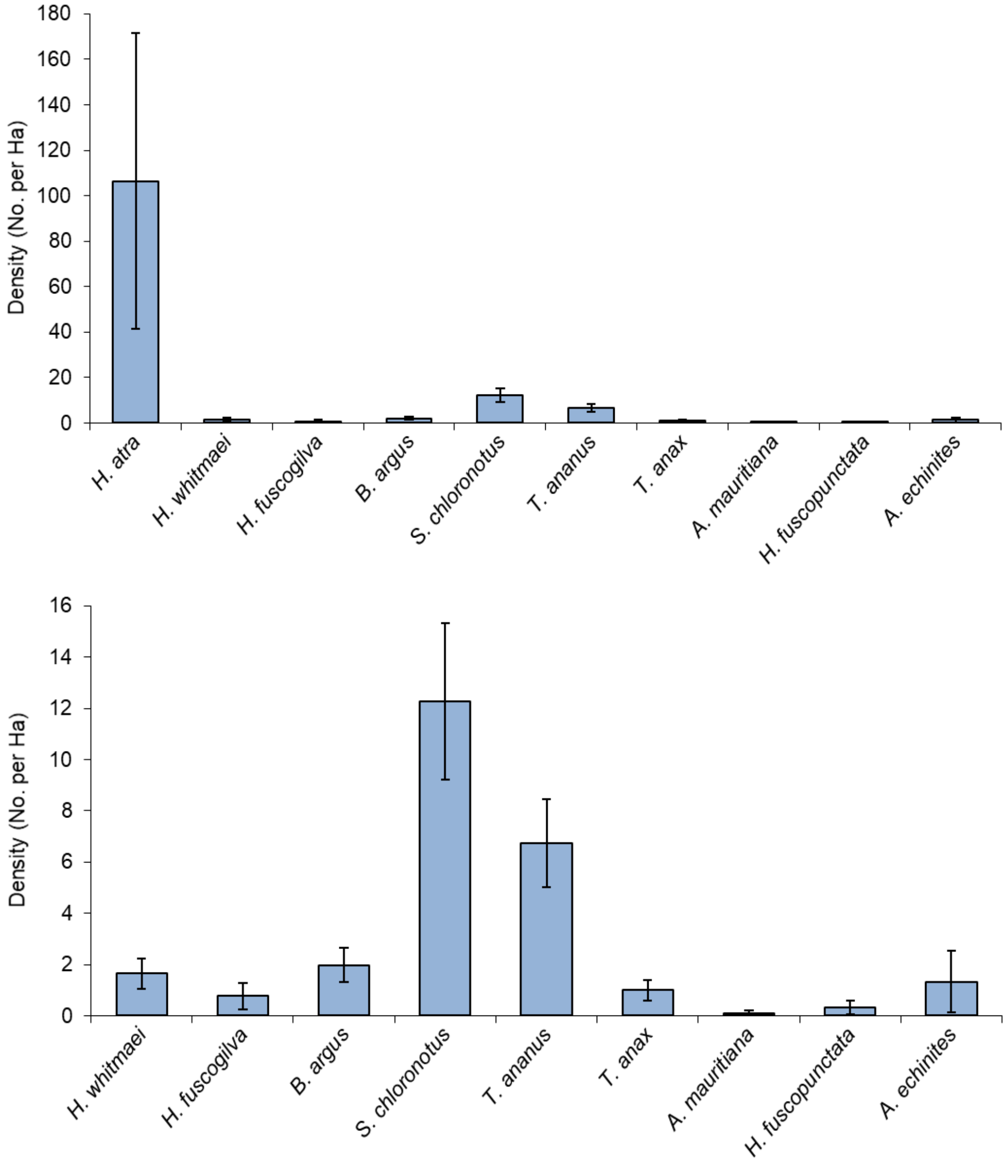


Figure 4-1. Density (stratified) of sea cucumbers in all reefs and habitats surveyed in 2017. (Error bars are 1 s.e.)

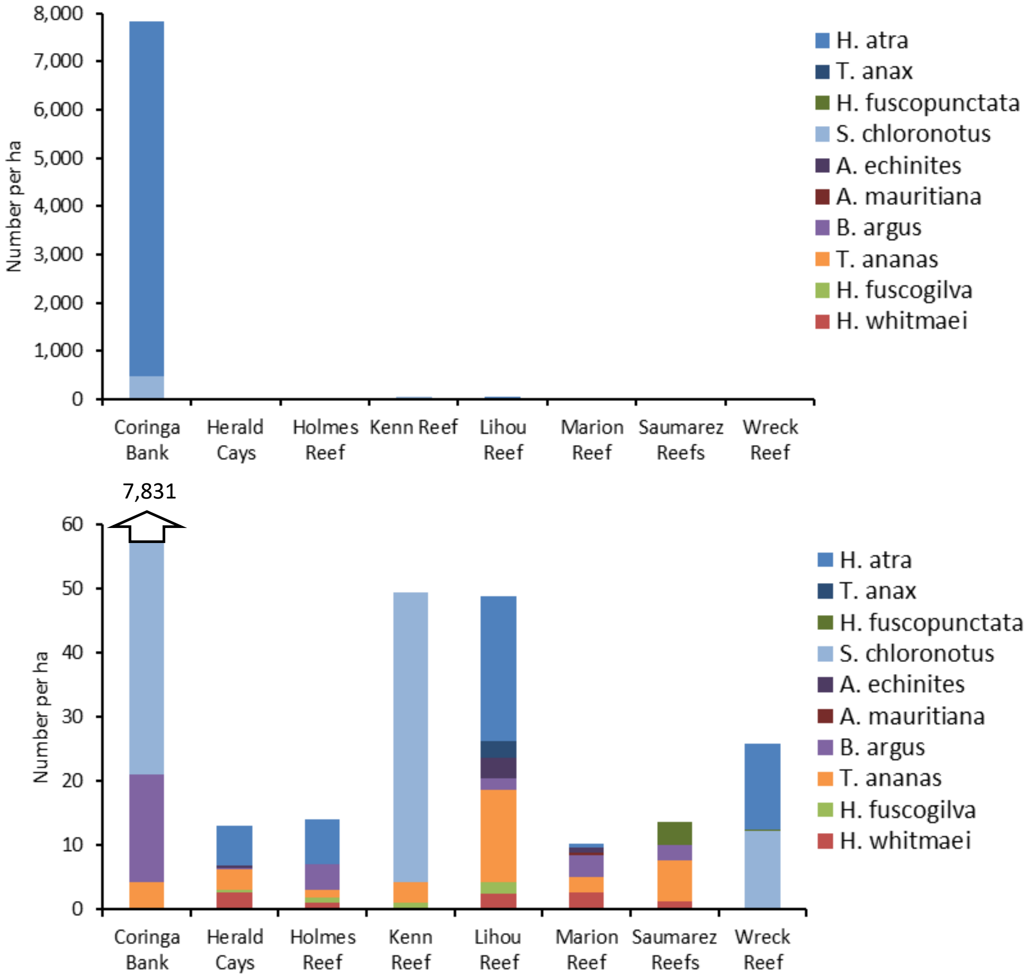


Figure 4-2. Density (stratified) estimates of sea cucumbers for each reef sampled during the 2017 survey by species.

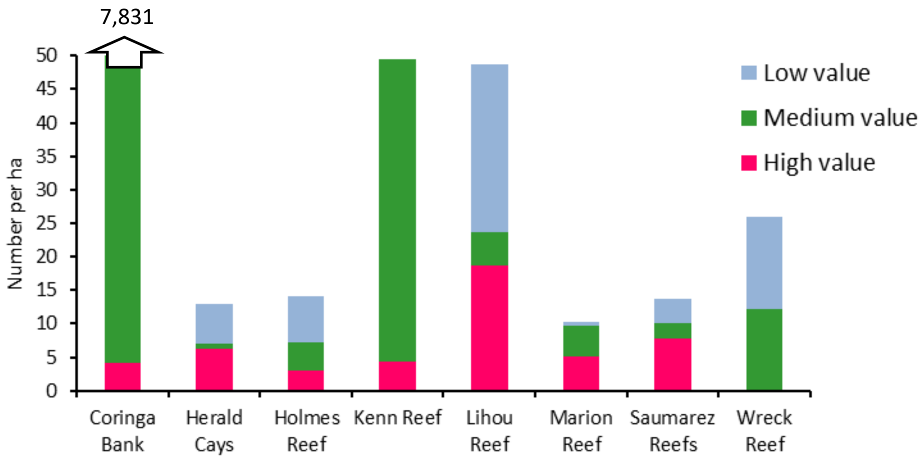


Figure 4-3. Density (stratified) estimates of sea cucumbers for each reef sampled during the 2017 survey by value category.

The backreef habitat had the highest overall density of sea cucumbers throughout the study area (Figure 4-4), but this was almost entirely due to high densities of *H. atra* on Coringa Back, Lihou Reef and Wreck Reef (Figure 4-2).

