MARINE RESEARCH

SURVEY AND STOCK SIZE ESTIMATES OF THE SHALLOW REEF (0-15 M DEEP) AND SHOAL AREA (15-50 M DEEP) MARINE RESOURCES AND HABITAT MAPPING WITHIN THE TIMOR SEA MOU74 BOX

VOLUME 1: STOCK ESTIMATES AND STOCK STATUS

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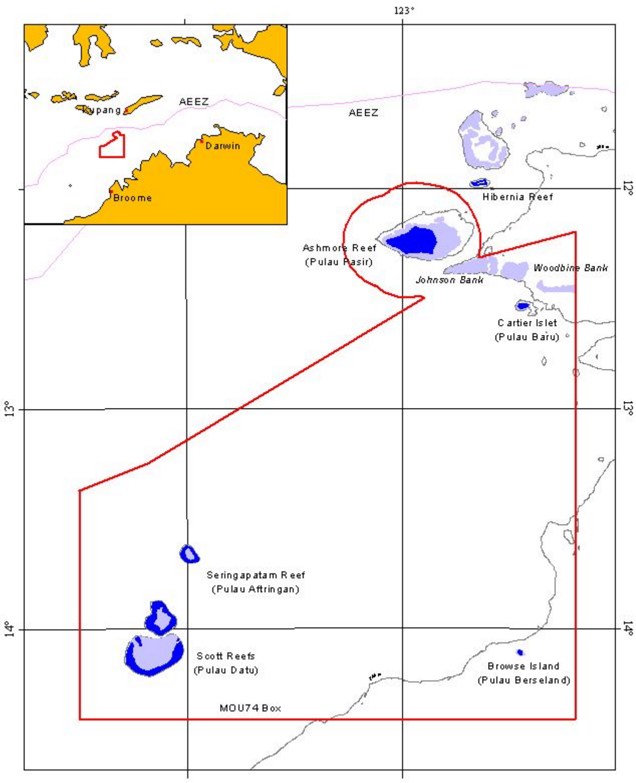

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This report is one of a series produced by the CSIRO Division of Marine Research from a survey of the shallow reef and shoal fishery resources and habitats of the MOU74 Box off northwestern Australia. The series includes; Volume 2: Habitat Mapping and Coral Dieback; and Volume 3: Seabirds and shorebirds of Ashmore Reef. The analysis contained in the reports is based on information collected in the MOU74 Box in September and October 1998. The study was funded by the FRRF and Environment Australia.

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EXECUTIVE SUMMARY

The MOU74 Box, off the northwest Australian coastline, is an area of approximately 50,000 km^2 within the Australian Fishing Zone. It contains five large, shallow reef systems (less than 15 m deep) ranging in size from 227 km^2 (Ashmore Reef) to 4.5 km^2 (Browse Island). They total approximately 560 km^2 in area. Immediately north of the MOU74 Box within the Australian Fishing Zone (Little Area A) is another shallow reef, Hibernia Reef. In addition to the shallow reefs, there is approximately 925 km^2 of shoal areas (15 to 50 m deep) within the MOU74 Box and 301 km^2 of shoal areas in Little Area A.

The reefs and shoals support populations of sedentary reef resources including several species of holothurians (beche-de-mer) and trochus, as well as reef-associated fin-fish and sharks. These resources have been fished for many years by Indonesian fishers. Ashmore Reef was declared a Marine Nature Reserve in 1983, banning the removal of fauna and flora to a depth of 50 m. The remaining reefs in the area are under continued, and probably increasing, fishing pressure.

The marine resources of the MOU74 Box are managed by the Australian Government. Under the terms of a memorandum of understanding (MOU) between the Australian and Indonesian governments, continued traditional fishing by Indonesian fishing vessels is allowed, principally for sedentary resources such as beche-de-mer (trepang) and trochus, but also fin-fish and reef shark. Apart from limited catch data collected by surveillance and regulatory authorities, little is known about the catch of the Indonesian fishers and the effects of fishing on the target species. There are concerns that the current level of fishing may be unsustainable.

In September and October 1998, CSIRO Division of Marine Resources surveyed the shallow reefs (0-15 m deep) and shoal areas (15-50 m deep) of the MOU74 Box area and Little Area A to the north. Its purpose was to assess the status of the reef resources in the area, and the environment that supports them. Fieldwork for the survey was completed on 10 October 1998.

Holothurians on shallow reefs. There was an estimated 753 tonnes wet weight (± 219 tonnes, 95% CI) of commercial species of holothurians on the shallow reefs of the study area, which equates to approximately 45 tonnes of dried beche-de-mer. The most abundant commercial species was *Holothuria atra* (lollyfish), which made up almost half the biomass of commercial species on the shallow reefs. Ashmore Reef had the highest abundance of commercial holothurians of all the reefs in the study area, and approximately 74% of all commercial holothurians on the reefs by weight. Seringapatam Reef (0.01%) and Hibernia Reef (0.3%) had the lowest biomass of commercial holothurians.

High-value beche-de-mer species — *Holothuria nobilis* (black teatfish), *H. fuscogilva* (white teatfish) and *Thelenota ananas* (prickly redfish) — totalled only 32.5 tonnes wet weight (± 37.5 tonnes, 95% CI) on the shallow reefs or approximately 2 tonnes of dried beche-de-mer. High-value species were either absent or at very low abundances on all reefs in the study area except Ashmore Reef; even this reef showed some evidence of depletion. There were clear indications that the high-value species have been severely depleted in the study area, and that fishing effort has switched to the medium- and low-value species.

Medium- and low-value beche-de-mer species occurred in low densities on most reefs, but were more abundant on Ashmore Reef. Some currently targeted species, such as *Holothuria atra*, showed evidence of severe depletion on some of the unprotected reefs. One beche-de-mer species of little or no current value, *H. leucospilota*, was very abundant on Ashmore Reef and common on Scott Reefs.

Holothurians on shoals. There was an estimated 546 tonnes wet weight (± 251 tonnes, 95% CI) of commercial holothurians on the shoals of the study area, or approximately 33 tonnes of dried beche-de-mer. Most shoals in the study area had a generally low abundance except for shoal A, Browse Island surrounds and the Scott Reef Nth lagoon, which had few holothurians. The species composition was different to the shallow reefs: the main species were the low-value species *H. fuscopunctata* (elephant truckfish), giving it the second highest total biomass of any commercial holothurian in the study area, after *H. atra*. Relatively high densities of a high-value species, *Thelenota ananas*, and a medium-value species, *Actinopyga echinites* (deepwater redfish) occurred on a small area of hard bottom habitat on the Woodbine and Johnson shoals.

While the holothurian resources on the shoals are currently being exploited by a few Indonesian fishers, there were no indications of severe depletion. The depth of the shoal areas (usually >20 m) would offer some protection from fishing. Management interventions that stabilise the fishing effort to current levels should be considered as an initial step towards managing these resources.

Trochus on shallow reefs. There was an estimated 4.6 tonnes (± 3.5 tonnes, 95% CI) of trochus (*Trochus niloticus*) on the shallow reefs of the study area. Trochus have been virtually fished out on most reefs, with the exception of Ashmore Reef — Cartier Island and Scott Reef had small remnant populations. However, even on Ashmore Reef the density of trochus still indicated a heavy depletion when compared with the trochus fishery in Torres Strait.

Finfish on shallow reefs. A total of 19557 fin-fish and sharks from 17 families and 104 species were recorded during the survey on the reef-edges. Overall, the mean density of fish on the reef-edges in the study area was 481 per ha (~244 kg per ha). Fish density was highest and similar at Scott Nth (586 per ha) and Ashmore (554 per ha) Reefs. There was an estimated 1168 tonnes (± 132 tonnes, 95% CI) of fish on the reef-edges of the MOU 74 Box and about 85% of this biomass came from three reefs: Ashmore, Scott Nth and Scott Sth, which also accounted for ~80% of the total area of reef-edge. Ashmore Reef accounted for ~25% of the total fish biomass. Surgeon fishes (Acanthuridae) were the only family showing highest density in the Ashmore reef marine reserve. The snappers (Lutjanidae), emperors (Lethrinidae) and cods (Serranidae) were all more abundant on the Scott-Seringapatam reefs. The most abundant fish species were *Lutjanus gibbus* (130 t) and *Lutjanus bohar* (160 t).

The surveys suggest that the current level of fishing effort in the MOU Box has not caused a significant depletion of the fin-fish stocks on the reefs outside the Ashmore Reef marine reserve. However, it is not possible to measure the actual impact of fishing on the stocks as accurate and current catch-data are not available for comparison with the estimated stock sizes. Nevertheless, given that the densities of most species are higher at reefs outside the marine reserve, and size distributions show no signs of over-exploitation, current effort appears to be sustainable.

Finfish on shoals. The mean density of commercial fish on the shoals of the MOU 74 Box was very low (5 per ha) compared to that on the reef-edges, due to the predominance of unsuitable habitat (mainly sand/algae) on the shoals. There was an estimated 550000 (±78.58%, 95% CI) commercial fish on the shoals, of which 73% came from Scott Sth, at sites where the seabed was consisted of reef. There was an estimated 6830000 (±48.52%, 95% CI) non-commercial fish on the shoals, of which 70% came from Scott Sth and Shoal B. Mid-water acoustic signatures confirmed the distribution and overall paucity of fish on the shoals.

The low density and abundance of commercial fin-fish on the shoals indicated that it is unlikely this area would support commercial fishing, even at Scott Sth where fish density was highest.

Sharks. Reef associated sharks were extremely rare (< 1 per ha) on the reef-edges in the MOU 74 Box and only two species, *Carcharhinus amblyrhynchos* and *Triaenodon obesus*, were recorded. Commercially exploited sharks were not observed during the video transects on the shoals; however, longlines, presumably set to catch sharks, were observed on some transects.

The very low estimates of shark abundance and biomass on the shallow reef-edges and shoals of the MOU 74 Box, particularly carcharhinids, suggest that current effort, particularly with long-lines, may be seriously depleting the shark population.

Conclusions. Overall, the sedentary marine living resources on the shallow reefs were heavily depleted with the high-value species over-exploited and the lower value species probably either fully or over-exploited. Despite the low density, there appears to be a sustained fishing effort by Indonesian fishers in the area. A drastic reduction in effort would be required to allow for a recovery of the higher value species, and to protect other species from severe depletion.

The exception is Ashmore Reef, where there were significant populations of most target species. However, there is most likely some illegal fishing occurring on Ashmore Reef and there is clear evidence of exploitation of at least the high-value resources. The nature of these fisheries and the depleted state of the other reefs in the MOU74 Box suggests that the remaining resources on Ashmore Reef could be quickly depleted if the protection currently given to the reef is not maintained and possibly enhanced. For many reasons, including the potential for recruitment of larvae to depleted reefs, it is important that these populations are protected. Year round protection of the resources on Ashmore Reef should be considered.

Management recommendations

1. Include all reefs and shoals in an integrated management plan for the whole area.

2. Cease fishing effort on at least the high-value beche-de-mer, trochus and shark in the MOU74 Box for at least three years.

3. Reduce and regulate effort/catch on the lower value beche-de-mer species on the shallow reefs (especially *H. atra* on Scott Reefs and *H. edulis* on Scott Reef North).

4. Regulate effort (probably to current levels) on the shoal beche-de-mer.

5. Stop illegal fishing effort on Ashmore Reef.

6. Establish a cost effective monitoring program.

1. INTRODUCTION

The MOU74 Box, off the northwest Australian coastline, is an area of approximately 50,000 km^2 within the Australian Fishing Zone. It contains six large, shallow, reef systems ranging in size from 227 km^2 (Ashmore Reef) to 4.5 km^2 (Browse Island). They cover a total area of approximately 560 km^2 (excluding the deep lagoons of the Scott Reefs) (Fig. 1, Table 1). The area immediately north of the MOU74 Box within the Australian Fishing Zone (Little Area A) also contains one shallow reef; Hibernia Reef (Fig. 1). These reefs support populations of sedentary reef resources including several species of holothurians (beche-de-mer) and trochus, and reef-associated fin-fish and sharks.

In addition to the shallow reefs, there are approximately 925 km^2 of shoal areas (15 to 50 m deep) within the MOU74 Box and 301 km^2 of shoal areas immediately north of the MOU74 Box in Little Area A (Fig. 1, Table 1). Most of the shoal areas are adjacent to the shallow reef systems, the exception being the Johnson and Woodbine Banks and Shoal C east of Ashmore Reef, and Shoal A and B north of Hibernia Reef (Fig. 1). The shoals probably represent ancient coral reefs that did not keep pace with sea level rise during the past 20,000 years (Anon, 1989; Berry, 1993). The shoal areas also contain stocks of sedentary target species, fin-fish and shark.

Table 1. Area of shallow reefs (0–15 m deep) and shoals (15–50 m deep) in the MOU74 box and Little Area A in the Timor Sea. Also shown is the length of reef edge for each reef.

Type	Name	Area (km^2)	Edge length (km)
Reef	Ashmore Reef	226.97	73.26
Reef	Browse Is	4.55	6.82
Reef	Cartier Is	10.85	12.21
Reef	Hibernia Reef	11.47	22.11
Reef	Scott Nth Reef	106.13	93.28
Reef	Scott Sth Reef	144.00	155.10
Reef	Seringapatam Reef	55.19	45.87
	Total reefs	**559.18**	**408.65**
Shoal	Ashmore Reef	303.83	
Shoal	Browse Is	5.42	
Shoal	Cartier Is	8.67	
Shoal	Johnson Bank	137.23	
Shoal	Scott Nth Reef lagoon	33.10	
Shoal	Scott Sth Reef lagoon	288.95	
Shoal	Shoal A	75.85	
Shoal	Shoal B	225.17	
Shoal	Shoal C	54.58	
Shoal	Woodbine Bank	93.54	
	Total shoals	**1226.34**	

The marine resources of the MOU74 Box are managed by the Australian Government. Under the terms of a memorandum of understanding (MOU) between the Australian and Indonesian governments, continued traditional fishing by Indonesian fishers is allowed, principally for sedentary resources such as beche-de-mer (trepang) and trochus, but also for fin-fish and reef shark. Apart from limited catch data collected by surveillance and regulatory authorities, little is known about the catch of the Indonesian fishers or the effects of fishing on the target species. However, an analysis of limited catch data suggested that sedentary species on and around reefs in the MOU74 Box were probably heavily depleted (Wallner and McLouglin, 1996). There is an urgent need for stock surveys as well as catch-and-effort data to develop appropriate management plans for the sustainable harvesting of the living marine resources of the area.

The general experience with these fisheries throughout the world, including other areas of Australia such as Torres Strait and the Great Barrier Reef, is that these sedentary marine resources have proved particularly susceptible to overexploitation (Wright and Hill, 1993). For example, beche-de-mer fisheries in other areas of Australia have been under strong pressure in recent years due to increased prices for beche-de-mer in Asia (Conand, 1996). In Torres Strait, where similar species to those in the MOU74 Box are caught, the fishery has been overexploited for sandfish (*H. scabra*), the main commercial species taken. Resource surveys (similar to this survey) carried out by CSIRO in 1995 and 1998 concluded that this fishery was overexploited (Long *et al.*, 1996; Skewes *et al.*, 1998) as a result of which strict management regimes, including a cessation of fishing for all of 1998, were enforced by the Queensland Fisheries Management Authority.

Sustainable management of the resources in the MOU74 Box requires at least this level of information for evaluating the effects of fishing effort on targets stocks and the effectiveness of protected areas (marine reserves). Such knowledge is essential to develop management for the area, especially given the complex fishing arrangements with Indonesia, and potentially increasing fishing effort (Wallner and McLouglin, 1996).

1.1 Fishing activity

The reefs and shoals of the MOU74 Box have probably been fished for several centuries. The earliest records of fishing activity are by the Macassans (now Sulawasi in Indonesia) fishing for beche-de-mer over a wide area of the Australian coastline, including the reefs of the MOU74 Box from the mid-1600s to about 1900.

After about 1900 the catch diversified to include trochus shell, fish and clam meat and turtle (meat and shell) as well as beche-de-mer (Anon., 1989), and seabirds and turtle eggs were exploited (mainly on Ashmore Reef). Often, however, effort was concentrated on a particular resource (e.g. trochus in the 1970s) depending on market forces (Wallner and McLouglin, 1996).

The recent trend is for Indonesian fishers to target a range of species. A survey of Indonesian fishing vesssels, perahus, in 1987 found the main commercial catches to be beche-de-mer, trochus, pearl oysters and shark. The catch also occasionally included reef fish (mainly for consumption by fishers but some was dried for consumption or selling in Indonesia.), clam meat, squid, octopus, helmet and baler shells (Russell and Vail, 1988). We observed canoes with finfish, trochus and holothurians collected during a single fishing expedition.

It is difficult to obtain accurate data on fishing effort in the MOU74 Box and quantitative estimates of fishing effort are rare. Prior to 1900, it was estimated that up to 200 perahus (Anon., 1989) and 8000 fishers (Wallner and McLouglin, 1996) per year visited the northern

Australian coast. In October 1949, 30 perahus were recorded from Seringapatam to Hibernia Reef, including 23 at Ashmore Reef (Anon., 1989). In the early 1990s, the number of fishing trips to the MOU74 box was estimated at 200, based on observations by the monitoring vessel at Ashmore Reef (Wallner and McLouglin, 1996).

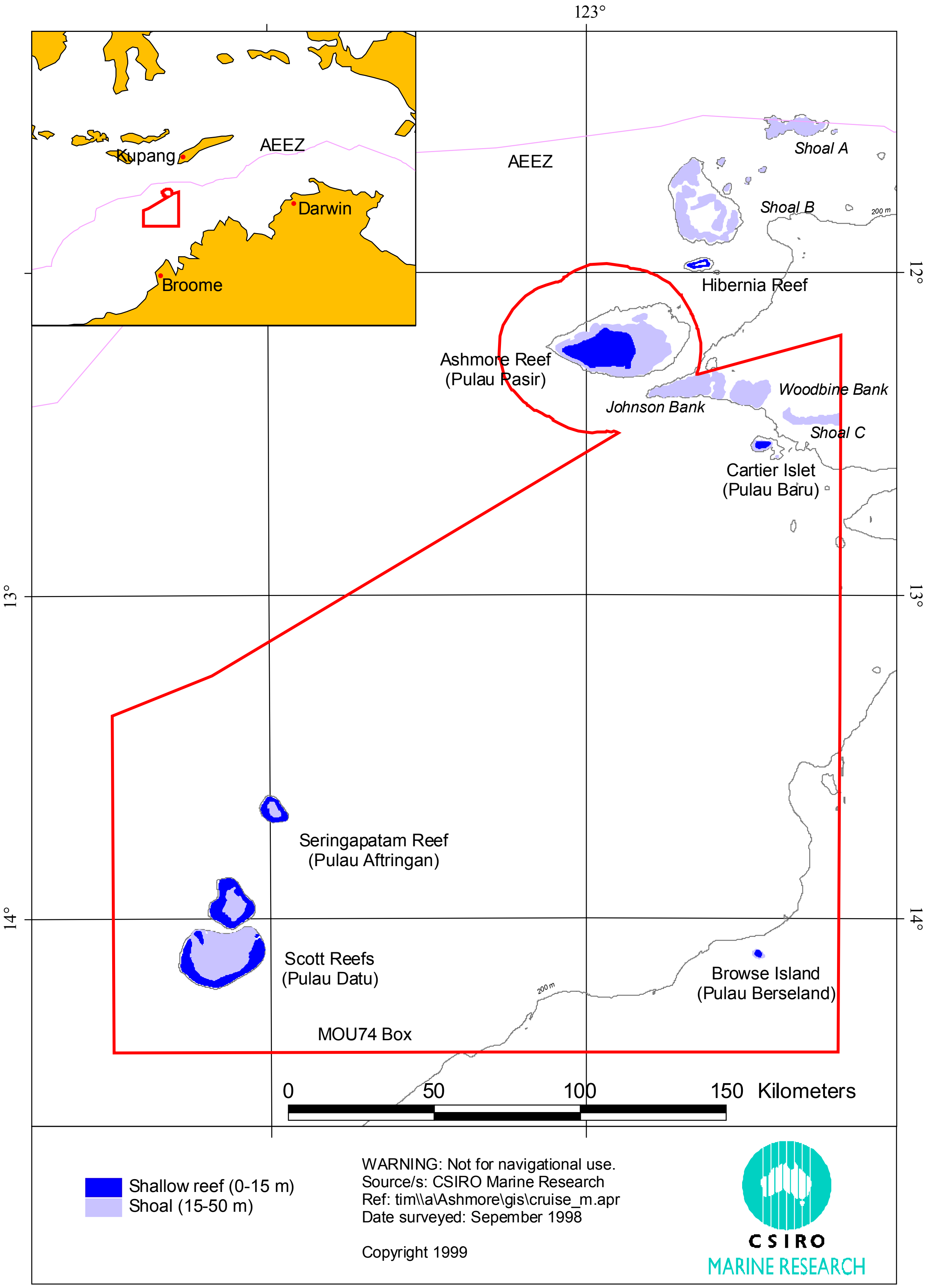
Information from surveillance authorities indicates that fishing effort has increased considerably in recent times (Des Pike and Steve Tester, Environment Australia, *pers comm*.; Caddy, 1995). This has been driven by higher product prices and the depletion of Indonesian reefs and, more recently, by the severe economic downturn in Indonesia. Although some of this effort has come from illegal fishing in and outside the MOU74 Box (Caddy, 1995), much has come from an increase in visits by traditional fishing vessels.