The next highest density habitat was the lagoon pinnacle habitat, and this included relatively high densities of the high value sea cucumbers, *T. ananas*, *H. whitmaei* and *H. fuscogilva* (Figure 4-4). The average density of *H. whitmaei* on the reef pinnacle habitat was by far the highest for this species in the study area at 38.5 per ha (s.e. 19.3), and similarly for *H. fuscogilva* at 17.2 per ha (s.e. 12.6) resulting in the lagoon pinnacle habitat having the highest density of high value sea cucumbers of any habitat in the study area.

The next highest density habitats were reef pass, mostly made up of *T. ananas* and *H. atra*, and reef flat habitats, with the later almost entirely due to *S. chloronotus* (Figure 4-4). The deep lagoon, inner slope and subtidal reef flat had very low density (Figure 4-5).

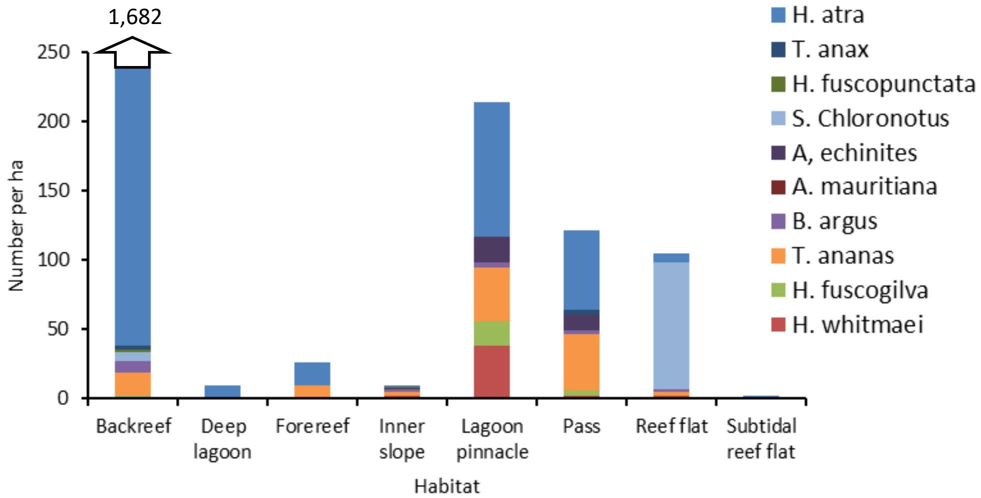


Figure 4-4. Sea cucumber average density by habitat and species for the 2017 survey.

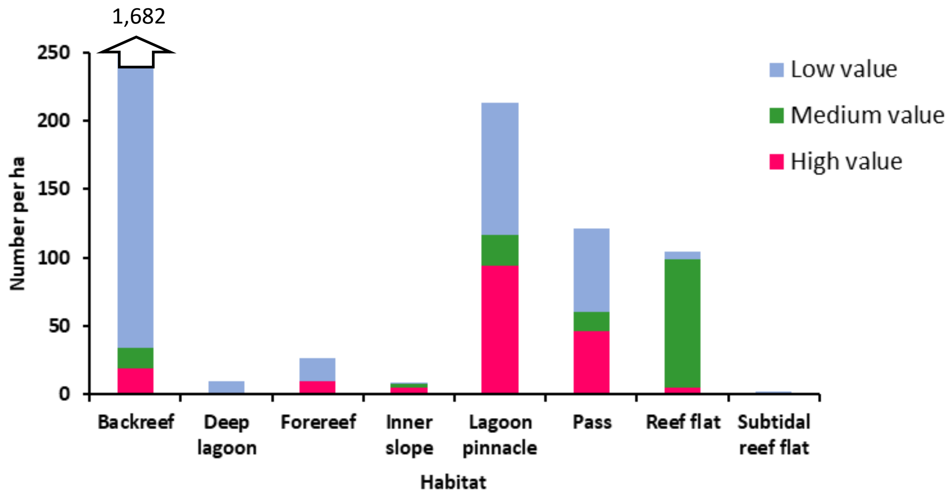


Figure 4-5. Sea cucumber density by habitat and value category for the 2017 survey.

4.1.1 Open versus closed

There was a large difference in the density of all sea cucumbers sampled on the open and closed (Lihou Reef, Coringa Bank and Herald Cays NNR) reefs (*P*<0.01), with the overall density on the closed reefs, at nearly 300 per ha, being almost 14 times higher than the density on the open reefs (22 per ha) (Figure 4-6). While most of that difference was attributable to *H. atra* (Lollyfish) on Coringa Bank reefs, every other species apart from *H. fuscopunctata* (Elephant trunkfish) and *A. mauritiana* (Surf redfish) had a higher density on the closed reefs (Figure 4-7).

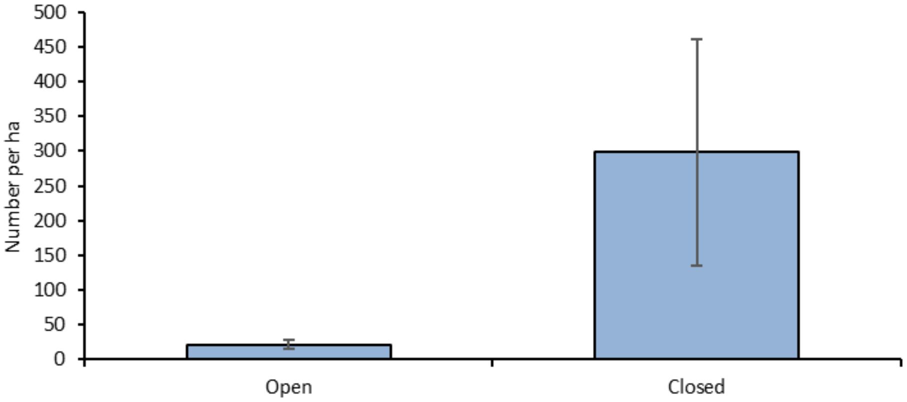


Figure 4-6. Density (stratified) of all sea cucumbers in open and closed reefs sampled during the 2017 survey.

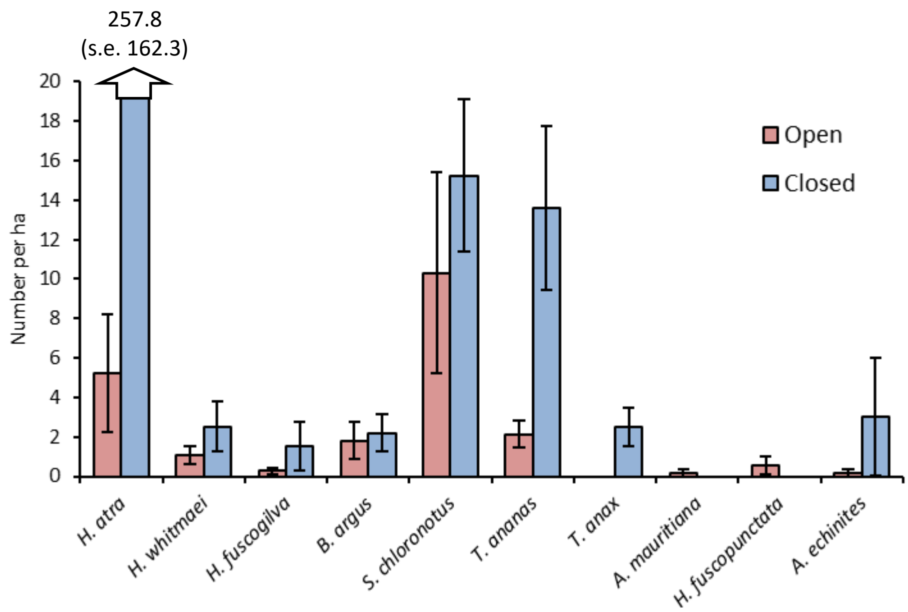


Figure 4-7. Density (stratified) of sea cucumber species on open versus closed reefs. (Error bars are 1 s.e.)

4.1.2 Lihou Reef

The overall density of sea cucumbers at sites sampled on Lihou Reef was 48.8 per ha (s.e. 13.5) in the current survey compared to 6.1 per ha (s.e. 1.88) in 2004 (Oxley et al., 2004) and 17.7 per ha (s.e. 2.5) in 2008 (Ceccarelli, 2009). In 2008, 10 species were recorded across all surveyed sites, of which *Holothuria atra* (Lollyfish), *H. whitmaei* (Black teatfish) and *T. ananas* (Prickly redfish) together made up 78.7% of the overall density (at 42%, 27.2% and 9.5% respectively). *H. whitmaei* and *A. mauritiana* (Surf redfish) were the only species that had a lower density in the 2017 survey, perhaps due to illegal fishing activity by FFV. *H. whitmaei* was about half the density in 2017 as in 2008, though it was not possible to test the difference statistically.