During the survey in September/October 1998, we observed approximately 150 vessels in the MOU74 Box (Table 2). Given that not all the fishing vessels would be in the MOU74 Box at any one time, and that each vessel may make two or more trips per year, the current fishing effort is probably greater than the 200 trips per year estimated for the early 1990s (Wallner and McLouglin, 1996).

Table 2. Records of Indonesian fishing vessels observed anchored at reefs and shoals during this survey. An additional 30-50 vessels were also observed under sail or in the vicinity of Ashmore Reef during the survey.

Date	Reef/Shoal	Vessels anchored
5-Sep-98	Shoal A	0
7-Sep-98	Shoal B	2
10-Sep-98	Johnson Bank	7
11-Sep-98	Woodbine Bank	11
12-Sep-98	Shoal C	0
12-Sep-98	Cartier Is	6
13-Sep-98	Browse Is	0
15-Sep-98	Scott Rf (South)	54
17-Sep-98	Scott Rf (North)	35
29-Sep-98	Seringapatam	3
5-Oct-98	Hibernia	0

Figure 1. Timor Sea MOU 74 Box showing shallow reefs (0-15 m deep) and shoal areas (15-50 m deep). Also shown is the boundary of the Australian EEZ and the 200 m bathymetric line.



1.2 Ashmore Reef National Nature Reserve

Ashmore Reef was declared a Marine Nature Reserve on the 16 August 1983, and the removal of fauna and flora was banned. It covers 583 square kilometers of the reef down to approximately the 50 m contour. The nearest marine protected area is over 600 km away (part of the Rowley Shoals).

Ashmore Reef was selected as a nature reserve because of its high conservation value. It provides important nesting habitats for seabirds, breeding and feeding habitats for marine turtles, and contains an unusually high abundance and diversity of seasnakes.

Ashmore Reef was subject to a high level of anthropogenic impacts prior to the declaration, including fishing, extraction of guano and exploitation of the seabirds and turtles that lived and nested around its three sand cays.

1.3 Physical environment

The MOU74 Box has a maximum tidal range of about 5 m with a semidiurnal tidal cycle. This produces considerable tidal streams over the reef top and through tidal channels on the reef and through gaps or channels through reef atolls.

South-east trade winds are prevalent from April to September. From May to August the winds average 11 to 30 km/h; however winds stronger than 31 km/h are not uncommon (21% of observations). The trade winds are usually associated with fine dry weather. They produce a large swell that impacts on the southern side of most reefs in the area, producing consolidated crustose coraline algae and limestone substrates on the reef slope to depths characteristic of outer reefs or oceanic atolls (Anon, 1989).

The north-west or west monsoons prevail from December to March and are associated with prominent cloud, rain and thunderstorm activity. Cyclones may occur between December and April. Typically, cyclones move south-west across the Arafura and Timor Seas. Gale to hurricane force winds are liable to be encountered over an area between about 32 and 240 km wide.

During the south-east tradewinds (April to September), the predominant direction of the ocean current is west-south-west. In the monsoon season (December to March), when winds come from the north-west or west, the direction of the ocean current reverses, becoming east-north-east. The mean rate of ocean currents throughout the year is usually less than 0.5 knots (Anon, 1989)

1.4 Research objectives

CSIRO Division of Marine Research surveyed the shallow reefs (0-15m deep) and shoal areas (15-50m deep) of the MOU74 Box area and Little Area A to the north in September and October 1998. The purpose of the survey was to assess the status of the reef resources in the area, and the environment that supports them. The specific research objectives were to:

1. Estimate the distribution and density of the main target species of beche-de-mer (trepang), trochus, fin-fish and reef shark on the shallow reefs and shoal areas in the MOU74 Box and area immediately north of the MOU74 Box in Little Area 'A'.

2. Provide stock size estimates (with appropriate confidence limits) of the main target species of beche-de-mer (trepang), trochus, fin-fish and reef shark on the shallow reefs and shoal areas on a by-reef and whole-area basis. This would include assessments of potential biases in the survey method, especially for fin-fish and shark on the reef edge and in the shoal areas.

3. Obtain size-frequency data of the main target species of beche-de-mer (trepang), trochus, fin-fish and reef shark and, where possible, analyse to provide the population structure and the relative strengths of the recruiting and fishery year-classes on a by-reef and whole-area basis.

4. Provide an indication of the stock status of the main target species of beche-de-mer, trochus, fin-fish and reef shark, in the study area on a by-reef, and whole-area basis. This would include a comparison of the stock size/density between the reefs within the study area, a comparison of stock size/density with similar reefs in the Torres Strait and on the northern Great Barrier Reef, and an analysis of the size/age structure of each species.

   The indication of stock status will be a qualitative estimate of the level of exploitation, and recommendations for future exploitation levels.

   Note: It is difficult to assess the status of any fishery where no baseline or catch and effort data has been collected. Nor is it possible to do a formal stock assessment from a single survey. The status of each stock will be estimated principally by comparing stock size, density and population size/age structure between reefs in the study area, and with similar reefs in the Torres Strait and northern Great Barrier Reef, and by relating these estimates to the estimated fishing effort data and habitat data. The stock size estimates will also be compared to estimates of the catch made from the limited surveillance data for the MOU74 box reported by Wallner and McLoughlin (1996). This may provide additional information for assessing the status of the resources in the MOU74 Box.

5. Assess the effectiveness of the Ashmore Reef Marine Reserve for protecting the populations of the main target species of holothurians (beche-de-mer), trochus, fin-fish and reef shark.

6. Provide information on the distribution and density of other conspicuous megafauna and quantifiable resources such as giant clams and spiny rock lobsters. This would include stock estimates where possible.

7. Provide maps of structural and biological components of the reefs and shoals in the study area, including seagrass, algae and coral cover, and substrate types.

8. Provide maps of habitats of the shallow reefs and shoal areas in the study area, especially those relevant to the distribution and abundance of sedentary reef resources.

This report contains the results of analyses relevant to objectives 1–6. The results of analyses relevant to objectives 7 and 8 are contained in volume 2: Habitat mapping and coral dieback.

An additional volume, on the seabirds of East Island, Ashmore Reef, was also produced from data collected during fieldwork for the project.

2. METHODS

2.1 Sample design

2.1.1 Shallow reefs (0–15 m deep)

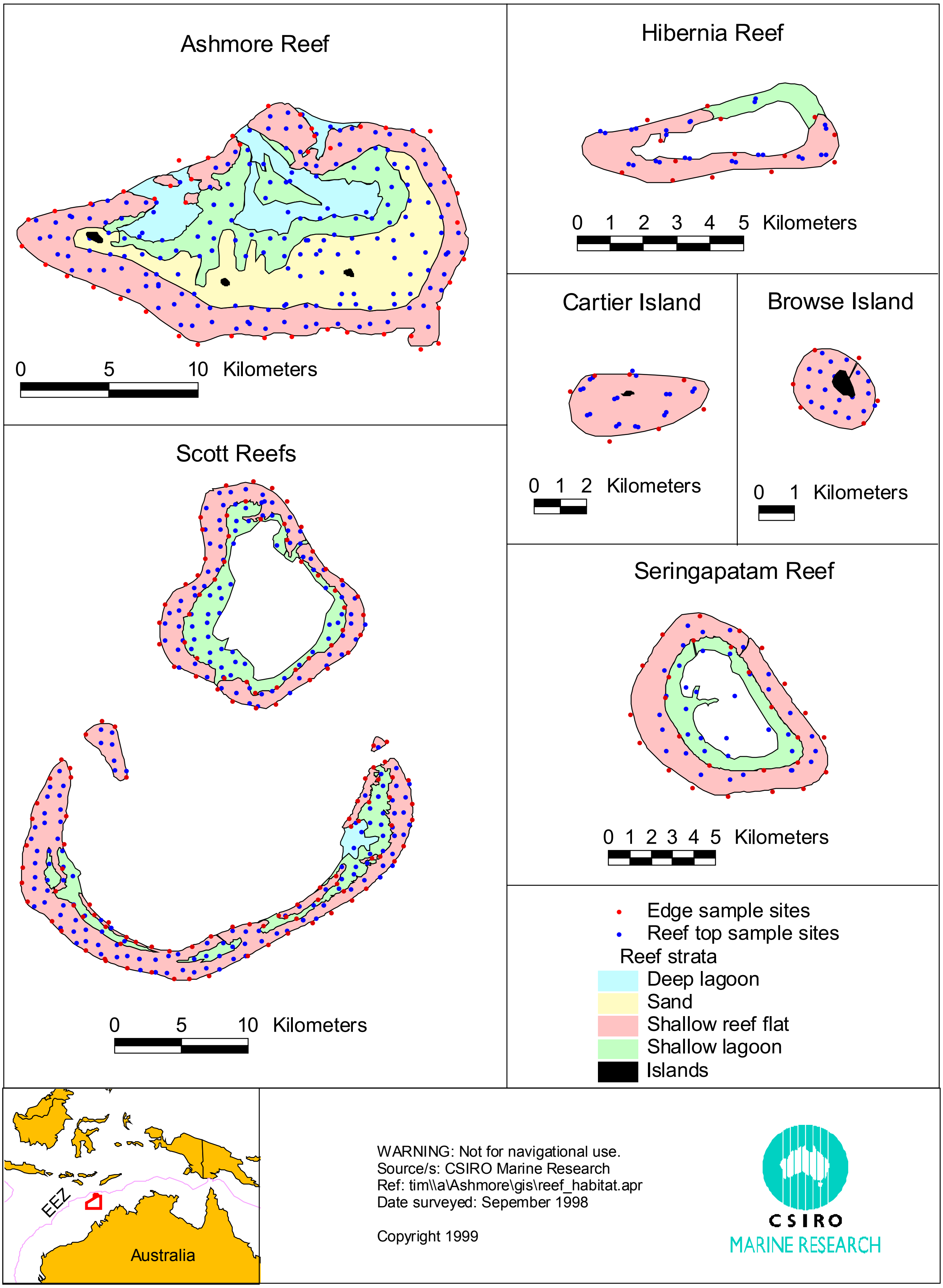
Initially, high-resolution Landsat satellite data of the reefs in the MOU74 box was used to map the shallow-water habitats and to produce provisional reef habitat types (Fig. 2). Information from previous CSIRO research on reefs in Torres Strait, the far northern Great Barrier Reef (GBR), and northern Australia was used to guide this initial classification of satellite images. The provisional reef habitats were input to a Geographical Information System (GIS) to assist in the design of field sampling: e.g. area analysis of provisional habitat types; sample site density (high in heterogenous areas, lower in homogenous lagoon areas) and targeted sampling (such as the trochus habitat and the reef edge habitat). The GIS also assisted with optimising cruise logistics and output of sampling sites to GPS navigators.