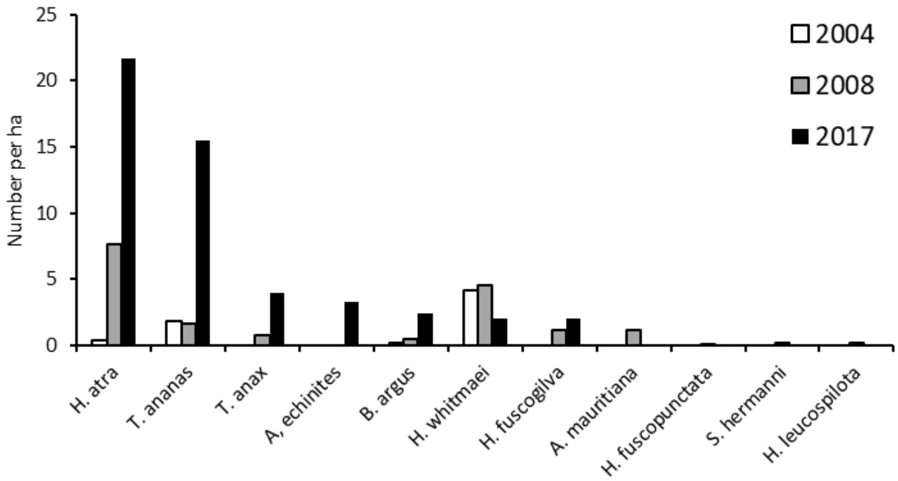


Figure 4-8. Density of sea cucumbers on all sites sampled on Lihou Reef in 2004, 2008 and 2017.

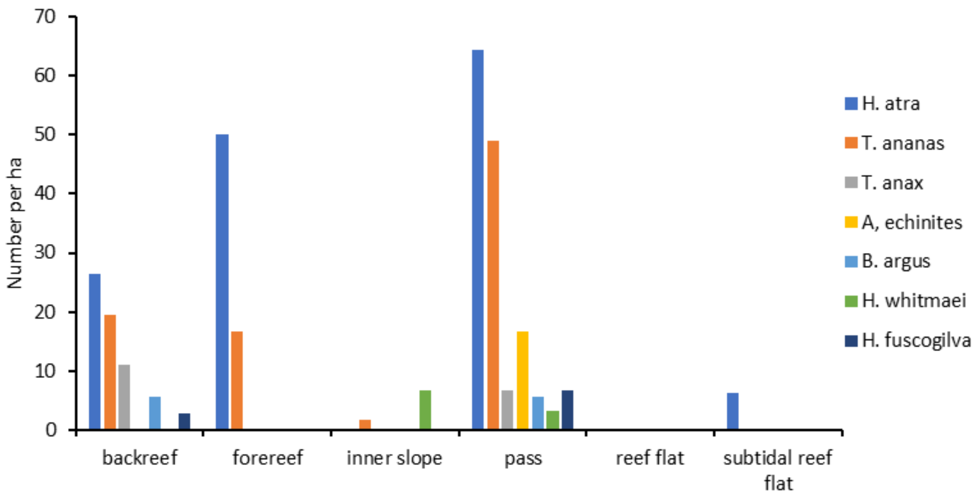


Figure 4-9. Density of sea cucumber species by habitat on Lihou Reef.

4.2 Population estimates

Population biomass estimates were formulated using data from all sampled reef habitats and size of surveyed sea cucumbers. Again, due to its very high density, *H. atra* (Lollyfish) had the highest estimated biomass in the sampled reef-habitat combinations, at 2,600 t (± 2,049 t, 90% CI) live weight (though with a high uncertainty). The next greatest biomass was *T. ananas* (Prickly redfish) with 1,903 t live weight (± 624 t, 90% CI). Both these species made up over 70% of all sea cucumbers in the study area by weight (Table 4-2, Figure 4-10).

The biomass estimates for the two other high value species were 340 t (± 155 t, 90% CI) for *H. whitmaei* (Black teatfish) and 187 t (± 158 t, 90% CI) for *H. fuscogilva* (White teatfish), though both with high levels of uncertainty. It is likely that the biomass estimate for *H. fuscogilva* is greatly underestimated due to the lack of survey data for deeper habitats. The estimate of landed weight for *H. fuscogilva*, 93.3 t, was not likely sufficient to account for the take of this species by the Australian fishery an illegal FFV fishers (Woodhams et al., 2015; Skewes 2017).

Coringa Bank and Lihou Reef had the greatest biomass of sea cucumbers, due to their large size and the high density of *H. atra* on Coringa Bank, and of *T. ananas* on Lihou Reef. Both reefs together had over 80% of all sea cucumbers by weight and over 77% of all high value species by weight (*H. fuscogilva, H. whitmaei and T. ananas*) in the study area (Figure 4-11, Figure 4-12)

Table 4-2. For each species, the average density, s.e., population stock estimate and landed (wet gutted) weight (N = 109).

Species	Common name	Value	Density	Density s.e.	Live weight (t)	Conversion factor	Est. Landed weight (t)
All commercial		Mixed	132.58	65.48	6,273.6	0.544	3,412.9
H. atra	Lollyfish	Low	106.43	65.06	2,600.1	0.544	1,414.5
H. whitmaei	Black teatfish	High	1.64	0.58	339.7	0.633	215.0
H. fuscogilva	White teatfish	High	0.77	0.51	186.6	0.500	93.3
T. ananus	Prickly redfish	High	6.73	1.71	1,903.1	0.583	1,109.5
S. chloronotus	Greenfish	Medium	12.28	3.06	259.7	0.544	141.3
B. argus	Tigerfish	Medium	1.97	0.67	496.2	0.544	269.9
T. anax	Amberfish	Low	1.00	0.39	343.6	0.544	186.9
A. mauritiana	Surf redfish	Medium	0.10	0.10	10.0	0.480	4.8
H. fuscopunctata	Elephant trunkfish	Low	0.33	0.28	48.4	0.544	26.3
A. echinites	Deepwater redfish	Medium	1.32	1.20	86.2	0.480	41.4

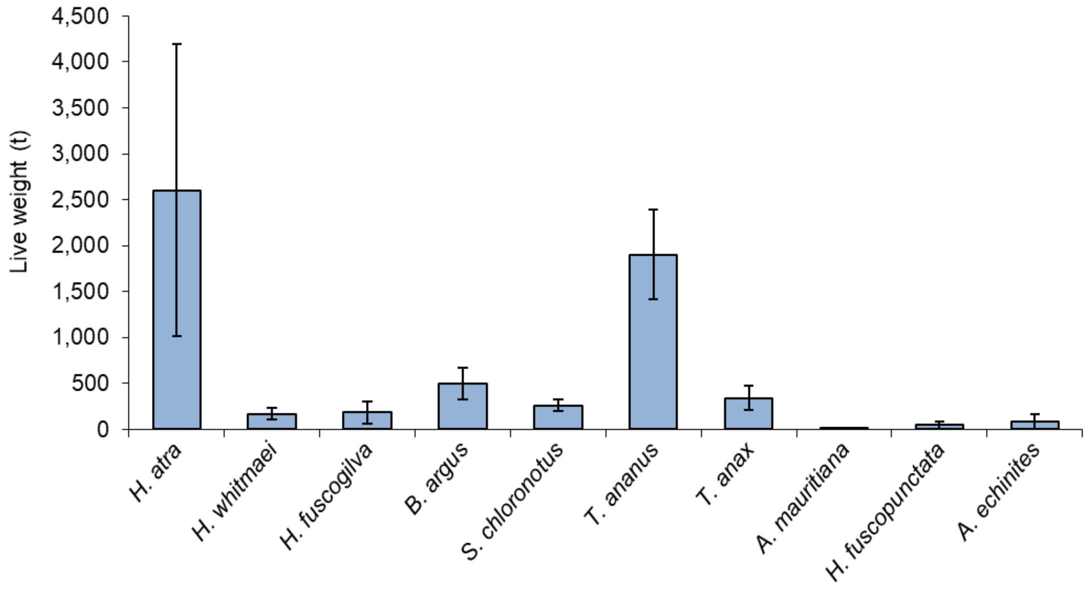


Figure 4-10. Live weight (stratified) of sea cucumbers on all reefs and habitats surveyed in 2017. (Error bars are 1 s.e.)

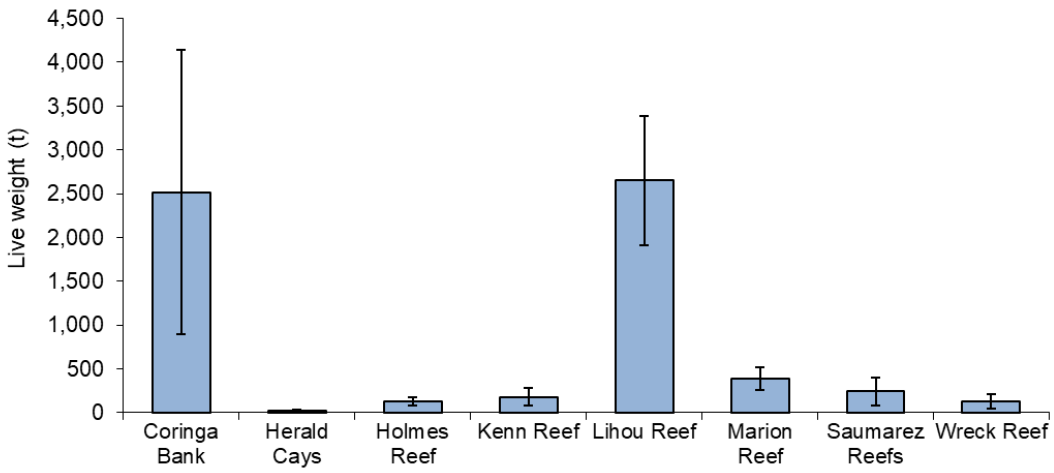


Figure 4-11. Live weight of sea cucumbers on all reefs surveyed in 2017. (Error bars are 1 s.e.)

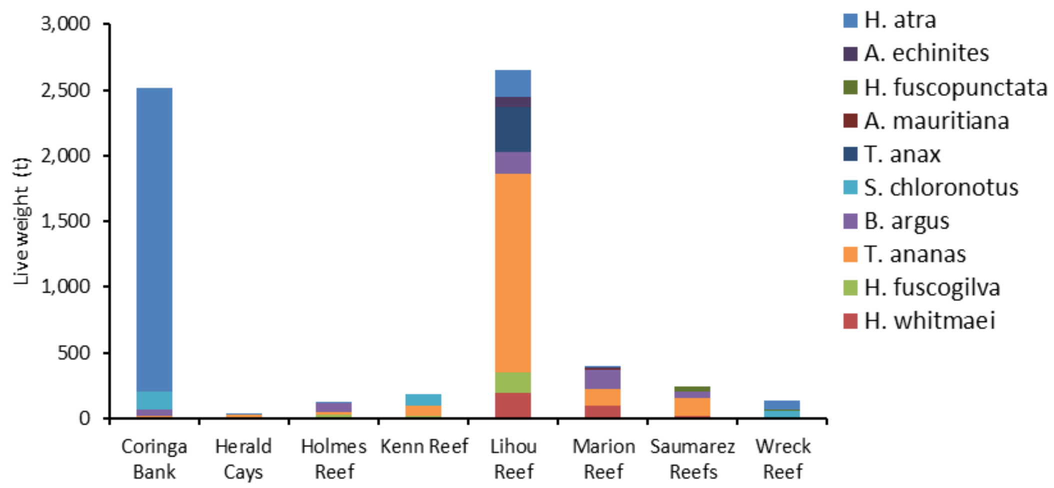


Figure 4-12. Live weight of sea cucumbers on all reefs surveyed in 2017.

4.3 Species size frequency

Average length, size range and calculated average weight using available conversion rates are shown in Table 4-3.

Table 4-3. Size of sea cucumbers surveyed in the Coral Sea in April 2017.

Species	common name	Count	Ave length (mm)	Stdev (mm)	Min length (mm)	Max length (mm)	Ave weight (g)	St dev of weight
H. atra	Lollyfish	213	140.4	86.4	50	440	236	385
H. whitmaei	Black teatfish	27	245.0	38.7	160	310	1996	228
H. fucogilva	White teatfish	4	287.5	29.9	250	320	2328	320
T. ananas	Prickly redfish	37	359.7	83.1	210	570	2732	717
S. chloronotus	Greenfish	78	173.6	58.7	60	360	204	174
B. argus	Tigerfish	10	325.5	40.6	240	400	2433	342
T. anax	Amberfish	1	430.0		430	430	3331	
A. mauritiana	Surf redfish	1	240.0		240	240	927	
H. funcopunctata	Elephant trunkfish	2	285.0	63.6	240	330	1418	695
A. echinites	Deepwater redfish	5	262.0	48.2	200	330	630	251

4.3.2 Holothuria atra and Stichopus chloronotus

Size frequency histograms for the two highest density species, *H. atra* (Lollyfish) and *S. chloronotus* (Greenfish), are shown in Figure 4-13 and Figure 4-14. *H. atra* displays a common pattern for this species of the bulk of the population being smaller than 200 mm total length, with larger individuals in lower densities and deeper habitat. It is likely that the smaller size ranges are fissiparous populations and the larger individuals sexually mature (Uthicke et al., 2001).

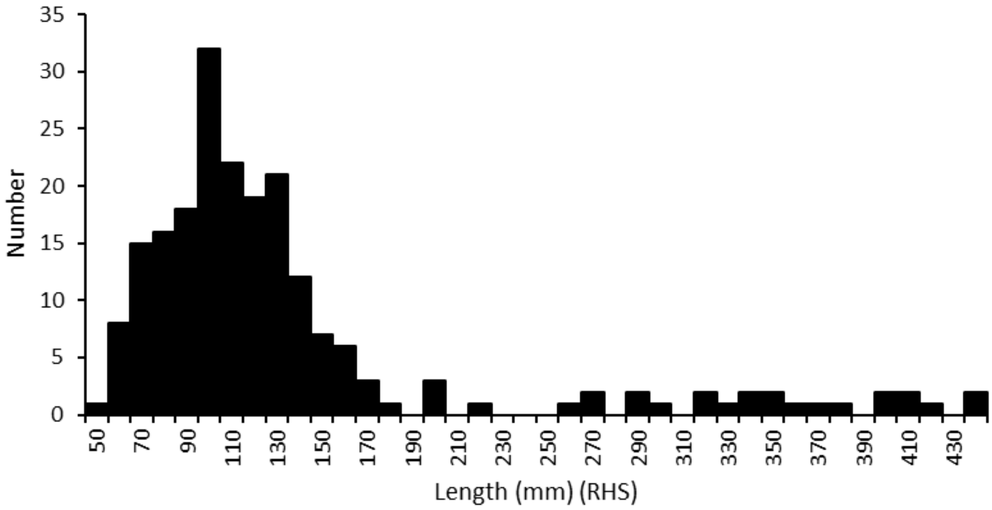


Figure 4-13. Size frequency, Total length (live) (mm) for *Holothuria atra* (lollyfish) sampled during the survey of Coral Sea reefs in April 2017.

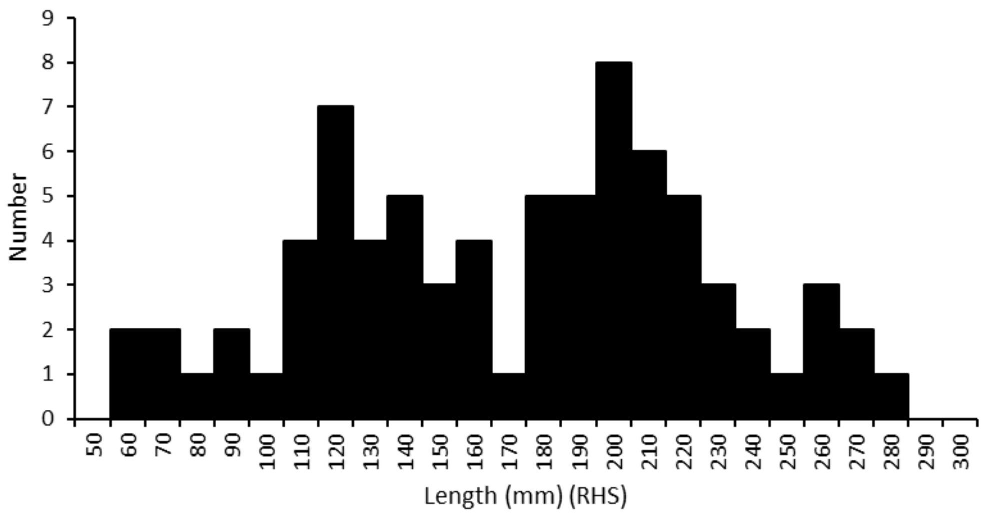


Figure 4-14. Size frequency, Total length (live) (mm) for *Stichopus chloronotus* (Greenfish) sampled during the survey of Coral Sea reefs in April 2017.

4.3.3 *Holothuria whitmaei*

The average length of *H. whitmaei* (Black teatfish) surveyed in the Coral Sea (245 mm) was larger than comparable data for a recovered population from Torres Strait (224 mm) (Skewes et al., 2010) (Figure 4-15, Figure 4-16). There were good proportion of the sampled population greater than the Australian Coral Sea Fishery minimum size limit (MSL) of 25 cm.

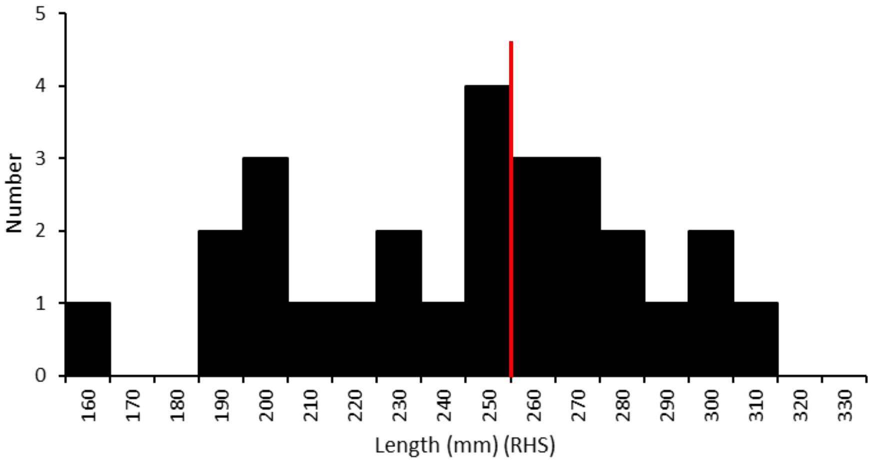


Figure 4-15. Size frequency, Total length (live) (mm) for *Holothuria whitmaei* (Black teatfish) sampled during the survey of Coral Sea reefs in April 2017. The red line is the Australian Coral Sea Fishery Minimum Size Limit (MSL).