The density of sampling on the reef top was either 1 site per 1 km^2 (shallow reef and shallow lagoon strata) or 1 site per 2 km^2 (deep lagoon strata) (Fig. 2). With an equivalent effort spent on the reef edge, this meant a sampling density of one site every 1.5 km around the reef edge (Fig. 2). This gave a total of 765 sites on the shallow reefs. Without pilot data, it was not possible to predict with certainty the precision of final stock estimates of commercial species. However, based on abundance and variance estimates of commercial species such as holothurians (beche-de-mer) and habitat spatial heterogeneity from previous surveys of reefs in Torres Strait and on the GBR, this density of sampling was estimated to provide useful stock size estimates (ie with 95% CI of ± 35%), and enable accurate habitat mapping (Long *et al.*, 1997a; Skewes *et al.*, 1998).

Surveying trochus required some additional sampling because of its restricted habitat. Extra reef-edge sites were assigned to trochus habitat mapped from satellite images at a density sufficient to give useful stock-size estimates based on previous studies in Torres Strait (Long *et al.*, 1993).

Survey sites were assigned by dividing each stratum on the reef top into 1 km^2 or 2 km^2 grids (depending on the stratum type), and the reef edge into sections 1.5 km long. Sample sites were then located within the grids/sections at random. For the reef top, this meant that the sample site was selected from 25 possible sites within a restricted area of the 1 km^2 or 2 km^2 primary sampling units. For the reef edge, the sample sites were selected from 8 possible sites available within a 700 m long section of each of the 1.5 km-long primary sample units.

Figure 2. Shallow reefs of the Timor Sea MOU74 Box showing provisional reef strata digitised by hand from LANDSAT TM satellite images using field data as a guide. Reef-top and reef-edge sample sites are also shown.



2.1.2 Shoal areas (15–50 m deep)

The shoals in the study area, delineated from existing depth data, included all the known areas shallower than 50 m (Fig. 1). The sample design was a grid pattern with a sampling density of approximately 1 per 7 km^2 (2 $n.mile^2$). This density of sampling gave a total of 176 sites in the shoal area (Fig. 2a), and was a similar sampling intensity to previous surveys conducted in Torres Strait and on the northern GBR (Long *et al.*, 1997*b*; Skewes *et al.*, 1996).

2.2 Field sampling

Field sampling was done from 1 September to 8 October 1998. Roughly half the field time was spent sampling the shoals and the other half the shallow reefs.

2.2.1 Shallow reefs (0–15 m deep)

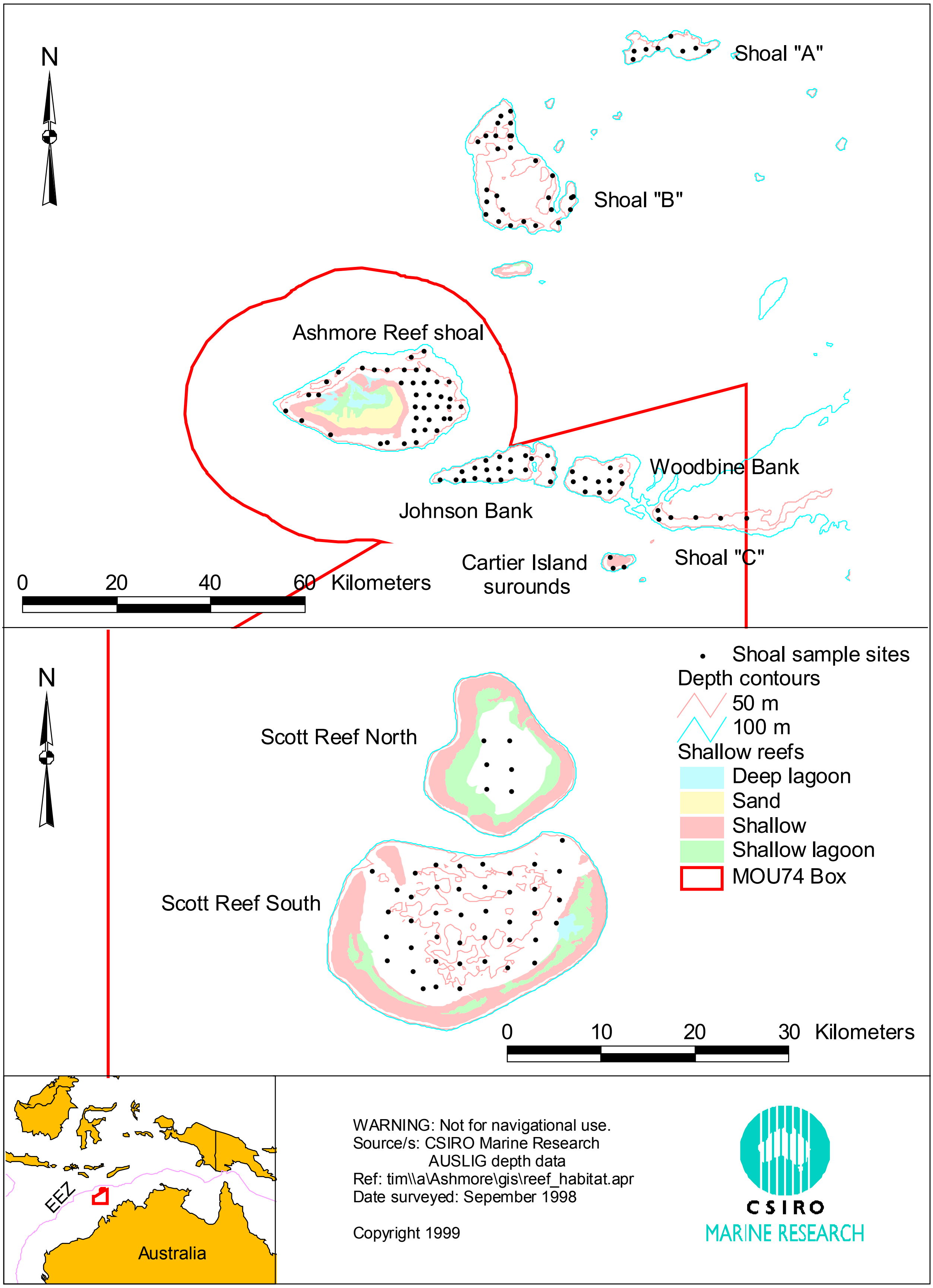
Field sampling was undertaken by small teams of divers operating from dinghies and locating sample sites using GPS. On the reef top, divers swam along a 20–100 m transect (depending on the stratum) and recorded information 2 m either side of the transect line. At each site, substratum was described in terms of the percentage of sand, rubble, consolidated rubble, pavement and live coral. The growth forms of the live coral component were also recorded. We also recorded recently dead coral (still in situ but covered in turf algae). The percentage cover of all other conspicuous biota such as seagrass and algae was recorded. Holothurians, trochus, clams and other benthic fauna of commercial or ecological interest were counted, taken to the dinghy, weighed, and replaced.

On the reef edge, two divers swam along measured length transects along the reef edge between 1 m and 15 m water depth. One diver recorded resource and habitat variables similar to those recorded on the reef top, but also including giant clams and spiny rock lobster, while the other diver recorded numbers and sizes of reef fin fish and reef sharks. Video was taken at representative sites on the reef top and reef edge for display, later analysis and baseline visual data.

Underwater Visual Census (UVC)

The fin-fish and shark populations were surveyed at 231 reef-edge sites (Fig. 2), using both stationary point count and strip-transect methods (see Samoilys, 1997, for details of methods). By conducting both methods at each site we were able to assess which gave the most precise fish abundance estimate. To reduce observer bias, the censuses were made by only two of the authors (DM, DD). Only species that could potentially be used as a food source, particularly species attaining large size, were surveyed. Thus, several fish families that contain predominantly small or poisonous species were excluded from the surveys, including numerically abundant families such as Pomacentridae, Gobiidae, Chaetodontidae and Apogonidae.

Figure 2a. Shoal areas (<50 m deep) of the MOU74 Box and areas north and video transect sample sites.



At each reef-edge site a single diver entered the water and swam to a point 20 fin-kicks away from the dinghy. The diver was equipped with a clipboard and data-sheet, listing the fish families, a Chainman ® measuring device and an Aladdin pro dive computer for monitoring depth and dive time. Once at the random point, the diver estimated the number and size of all fishes within a 7 m radius. On the completion of the stationary point count, the diver attached twine from the Chainman ® to the seabed and swam off parallel to the reef-edge to conduct the strip transect. The diver estimated the number and sizes of all fishes within 7 m either side of a 100 m transect, measured accurately with the Chainman ®. Thus, each stationary-point count census covered an area of 154 m^2 and each strip-transect census covered an area of 1400 m^2. The estimated fish lengths were converted to weights using derived length-weight conversions (Weight = a*Length^b) available in the relevant literature.

Several capture methods were used to supplement information on the fin-fish and shark populations gained by UVC methods. All fin-fish and sharks caught were identified, measured, and most were weighed. Three capture methods were used.

Drop-lines and long-lines. Monofilament drop-lines and long-lines were used from the mother vessel *James Kirby*, both by day and by night, and to depths of 100 m. Each dropline had one or two 6/0 or 7/0 hooks baited with fish flesh, sardines or pilchard. The location, duration, number of fishers and number of hooks were recorded on each occasion.

Trolling. Troll lines consisting of a 600 lb monofilament main-line, wire trace and spoon lure were used from both the mother vessel and sampling dinghies to capture large pelagic fish that are not normally encountered during UVC's. The location, duration and number of lines used were recorded on each occasion.

Gill-nets. Gill-nets (6″, 5″ and 4″) were used on one occasion adjacent to the reef edge at Seringapatam Reef, to capture scarids and reef sharks. The nets were set at sunset and retrieved the following morning.

2.2.2 Shoal areas (15–50 m deep)

At each site, we surveyed a 500 m long transect of seabed with a video camera and collected acoustic and depth data with multiple acoustic sampling systems. A grab was used occasionally to take representative sediment samples. Position was logged on both the video and acoustic track by GPS. Semi-quantitative descriptions of the epibenthos and substrate at each site were made from the video, using the same protocol as for previous surveys in Torres Strait and on the GBR (Skewes *et al.*, 1996; Long *et al.*, 1997b). Additionally, the habitats on the video transects were coded every second in real time along the transect, using a classification system based on a range of epibenthos and substrate descriptions. The number of target sedentary species, such as beche-de-mer and lobster, and the composition of the seabed substrate, particularly the relative amounts of reef, rock, rubble, sand and mud, and sessile megabenthos, were estimated along the transect. Information was recorded in real time, but also using video playback where there were uncertainties. Fin-fish and shark were counted from the video and were also sampled by drop-lines, long-lines and trolling to attain comparative length-frequency information, CPUE data and positive identifications of some species.