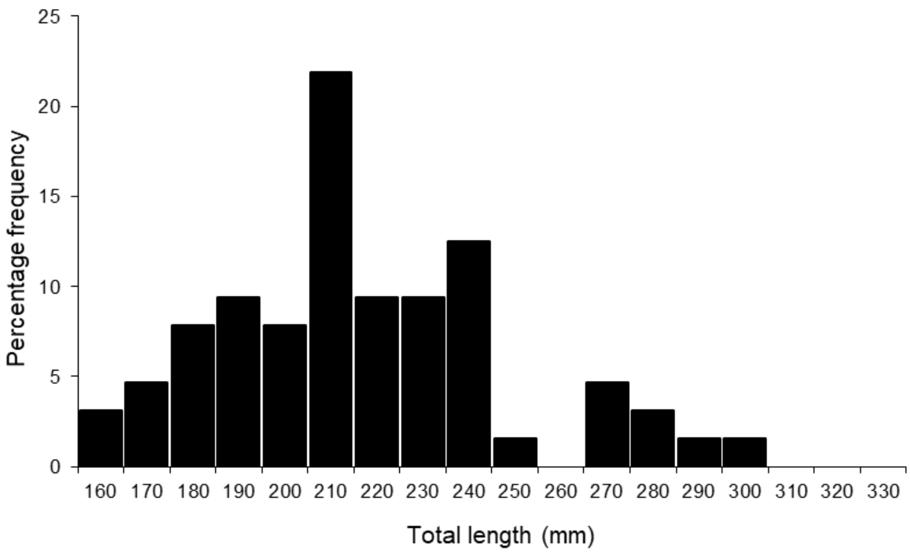


Figure 4-16. Size frequency, Total length (mm) for *Holothuria whitmaei* (Black teatfish) sampled in Torres Strait in 2009.

4.3.4 *Thelenota ananas*

The average size of *T. ananas* (Prickly redfish) in the Coral Sea region (359 mm) was similar to comparable data from Torres Strait (370 mm) (Skewes et al., 2010). There were good proportion of the sampled population greater than the Australian Coral Sea Fishery minimum size limit (MSL) of 30 cm (Figure 4-17, Figure 4-18).

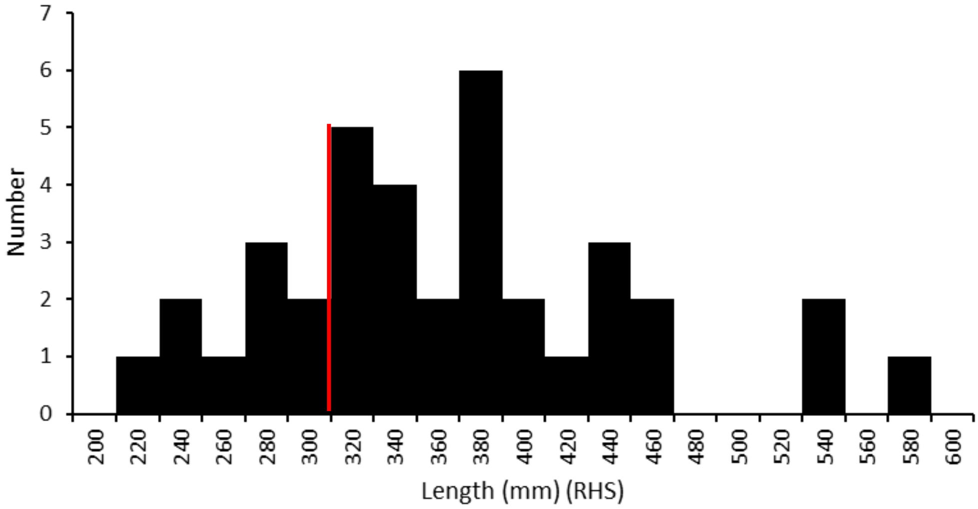


Figure 4-17. Size frequency, Total length (live) (mm) for *Thelenota ananas* (Prickly redfish) sampled during the survey of Coral Sea reefs in April 2017. The red line is the Australian Coral Sea Fishery Minimum Size Limit (MSL).

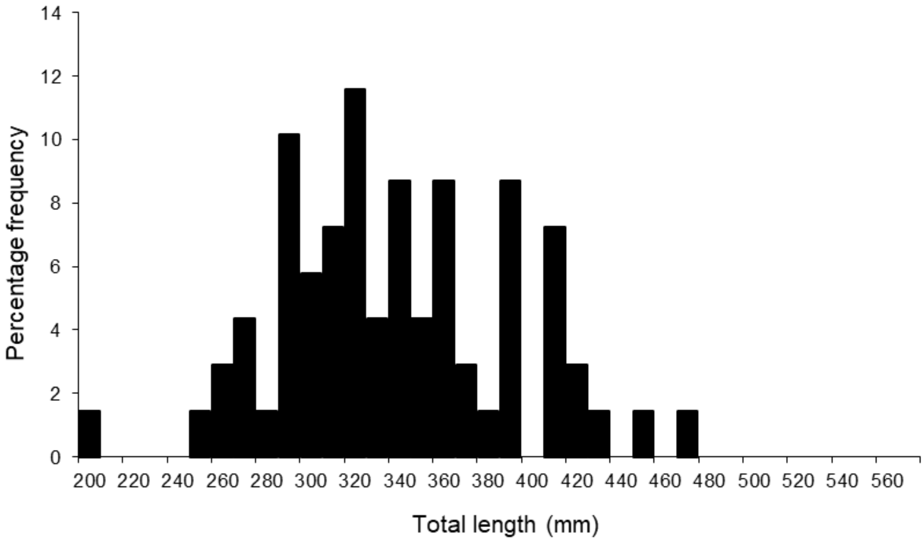


Figure 4-18. Size frequency, Total length (mm) for *Thelenota ananas* (Prickly redfish) sampled in Torres Strait in 2009.

5 Discussion

This survey assessed sea cucumbers on 8 of the 18 shallow reef systems within the Coral Sea Commonwealth Marine Reserve (CSCMR), with 5 of those reefs being for the first time. In all, we sampled 28 out of a possible 105 shallow reef-habitat combinations within the region (excluding deep terrace and drowned bank habitats; and Cato and Mellish Reefs), which contained about 51% (by area) of the available shallow reef habitats in the CSCMR. Reef habitats that remained under-sampled on surveyed reefs included: forereef habitat on most reefs; reef pinnacles on Lihou Reef and Coringa Bank; and deep lagoon habitats. Additionally, the number and spatial coverage of survey sites within most reef-habitat strata was limited by logistical and time constraints. However, the survey was able to estimate the density and population biomass of 10 commercial species, and investigate trends in density between reefs and habitats with sufficient precision to make some inferences about their biogeography and population status.

Survey availability of sea cucumbers is a well-known problem for visual surveys; especially for diurnally burying and nocturnal species, and for species with cryptic juveniles: (Mercier et al., 1999; Skewes et al., 2000; Breen 2011; Prescott, 2013). There is the possibility of large populations of diurnally burying species occurring in sandy reef habitats, such as for *Bohadschia koellikeri* on Scott Reef (Prescott, 2013), and *Actinopyga spinea* (Burrowing blackfish) on the Great Barrier Reef (Leeworthy, 2007). In general, however, larger individuals of higher value species will have a relatively high survey visibility (Skewes et al.; 2000; 2010; Benzie and Uthicke, 2003). Species that would likely be affected by significant under estimation during this survey include *A. mauritiana* (Surf redfish) (no sampling on weather edge); *B. argus* (Tigerfish) and other Bohadschia species (diurnal burrowing); *H. fuscogilva* (White teatfish) and *T. ananas* (Prickly redfish) (depth restrictions on survey sites); and juveniles of most species (diurnally cryptic).

Species composition was extremely variable among reefs sampled. This could be due to 3 factors: 1) differences in representative sampling of reef habitats; 2) differences in large scale biogeography driven by microscale differences in habitat and/or recruitment processes; or 3) spatially variable impacts such as extractions from fishing. Given that sampling was stratified to take habitat differences into account, and site counts on even very similar habitats on different reefs (e.g. reef flat adjacent to island cays) showed marked differences in species population structure, much of the difference in between reefs is likely to be a combination of sea cucumber biogeography and fishing pressure.

Generally, sea cucumber species densities were lower on Coral Sea reefs than on the GBR (Benzie and Uthicke, 2003; Skewes et al., 2013) and Torres Strait (Skewes et al., 2010); apart from high density populations of *H. atra* (Lollyfish) which were found on Coringa Bank. This is consistent with previous surveys of the Coringa Bank, Herald Reefs and Lihou Reefs (Oxley et al., 2003, 2004; Ceccaralli 2007, 2009) and probably reflects a lower carrying capacity on Coral Sea reefs to some extent at least. However, the Coral Sea species density were generally higher than the offshore reefs of the Timor MOU box (Skewes et al., 1999), apart from the higher density populations of *H. leucospilota* (Snakefish) found on Ashmore Reef (Skewes et al., 1999).

The species with the highest average density in the study area by far was *H. atra* (Lollyfish). They were found throughout the study area but were in highly abundant densities at several sites, usually on the shallow reef or backreef habitats in close proximity to coral cays. The highest density sites were found on Coringa Bank backreef habitats, which appears to be a persistent pattern based on previous surveys in 2003 and 2008 (Oxley et al., 2003; Ceccarelli et al., 2008). *S. chloronotus* (Greenfish) was the second most abundant species, and (similarly to *H. atra*) was found in a few high-density locations on the shallow reef flat in close association with reef cays, primarily on Coringa Bank reefs and Kenn Reef.

The third highest density species was *T. ananas* (Prickly redfish), which was found in the majority of habitats and on most reefs, but was highest on the reef passes and lagoon pinnacles, and on Lihou Reef. The population biomass estimate of *T. ananas* was 1,903 t live weight (± 624 t; 90% CI) and made up over 30% of all sea cucumbers surveyed biomass (*H.atra* having the highest biomass at an estimated 2,600 t (±

2,049 t; 90% CI)). The fishery (landed) biomass estimate for *T. ananas* of 1,109 t (± 364 t; 90% CI) is encouraging given the estimate of catches for the Australian Coral Sea Sea Cucumber Fishery (CSSCF) (18 t between 1997–98 and 2008–09 — Woodhams et al., 2016) and illegal foreign fishing vessels (FFV) catches (240 kg for one vessel apprehended in early 2017 — Skewes et al., 2017).

The highly targeted high value species, *H. fuscogilva* (White teatfish), was found at very low densities throughout the study area, but was particularly scarce on the southern reefs, and was not surveyed at all on Saumarez Reef or Wreck Reef. This could be attributed, in part at least, to high fishing effort. *H. fuscogilva* has made up the largest component of the Australian CSSCF catch at 40.6% between 1997–98 and 2008–09 (Woodhams et al., 2016). This species has also been the focus of recent illegal fishing by FFV in the CSCMR area, making up 86% of the catch of 2 FFV apprehended on Saumarez Reef in early 2017 (Skewes, 2017), indicating a strong causal link.

However, the estimated density and population size for *H. fuscogilva* from this survey will be underestimated due to limitations on survey depth (generally <20 m) and sea cucumber visibility, especially of juvenile *H. fuscogilva*. Information from the Australian CSSCF shows that more than 65 per cent of the *H. fuscogilva* catch was taken at locations with a maximum depth recorded of between 30 and 40 metres (Woodhams et al., 2015). Similarly, available evidence suggests that the illegal FFV fishing effort is concentrated in the deeper lagoon and reef pass habitats, with GPS marks from apprehended vessels located in water depth of >40 m (AFMA, unpublished data). It is likely that some stocks of *H. fuscogilva* still occur in deeper habitat on the southern reefs (Saumarez Reef, Wreck Reef etc), due to the predominance of *H. fuscogilva* in the catch of a FFV apprehended at Saumarez Reef in early 2017 (Skewes et al., 2017), though some of these at least may have been sourced at other reefs in the Coral Sea or from the Swains Reefs on the GBR.

Most of the larger reef systems in the Coral Sea (e.g. Coringa Bank, Lihou Reef and Saumarez Reef) have extensive areas of deep lagoon habitat in the 20 to 40 m depth range that may well provide suitable habitat for a deep-water species such as *H. fuscogilva*. Very little is known about these deep lagoon areas, making it difficult to assess the status of *H. fuscogilva* populations. The use of drop cameras to sample representative areas of deeper lagoon habitat will be required to fully assess the population status of this deeper water species.

Even so, it is likely that the shallower back reef slope habitats that were likely to have held some populations of *H. fuscogilva*, as on the GBR (Benzie and Uthicke, 2003) and Torres Strait (Skewes et al., 2010), have been depleted, by either the Australian fishery or FFV fishing pressure. Some of the deeper backreef sites surveyed on the southern reefs in particular appeared to be suitable habitat for sea cucumbers such as *H. fuscogilva* but were bare. Many of these sites also had a layer of microalgae (scum) on the surface that has been associated with sea cucumber depletion (Purcell et al., 2016; G. Leeworthy, *pers. Comm.*).

The density of the other high value species, *H. whitmaei* (Black teatfish), was relatively low (1.64 per ha), and reefs with the highest density (Lihou Reef and Marion Reef) did not exceed 2.6 per hectare. This compares to the density estimate in 2008 on Lihou Reef that found approximately 4.5 per hectare (Ceccarelli et al., 2009). By comparison, densities (whole reef) in Torres Strait ranged from 1.9 per ha for a depleted population in 2002 to 9.4 per ha in 2009, when the population was deemed to have substantively recovered (Skewes et al., 2010). Densities of *H. whitmaei* on GBR reefs in the “main habitat” on the reef flat was 20.9 individuals per ha on closed reefs and 5 per ha on open reefs (considered overexploited) (Uthicke and Benzie, 2000). A review of survey data from throughout the west Pacific has concluded that, for *H. whitmaei*, densities above 12.5 per Ha represent a “natural density” in “suitable habitat” (Kinch et al., 2008). On this basis, the low population density and downward trend of *H. whitmaei* would appear to indicate some fishery related depletion of this species.

Even so, the estimated biomass for *H. whitmaei*, 215 t (± 155 t, 90% CI) landed weight was large in relation to the known annual catch of the Australian CSSCF of less than 2 t per year (Woodhams et al., 2015); and the estimated catch for one apprehended FFV of 0.6 t (Skewes et al., 2017). The survey biomass estimate was similar to the population biomass for the same reefs, 333 t (Woodhams et al., 2015), that was used to determine that the *H. whitmaei* stocks in the Coral Sea were at > 99% of virgin biomass levels, however this did not account for illegal FFV catch. It may be that undocumented FFV catch of this specie has occurred in recent times.

The high density of high value species on the reef pinnacle habitat (38.5 per ha for *H. whitmaei* and 17.2 per ha for *H. fuscogilva*) indicate that this habitat may not have been fished to a large extent, and may at natural densities and be a significant source of recruitment for these high value species. The reef pinnacles are not well mapped on available nautical charts which may have resulted somewhat to their protection from fishing by the Australian and FFV fishing effort. Due to their potential to hold significant populations of high value species, sampling the numerous reef pinnacles on Lihou Reef and Coringa Bank would be a high priority to further asses the status of these species.

The protection afforded by the historical NNR status to Lihou Reef, Coringa Bank and Herald Reef would appear to have afforded some protection to the higher value species at least, which had a density on the protected reefs (17.6 per ha) that was 5 times higher than the open reefs (3.4 per ha). The lower density on fished reefs, especially for high value species, again implicates fishing pressure as the driver of low density for those species.

The low and most medium value species (e.g. *H. atra* and *S. chloronotus*) have been only lightly exploited and are likely to be in near virgin biomass levels. Very dense (>1000 per ha) populations of *H. atra* and *S. chloronotus* (and likely *H. leucospilota* – previously documented) occur in a few locations, usually in close proximity to reef cays.

5.1 Sea cucumbers as ecological indicators

Apart from providing the basis for sustainable fishery utilisation, using sea cucumber density as an ecological indicator species would appear appropriate as they are an important animal group for ecosystem functioning, and they are at risk from a range of threats, including fishing and climate change. Sea cucumbers play a variety of roles in the ecology of reefs (for a recent comprehensive review of the ecological roles of sea cucumbers, see Purcell et al., 2016). This includes bioturbation of sediments by feeding and burying, and by grazing sedimentary algae and bacteria. They, in turn, are predated upon by a wide range of echinoderms (19 species), crustaceans (17) and fishes (30). They also have a range of escape and defence mechanisms (evisceration, disintegration, extruding cuverian tubules) that also provide food for predators and scavengers while not resulting in the loss if the individual sea cucumber. They ingest calcium carbonate sediments while feeding and excrete ammonia, which is a nutrient and also increases the alkalinity of seawater in their vicinity. In these ways, sea cucumbers play an important role in recycling nutrients in oligotrophic reef systems, and may play some role in buffering the impact of ocean acidification due to anthropogenic related increases in CO_2 in the oceans.

Beside their own value for biodiversity of reef systems, sea cucumbers are also associated to many symbiotic relationships, many of them obligate (meaning the symbiont would not survive without the host sea cucumber). Symbionts from nine different phyla and from all symbiosis categories (parasitism, mutualism and commensalism) have been found to associate with tropical sea cucumbers (Purcell et al., 2016).

However, the extremely patchy distribution of some species means there could be large changes in density and distribution due to natural environmental and recruitment related factors, such as the high-density populations of *H. atra* (Lollyfish) and *S. chloronotus* (Greenfish). The higher density patches appear to be persistent in time and spatially based on limited comparisons to previous surveys (Oxley 2004; Ceccarelli, 2009). However, the drivers of their distribution are poorly understood. Because of this uncertainty, they may not be a good candidate for an indicator species.