Seabed acoustic and depth data were also collected while steaming between sites. Where possible, the ship's track was optimised to provide the most useful information, such as over shallow pinnacles.

Acoustic fish biomass index

Acoustic signal returns from the water column were collected for analysis as a potential fish biomass index. In order to evaluate broad scale indicators of water column finfish biomass and distribution, acoustic echogram data was recorded over the entire study area using the Simrad EY500 portable scientific echosounder. The EY500 transmits a pulse of high frequency sound which is reflected by water column and seabed targets including finfish, plankton, epibenthic organisms such as coral and sponges, as well as the seabed itself. The reflected acoustic signal was converted to electrical signals by the echosounder transducer and stored digitally for later analysis. Position was logged for the acoustic track using GPS.

The CSIRO-developed software ECHO (Waring *et.al*., 1984), was used to process the digitised acoustic echogram data (Fig. 3). Quality assurance and post-processing stages included, editing the echograms for bad data, removing background noise (including sea state, man-made acoustic and electrical noise), and setting threshold values for targets of interest (e.g. finfish).

The data were restricted to exclude: data shallower than 5 m (due to sea-surface bubble layer effects); below bottom data (unnecessary for this analysis); and bad data. Seabed layer was automatically defined from the EY500 bottom pick and checked for quality. Bad data were edited out of the echogram.

An analysis overlay was developed for a layer referred to the seabed from 2 m above bottom to the sea surface. This was done to exclude any erroneous or mis-picked seabed data from the fish analysis; these high-bottom signal values would corrupt the acoustic data. The analysis overlay allowed the integration of targets of interest over the whole water column — regardless of depth variations. This layer was then integrated along the echosounder ping (vertically on the echogram worksheet) and then along the ship track over intervals of 0.1 n.mile (horizontally on the echogram worksheet). Using this method referenced to the seabed bottom pick, it was possible to set up the integration layers automatically (to have the defined layer closer to the seabed signal would require hundreds of hours of hand-editing of the echogram).

For this analysis we considered all water column targets during echo integration, including both plankton and fish. Data modifiers were set to exclude as much as possible of the smaller target strength plankton signal from the analysis, by setting signal level thresholds. However it is impossible without extensive hand-editing of the echograms to exclude small schooling bait fish signals from the analysis.

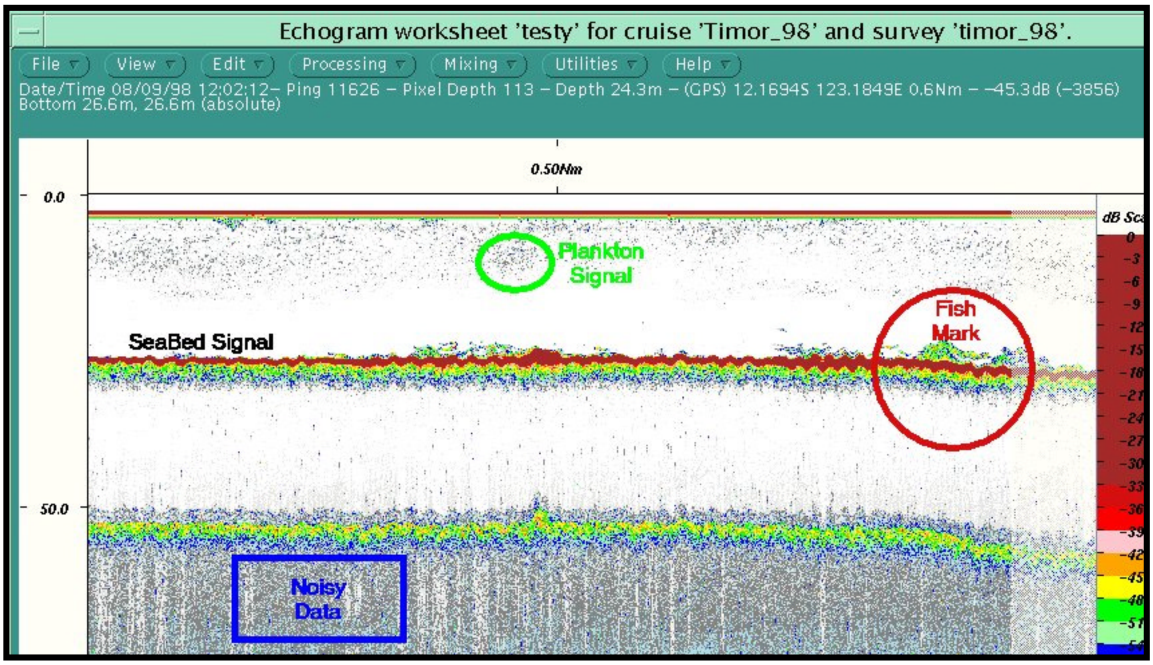


Figure 3. Screen Capture of ECHO acoustics analysis software showing Simrad EY500 echogram data for a fish mark (circled in red). The screen capture also shows other significant components of the acoustic echogram signal including seabed signal, background noise and plankton signals, as well as cross-reference navigation data.

2.3 Data analysis

The data obtained from the field work were input into statistical and GIS software for analysis. Standing stock and density (number per hectare) estimates were calculated from site counts using a stratified sample design that takes into account the heterogeneity of abundance and variance in different habitats in the study area (Appendix R).

Stratified mean and variance estimates of quantifiable resources for reef-top and reef-edge strata were used to calculate total abundance by reef and for the whole area for holothurians, trochus, finfish and sharks, using average weight of collected specimens where available (Appendix I), and standing stock (biomass). A similar analysis was carried out for shoal holothurians and finfish. An example is shown in Appendix C for *Holothuria atra*. Beche-de-mer, the dried product, is typically 5–10% the wet weight of the live holothurians, depending on the species. Generally, higher-value species have higher conversion rates. Product (dried beche-de-mer) weights for most species have been calculated from published conversion rates (Conand, 1990).

Stock status of the main target species was assessed by comparing the stock size/density between the reefs within the study area, comparing stock size/density with similar reefs in the Torres Strait and on the northern Great Barrier Reef (GBR), and analyse the size/age structure of each species. The stock size estimates were then related to the estimated fishing effort data and habitat data. The stock size estimates were also compared to estimates of the catch made from the limited surveillance data for the MOU74 Box reported by Wallner and McLoughlin (1996), and to the limited survey data collected by the WA and NT Museums in the 1980s (Berry,1986; Berry, 1993).

Finfish stock abundance and biomass

Stratified mean density and standing stock with 95% confidence limits of all fish, fish families and selected fish species were calculated from estimated fish numbers, using methods outlined in Appendix R. Total biomasses were estimated as the product of the estimated abundance and mean fish weight. Data collected by fixed-point sampling and strip-transect sampling were analysed separately to determine which of these methods provided the most precise (p=SE/mean) abundance and biomass estimates.

Differences in fish abundance for separate families between reefs was analysed by one-way ANOVA and Tukey HSD multiple comparisons.

3. RESULTS

3.2 Beche-de-mer

3.2.1 Distribution and abundance

Shallow reefs

The number of species seen at Ashmore Reef was greater than for any other reef in the MOU74 Box (Table 3). This is consistent with the results of previous faunal surveys (Marsh *et al.*, 1993). Possible reasons for this difference are the wide range of habitats on Ashmore Reef compared to the southern reefs, including large areas of sand and seagrass flats, and the reefs proximity to the coastline and the Indonesian archipelago, which would provide recruits to the area (Anon, 1989). The depauperate nature of Seringapatam Reef was also reflected in faunal surveys carried out in 1978 (3 holothurian species) and 1984 (4 species) compared to Scott Reef (21 holothurians species in 1984) (Marsh, 1986; Marsh *et al.*, 1993).

Table 3. Number of commercial holothurian species found during the resource survey carried out in September 1998.

Reef	Commercial species observed
Ashmore Reef	13
Browse Island	2
Cartier Reef	1
Hibernia Reef	6
Scott Reef North	7
Scott Reef South	9
Seringapatam Reef	1

One holothurian species that was not observed during this survey on Ashmore Reef, *H. acueata* (now *H. timana*), made up 11% of the catch in 1988 (Russell and Vail, 1988), and was reported at several locations during surveys in 1986-87 (Marsh *et al.*, 1993). Also, another high-value species that was found on Ashmore Reef in 1978, *H. scabra* (sandfish) (Marsh *et al.*, 1993), was not found during this survey or during surveys in the late 1980s.

There was an estimated 753 tonnes wet weight (± 219 tonnes, 95% CI) of commercial holothurians on the shallow reefs of the MOU74 Box and Hibernia Reef (Appendix D). This equates to approximately 45 tonnes of dried beche-de-mer using published conversion rates (Conand 1990). The most abundant commercial species on the shallow reefs was *Holothuria atra* (62.3% and 44.2% by numbers and weight respectively) (Figs. 4.2, 4.3, Appendix D). Ashmore Reef had the highest abundance of commercial holothurians in the study area. By weight, it had approximately 76% of all shallow reef, and 43% of study area commercial holothurians (Fig. 4.3, Appendix D). Seringapatam and Hibernia Reefs had the lowest abundance of commercial holothurians and, by weight, less than 1% of the commercial holothurians in the study area.

High-value beche-de-mer species (*Holothuria nobilis, H. fuscogilva, Thelenota ananas*) totalled only 97 tonnes (± 63 tonnes, 95% CI) on the shallow reefs or approximately 7 tonnes of dried beche-de-mer (Conand, 1990). High-value species were either absent or at very low abundances at all reefs in the study area except for Ashmore Reef (Appendix D). Surprisingly, because of Hibernia Reefs small size and proximity to Indonesian fishing ports, low densities of some high-value holothurians were found there, although the stock estimate had a very low precision.

Medium- and low-value beche-de-mer species (eg. *H. atra, H. edulis, H. fuscopunctata*) occurred in low densities on most reefs, but generally in higher densities on Ashmore Reefs (Appendix D). Seringapatam and Hibernia Reefs, were heavily depleted. Scott Nth Reef was the least heavily depleted of the southern reefs with significant stocks of *H. edulis* (pinkfish). One beche-de-mer species of little or no current value, *H. leucospilota*, was very abundant on Ashmore Reef, and to a lesser extent on Scott Nth and Scott Sth Reefs.