Given the unbalanced design and limited coverage of this survey (both within sampled reef-habitat combinations and un-sampled reef-habitat combinations) it is likely that more sampling will be required in locations as yet under-sampled, and some reef-habitat combinations, before a there is a sufficient understanding of sea cucumber biogeography to make totally informed decisions about future monitoring sampling strategies, especially if a Coral Sea wide assessment is the goal (Hosack and Lawrence, 2013; Hayes et al., 2015).

However, if the existing NNR of Lihou Reef and Coringa Herald NNR should be the focus, then the 3 known surveys carried out so far in those locations should provide enough information to formulate a survey approach suitable for monitoring sea cucumbers in those locations.

A key issue is the identification of explicit goals for the Coral Sea monitoring program (Hosack and Lawrence, 2013; Hayes et al., 2015). Once determined, these goals can be used to determine the sample design, extents and periodicity. This would include a spatially explicit description of the ecological system that is the focus of the monitoring, and scenarios of change in response to impacts. The indicator species selected would be predicted to respond in a consistent fashion across these scenarios (Hayes, 2015). Hosack and Lawrence, 2013 advocate for an approach that that attempts to assess whether or not abundance has changed over time rather than assessing apparent abundance and therefore recommends using a sample design that repeatedly samples the same sites in successive years. However, this approach has less utility for fishery management and assessing the effects of fishing.

Goals of the monitoring program will need to consider the species targets (given that some species will be difficult to sample) and coverage (a whole of Coral Sea survey would be expensive and time consuming). Whatever the decisions in this regard, some basic advice from this and previous work (Hosack and Lawrence, 2013) would be:

1. Use a common sampling design for all future surveys using information provided by previous surveys and consultation with field researchers with experience in the Coral Sea, possibly within a workshop setting;
2. Sites should be representatively and randomly allocated within reef habitat strata, and allocated to optimise temporal change metrics according to monitoring goals. Hosack and Lawrence (2013) recommend a Generalized Random-Tessellation Stratified design (GRTS) design for monitoring sea cucumbers) that would allow for representative sampling at different sample intensities (and sampling effort).
3. The sample design should consider contingencies for problems with unexpected inaccessibility because of weather, health and safety concerns, and logistical constraints.
4. Some or all of sites should be repeatedly sampled by successive surveys.
5. Sample size should be sufficient to account for spatial and temporal variability, but should be at least in the order of 100 sites or more per reef unit;
6. Consistent field survey methods should be employed, utilising line transects of at least 200 m^2 in size but not longer than 100 m to ensure reef habitat strata integrity;
7. Survey data should be formally archived with adequate metadata.
8. Field surveys should receive adequate funding so that they may be properly implemented

5.2 Conclusions

The density of most sea cucumber species, and especially high value sea cucumbers was relatively low throughout the Coral Sea survey area, but especially those reefs that have been subject to most fishing by the Australian CSSCF and by illegal FFV. This low density is probably due to a naturally low carrying capacity but is also due to unsustainable fishing pressure by illegal FFV in particular. This is especially true for the southern reefs of the Coral Sea and also for the reef pass and sheltered deeper back reef habitats areas that would expect to hold significant populations of high value species.

The traditionally closed NNR reefs (Lihou Reef, Coringa Bank and Herald Reefs) appear to have provided some protection for sea cucumber populations, probably due to high levels of compliance by Australian CSSCF. The deep lagoon reef pinnacle habitats still have high densities of higher value species in particular that may have not been targeted in the past. These habitats are extensive in places and should provide some source of recruitment.

While this survey provided estimates of sea cucumber population density and biomass for several important reefs in the Coral Sea territory, the sampling was not representative of all reef habitats and the number of sample sites per reef was small. Estimates of within reef density and population biomass had a high uncertainty due to limited sampling effort and the patchy nature of sea cucumbers. Regular resurveys would provide more certainty to these estimates and provide information suitable for determining trends in sea cucumber density. Every opportunity should be taken to gather additional sea cucumber density data for the CSCMR region, particularly of un-sampled reef-habitats (forereef habitat; reef pinnacles on Lihou Reef and Coringa Bank; and deep lagoon habitats); and un-sampled reefs (e.g. Flinders Reef, Osprey Reef, Willis Islets, Diane Bank, Tregrosse Reefs). If revisiting already sampled reefs, the periodicity should be at least once every 3 years to maintain population trend connectivity regards year class strength and stock requitement considerations.

Sea cucumber fisheries globally have been overexploited by unregulated (and even sometimes regulated) fishing effort (Purcell et al., 2012). They are easy to deplete (especially the higher value species) and can be slow to recover (Uthicke et al., 2004; Skewes et al., 2010); highlighting the need for careful and responsive management. Australian fisheries are among the few tropical shallow water sea cucumber fisheries globally to have continued viability, especially for high value species. However, given the low apparent density of high value species on Coral Sea reefs subject to Illegal fishing effort, controlling this fishing activity is a high priority. Stock assessments and current management implemented in the Australian CSSCF should also be reviewed. The collection and analysis of fishery dependent data from the CSSCF should be a high priority, and, together with periodic surveys, should provide the basis for informed management decisions to promote sustainable utilisation and protect the values of the Coral Sea Commonwealth Marine Reserve.

Appendix A Sample site locations

SITE	Reef	Habitat	Depth (min)	Depth (max)	Longitude (decimal degrees)	Latitude (decimal degrees)
SWH-1-R4	Herald Cays	backreef	15	22	149.12679	-16.97577
SA-1-R1	Saumarez Reefs	reef flat	2	6	153.65192	-21.89508
SA-1-785	Saumarez Reefs	inner slope	12	12	153.64874	-21.89367
SA-1-749	Saumarez Reefs	inner slope	17	17	153.63960	-21.89535
SA-1-784	Saumarez Reefs	inner slope	13.3	13.3	153.64874	-21.88804
KR-1-275	Kenn Reef	inner slope	4	4	155.77478	-21.20205
KR-1-276	Kenn Reef	reef flat	5	5	155.77706	-21.19868
KR-1-R1	Kenn Reef	reef flat	1.5	1.5	155.77890	-21.19415
KR-1-255	Kenn Reef	inner slope	9	12	155.76792	-21.19474
KR-1-256	Kenn Reef	forereef	6	9.3	155.78220	-21.19305
WR-1-259	Wreck Reef	inner slope	5	12	155.36701	-22.18837
WR-1-355	Wreck Reef	deep lagoon	45	45	155.44240	-22.16137
WR-1-356	Wreck Reef	deep lagoon	25	25	155.44754	-22.17206
WR-1-367	Wreck Reef	inner slope	12.5	12.5	155.45154	-22.16700
WR-1-R1	Wreck Reef	inner slope	3	3	155.45627	-22.16843
WR-1-227	Wreck Reef	reef flat	1.5	4	155.33446	-22.19737
WR-1-238	Wreck Reef	reef flat	1	2	155.34189	-22.19568
WR-1-237	Wreck Reef	inner slope	5	12.8	155.34189	-22.19006
WR-1-248	Wreck Reef	inner slope	9	13	155.35102	-22.18500
WR-1-270	Wreck Reef	pass	23	25	155.37444	-22.18837
KR-1-395	Kenn Reef	reef flat	1	8	155.76792	-21.25605
KR-1-R4	Kenn Reef	reef flat	0.5	1	155.76340	-21.26013
KR-1-393	Kenn Reef	inner slope	22	25	155.75650	-21.25099
NEH-1-R2	Herald Cays	reef flat	1	2	149.19630	-16.94607
NEH-1-R3	Herald Cays	lagoon pinnacle	21.9	21.9	149.18013	-16.94157
HR-1-R5	Holmes Reef	pass	9	22	147.83980	-16.51283
HR-1-R6	Holmes Reef	reef flat	2	4	147.84263	-16.51047
HR-1-R7	Holmes Reef	reef flat	2	4	147.84342	-16.50825
HR-1-842	Holmes Reef	reef flat	2	3	147.81050	-16.53199
HR-1-R1	Holmes Reef	backreef	9.5	18	147.81022	-16.52765
HR-1-R2	Holmes Reef	backreef	1	6	147.81715	-16.53078
MR-1-1276	Marion Reef	inner slope	1	9	152.32360	-19.26704
MR-1-1277	Marion Reef	inner slope	6	8	152.33445	-19.26197
MR-1-1245	Marion Reef	reef flat	1.5	5	152.34187	-19.25972
MR-1-R1	Marion Reef	inner slope	4	5	152.34438	-19.25587
MR-1-R2	Marion Reef	reef flat	0.1	1.5	152.34483	-19.26027
MR-1-788	Marion Reef	inner slope	7	13	152.38585	-19.12698
MR-1-754	Marion Reef	inner slope	18.1	18.1	152.38356	-19.11798
MR-1-755	Marion Reef	inner slope	6	6	152.39270	-19.11798
MR-1-1244	Marion Reef	inner slope	5.5	7.5	152.33616	-19.25804
MR-1-756	Marion Reef	forereef	10	14.2	152.40184	-19.11967
MR-1-789	Marion Reef	reef flat	1.5	2.5	152.39670	-19.12698
MR-1-R3	Marion Reef	reef flat	1	3	152.40140	-19.12998
MR-1-821	Marion Reef	inner slope	16.8	16.8	152.39099	-19.13598
MR-1-623	Marion Reef	reef flat	2	4	152.38756	-19.08874
MR-1-590	Marion Reef	inner slope	4	6	152.38585	-19.07805
MR-1-622	Marion Reef	inner slope	15.1	15.1	152.38014	-19.08199
MR-1-655	Marion Reef	inner slope	12	14	152.38185	-19.09267