Shoal areas

There was an estimated 546 tonnes (± 251 tonnes, 95% CI) of commercial holothurians on the shoal areas of the MOU74 Box and Little Area A (Appendix G,H), which equates to approximately 33 tonnes dried beche-de-mer. Holothurians were found throughout the shoals in the study area except for Shoal A, Browse Island surrounds and the Scott Reef Nth lagoon, which had few holothurians. The species composition on the shoals was different to the shallow reefs, with the main species found on the shoal area being the low-value species *H. fuscopunctata* (55.7% and 54.7% of shoal beche-de-mer by number and weight respectively) (Figs. 4.3, 5.3). This meant it had the second highest total biomass of any commercial holothurian in the study area (23.1% of total biomass), after *H. atra* (36.4% of total biomass). Relatively high densities of a high-value species, *Thelenota ananas*, and a medium-value species, *Actinopyga echinites*, occurred on a small area of hard-bottom habitat on the Woodbine and Johnson shoals (Figs. 5.1-3, Appendix H).

3.2.2 Population structure

The size-frequency distributions for the holothurians with sufficient size measurements (generally n>8) collected on the shallow reefs and shoals are shown in Figure 6. Some species, especially the high-value species *H. nobilis* and *T. ananas*, have very few smaller size records, indicating the cryptic nature of these species juveniles. For the more common species such as *H. atra* and *H. edulis*, this is less evident. Most size-frequencies are characterised by relatively small numbers of very large individuals, reflecting the high mortality rates, both natural and fishing (Preston, 1993).

One species that was found on the shoals and reefs in sufficient numbers to produce a size frequency, *T. ananas*, showed a smaller size range and smaller average weight on the shoals than the shallow reef (Figs. 6, 7).

Figure 4.1. MOU74 Box showing population density of commercial holothurians sampled on the shallow reefs during the survey in September 1998. The area of the pie diagram is proportional to the total commercial holothurian abundance on each reef. (Range 48.1/ha (Ashmore Reef) to 0.1/ha Seringapatam Reef))

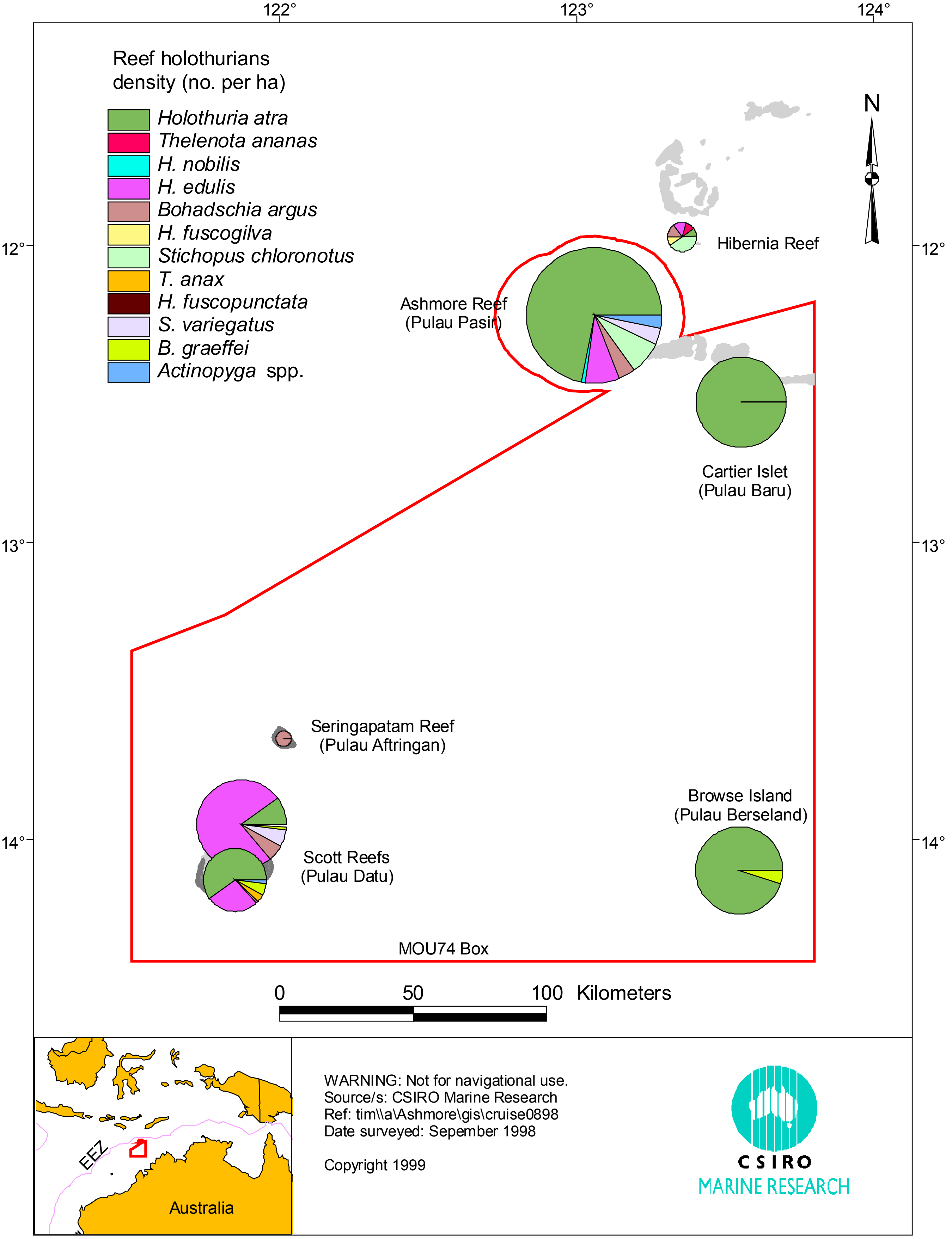


Figure 4.2. MOU74 Box showing total abundance of commercial holothurians for each shallow reef. The area of the pie diagram is proportional to the total abundance of commercial holothurian on each reef. (Range 1,092,523 (Ashmore Reef) to 430 (Seringapatam Reef))

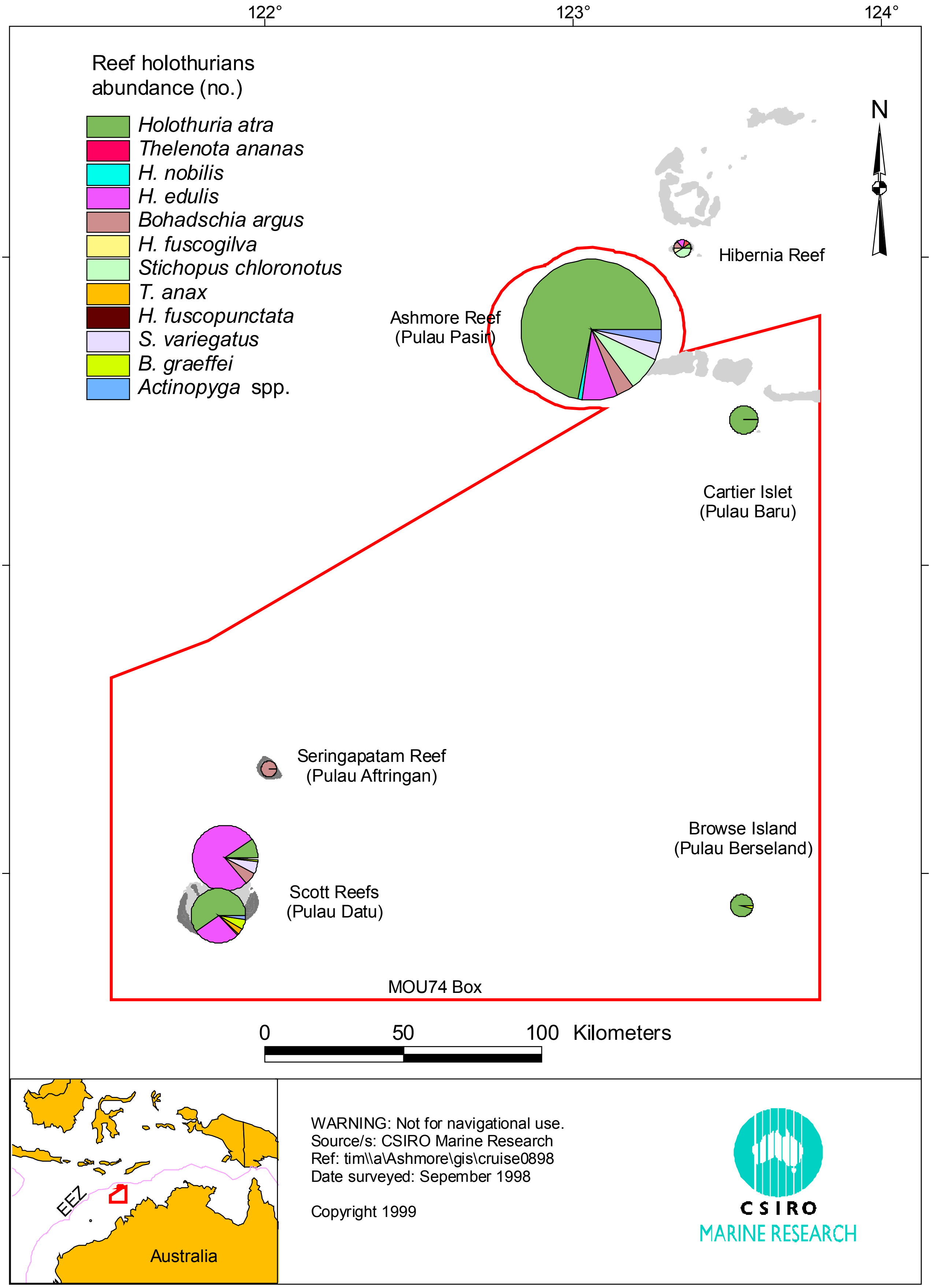


Figure 4.3. MOU74 Box showing total biomass of commercial holothurians for each shallow reef. The area of the pie diagram is proportional to the total biomass of commercial holothurian on each reef. (Range 560 t (Ashmore Reef) to 0.6 t (Seringapatam Reef))

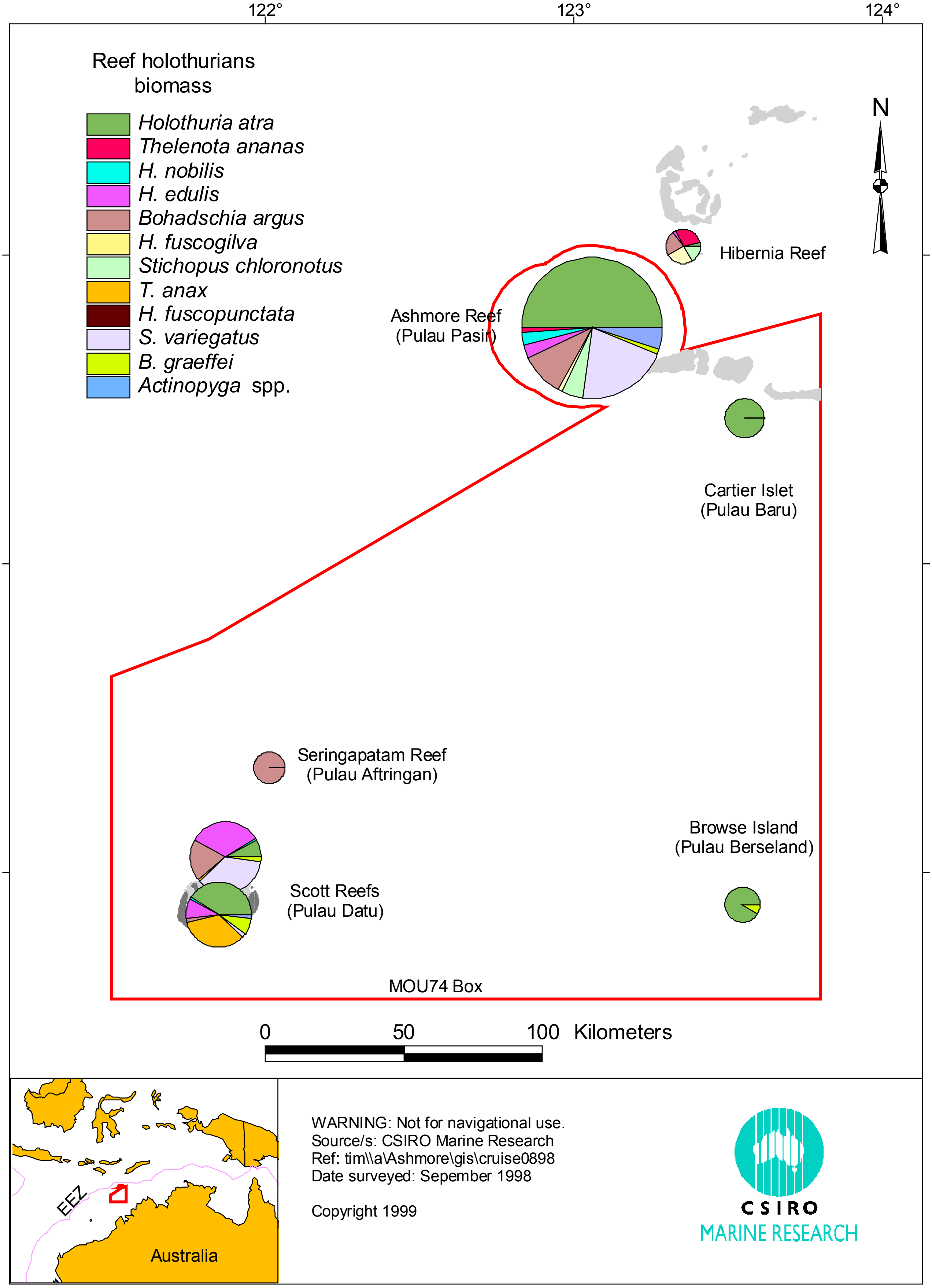


Figure 5.1. MOU74 Box showing population density of commercial holothurians sampled on the shoals (15-50 m) during the survey in September 1998. The area of the pie diagram is proportional to the total commercial holothurian density on each shoal. (Range 5.6/ha (Ashmore Reef shoal) to 1.5/ha (Woodbine Bank). We did not observe any holothurians on Shoal A, Scott Nth Reef deep lagoon or Browse Island surrounds.

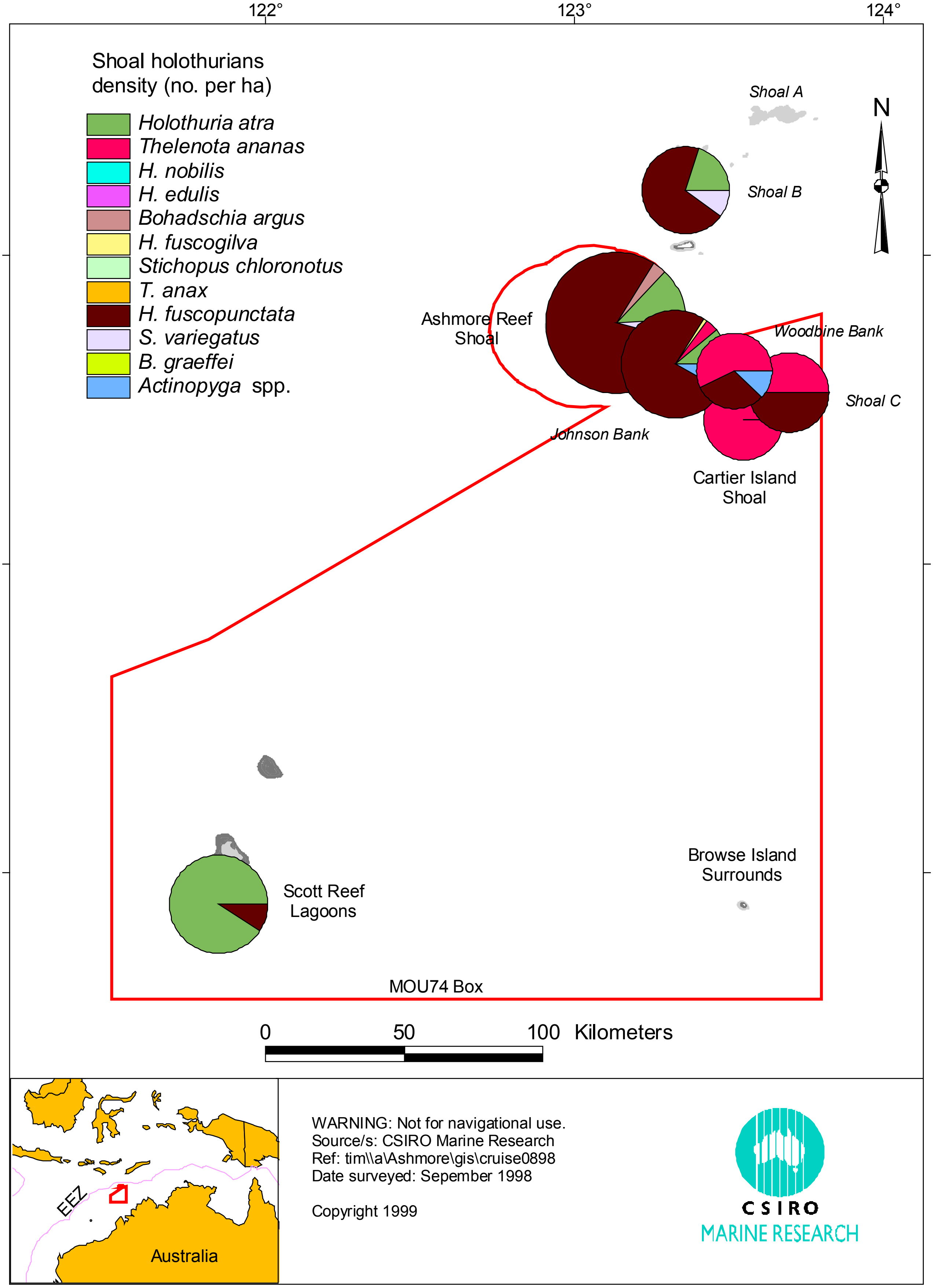


Figure 5.2. MOU74 Box showing total abundance of commercial holothurians sampled on the shoals (15-50 m) during the survey in September 1998. The area of the pie diagram is proportional to the total abundance of commercial holothurians on each shoal. (Range 169050 (Ashmore Reef shoal) to 1479 (Cartier Island surrounds). We did not observe any holothurians on Shoal A, Scott Nth Reef deep lagoon or Browse Island surrounds.