MR-1-656	Marion Reef	inner slope	7.1	7.1	152.38756	-19.09774
MR-1-689	Marion Reef	inner slope	5	6.5	152.38927	-19.09999
MR-1-R4	Marion Reef	inner slope	5	7.1	152.39117	-19.10255
LRGC1-Transects	Lihou Reef	pass	20	25	151.48852	-17.59902
LRGC2-Transects	Lihou Reef	inner slope	5	9.6	151.49880	-17.59272
LRGC-SN3-Snorkel-DC&DW	Lihou Reef	subtidal reef flat	5	7	151.50830	-17.59222
LR-1-R1	Lihou Reef	subtidal reef flat	5	7	151.51178	-17.59167
LR-1-R2	Lihou Reef	reef flat	0.8	2	151.74718	-17.47770
LR-1-R3	Lihou Reef	inner slope	16.1	16.1	151.74532	-17.47348
LR-1-R4	Lihou Reef	inner slope	14	13	151.75342	-17.46743
LR-1-R5	Lihou Reef	reef flat	1.5	2.5	151.76008	-17.46872
MR-1-R5	Marion Reef	lagoon pinnacle	4	22	152.35952	-19.06288
MR-1-220	Marion Reef	inner slope	3	8.5	152.32703	-18.97737
MR-1-221	Marion Reef	subtidal reef flat	4	5	152.33102	-18.97737
MR-1-222	Marion Reef	subtidal reef flat	4	5	152.34016	-18.97906
MR-1-189	Marion Reef	subtidal reef flat	4	5	152.34016	-18.96668
MR-1-188	Marion Reef	subtidal reef flat	4	5	152.33445	-18.96500
LR-1-R6	Lihou Reef	forereef	10	18	151.86538	-17.41708
LR-1-R7	Lihou Reef	pass	7	9.8	151.86480	-17.41357
LRAC3-Long Swim	Lihou Reef	inner slope	8.2	8.2	151.87785	-17.41170
LR-1-R8	Lihou Reef	reef flat	3.5	3.5	151.87468	-17.41400
LR-1-R9	Lihou Reef	pass	12.5	12.5	152.05500	-17.32052
LR-1-R10	Lihou Reef	pass	6	6	152.05382	-17.31847
HR-1-R3	Holmes Reef	backreef	15	25	147.80701	-16.52613
SWH-NE Flank 2	Herald Cays	backreef	19.6	19.6	149.13054	-16.97097
SWH-Mid Back 1	Herald Cays	backreef	13.3	13.3	149.12822	-16.98782
SWH-1-R1	Herald Cays	reef flat	3.5	3.5	149.13080	-16.98818
SWH-1-R2	Herald Cays	reef flat	1	2	149.13578	-16.98885
SWH-1-R3	Herald Cays	backreef	10	15.5	149.12683	-16.97643
HR-1-R4	Holmes Reef	pass	8	25	147.83958	-16.51305
NEH-SN4E	Herald Cays	reef flat	3.5	3.5	149.19281	-16.94269
NEH-Mid Back	Herald Cays	backreef	4.5	4.5	149.20078	-16.93509
NEH-SN6B	Herald Cays	backreef	5	6.5	149.20350	-16.92983
NEH-SN6E	Herald Cays	backreef	9.7	9.7	149.20142	-16.92528
NEH-NE Back	Herald Cays	backreef	16.4	12.5	149.19901	-16.92254
NEH-1-R1	Herald Cays	lagoon pinnacle	25.8	25.8	149.19652	-16.92535
LR-1-R11	Lihou Reef	inner slope	8.5	8.5	152.05663	-17.32732
LR-1-R12	Lihou Reef	backreef	20.7	20.7	152.07887	-17.11572
LR-1-R13	Lihou Reef	pass	15	40	152.07303	-17.12175
LR-1-R14	Lihou Reef	backreef	10	25	152.08465	-17.11397
LR-1-R15	Lihou Reef	reef flat	1	1	152.08102	-17.11835
LRLC4-Transects	Lihou Reef	backreef	15	40	151.84742	-17.11028
LRLC3-Transects	Lihou Reef	backreef	12	20	151.82533	-17.12527
LRLC-SN2-Snorkel-DC&DW	Lihou Reef	backreef	5	8.5	151.82030	-17.13282
LR-1-R16	Lihou Reef	backreef	10	16.9	151.81562	-17.13427
LR-1-R17	Lihou Reef	reef flat	2	2	151.83907	-17.11679

LR-1-R18	Lihou Reef	reef flat	1.5	2	151.83183	-17.12487
CO-1-R1	Coringa Bank	reef flat	1	1	150.00102	-16.93905
CO-1-R2	Coringa Bank	backreef	8	6	149.99735	-16.93600
CH-SN4B	Coringa Bank	backreef	6.5	6.5	150.00100	-16.93536
CH-BE	Coringa Bank	backreef	7.5	7.5	150.00228	-16.93331
KR-1-274	Kenn Reef	inner slope	22	22	155.76393	-21.20374
SA-1-855	Saumarez Reefs	inner slope	10.3	10.3	153.66016	-21.87736
SA-1-891R	Saumarez Reefs	reef flat	1	4	153.66647	-21.87950
SA-1-R2	Saumarez Reefs	reef flat	4	10	153.65995	-21.88538
SA-1-R3	Saumarez Reefs	reef flat	1	10	153.65743	-21.88957
SA-1-820	Saumarez Reefs	inner slope	10	10	153.65445	-21.88804
KR-1-R2	Kenn Reef	inner slope	0	25	155.76597	-21.20420
KR-1-295	Kenn Reef	inner slope	8	12	155.76964	-21.20599
KR-1-R3	Kenn Reef	inner slope	2	6	155.77230	-21.20667
CO-1-R3	Coringa Bank	backreef	15	20	150.00012	-16.93271

Appendix B Reef habitat area

Coral Sea reef habitats and area (ha)

Reef_name	Backreef	Deep lagoon	Drowned bank	Enclosed lagoon	Forereef	Inner slope	Lagoon pinnacle	Land on reef	Pass	Reef flat	Subtidal reef flat	Total reef
Abbington Reef					129.5	10.6				271.6		411.7
Bouganville Reef				285.3	243.2	303.0	1.3			582.1		1,414.9
Coringa Bank	905.9	240,001.1			1,405.8	369.7	475.6	76.6		432.4	10,890.2	254,557.1
Dart Reef	64.4			437.0	136.1					416.8		1,054.3
Diane Bank		92,481.7			836.9			7.6	1,684.8	45.1	15,164.0	110,220.1
Flinders Reef	1,026.3	72,243.2			1,654.9	5,399.9	114.0	3.2	7,415.6	4,795.5	2,252.3	94,905.0
Flora Reef	128.8	284.1			284.7	752.3				838.9	166.5	2,455.4
Fredrick Reef	103.7	6,766.1			1,066.8	329.0			135.7	676.2	315.4	9,392.7
Herald Cays	116.6	5,189.4		148.4	289.0		22.6	76.8		1,486.6		7,329.4
Heralds Surprise	86.3			378.5	200.7		10.4			439.4		1,115.3
Holmes Reef	1,149.1	7,027.8		359.8	991.7	5,132.0			59.8	5,671.4	731.8	21,123.4
Kenn Reef	953.5	15,131.8			2,150.2	4,983.3	7.7	2.8	1,236.8	1,730.2	2,897.2	29,093.6
Lihou Reef	4,814.9	211,958.5			4,680.0	11,243.9	424.4	126.8	7,446.6	6,109.0	4,242.0	251,046.1
Magdelaine Cays					235.3	297.3		13.7		356.3		902.5
Marion Reef	798.3	68,169.5			2,557.9	10,785.2	67.9	3.3	5,704.5	4,317.7	781.8	93,186.0
Moore Reef						182.6				555.1	234.5	972.2
Osprey Reef	146.7	11,782.5			1,003.5	2,326.5	3.6		93.9	4,228.2	48.3	19,633.2
Saumarez Reefs		67,769.8			5,629.5	5,569.9				2,295.5		81,264.8
Tregrosse Reef	118.9	331,610.3			368.7	352.5	513.5	62.7		719.7	6,574.9	340,321.1
Un-named shoal 1			1,135.2									1,135.2
Un-named shoal 2			2,323.8									2,323.8
Un-named shoal 3			527.0									527.0
Un-named shoal 4			7,228.0									7,228.0
Willis Bank		64,981.6			3,247.8	1,054.1		48.3		735.7	6,590.0	76,657.3
Wreck Reef	627.0	16,969.0			301.8			18.4	681.3	1,657.8	5.2	20,260.5
Total habitat	11,040.3	1,212,366.2	11,214.0	1,609.1	27,414.2	49,091.7	1,641.2	440.2	24,459.1	38,361.0	50,893.8	1,428,530.8

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CONTACT
Tim Skewes Consulting
m +61 0419 382 697
e timskewes@internode.on.net