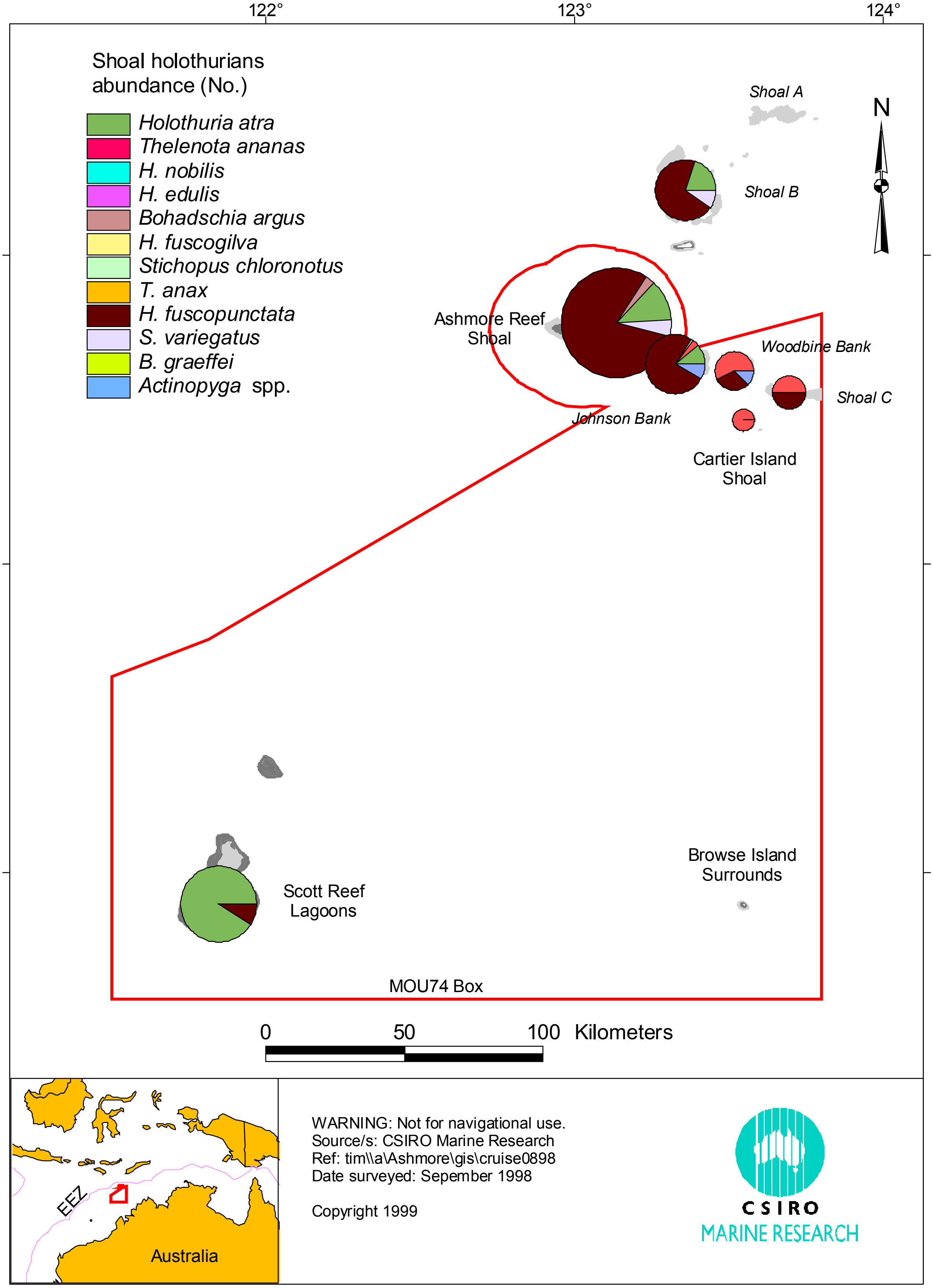
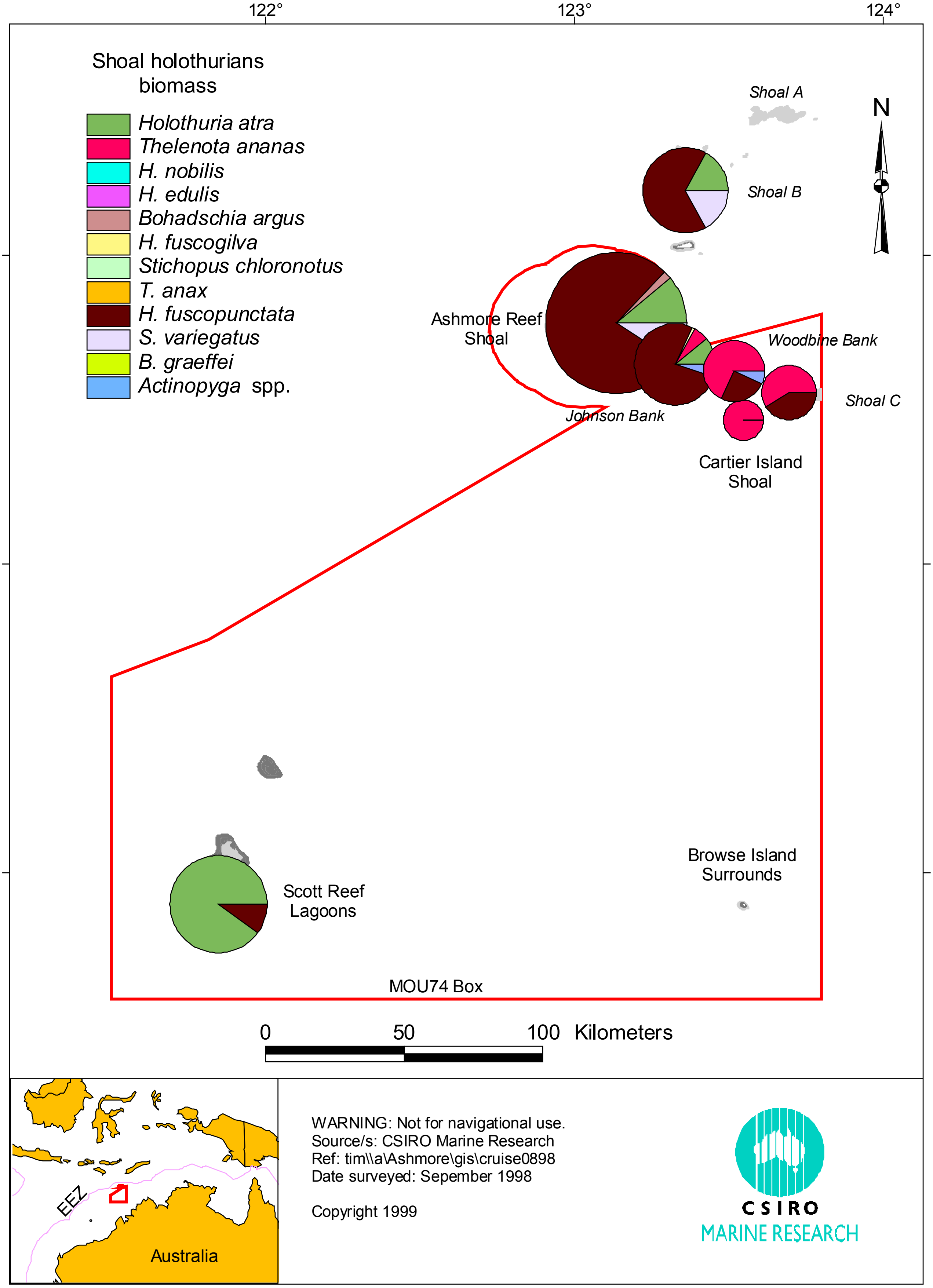


Figure 5.3. MOU74 Box showing total biomass of commercial holothurians on each shoal (15-50 m). The area of the pie diagram is proportional to the total biomass of commercial holothurians on each shoal. (Range 256.2 t [Ashmore Reef shoal] to 3.2 t [Cartier Island surrounds]). We did not observe any holothurians on Shoal A, Scott Nth Reef deep lagoon or Browse Island surrounds.



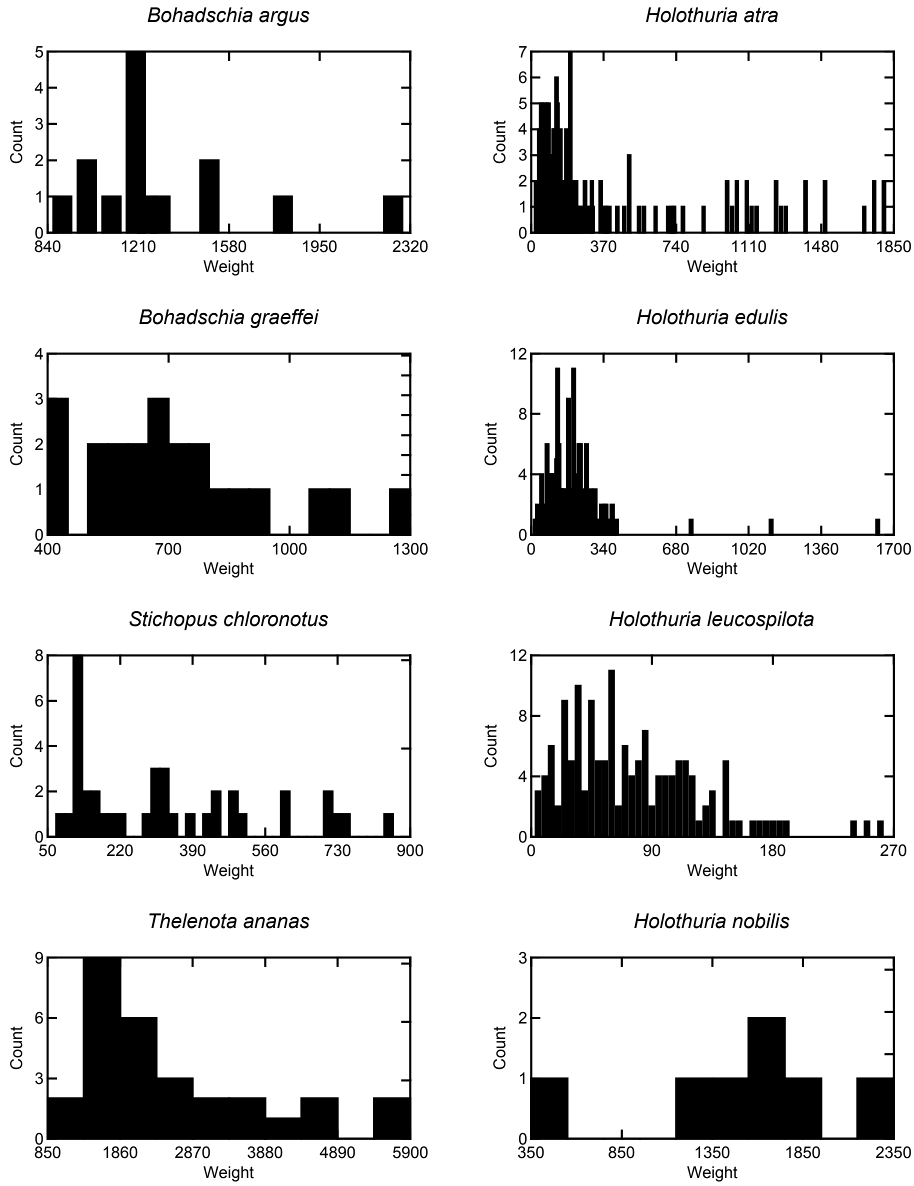


Figure 6. Size-frequencies (weight in g) of holothurians measured on the shallow reefs (where *n*>8).

The population of the most abundant species in the MOU74 Box, *H. atra* was made up of relatively large numbers of small individuals (< 300 g, mean 122.02 g, *n* = 115, 78%), and fewer larger individuals (>300 g, mean 914.67 g, *n* = 45, 22%) (Fig. 6). About 92% of the individuals over 300g were found on reef edge sites, and 80% of the smaller individuals were found on the shallower reef top. This is consistent with *H. atra'*s local distribution patterns in Taiwan (Chao *et al*., 1993, 1994), where populations of smaller individuals in shallow areas are exposed at low tide. The stress of exposure is thought to be a trigger for asexual reproduction by fission in *H. atra*, which contributes to the high percentage of small individuals. In contrast, most larger individuals were found to reproduce sexually.

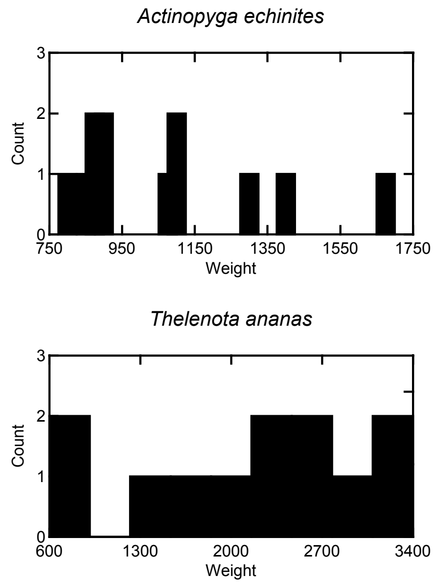


Figure 7. Size frequencies (weight in g) of holothurians measured on the shoals (where *n*>8).

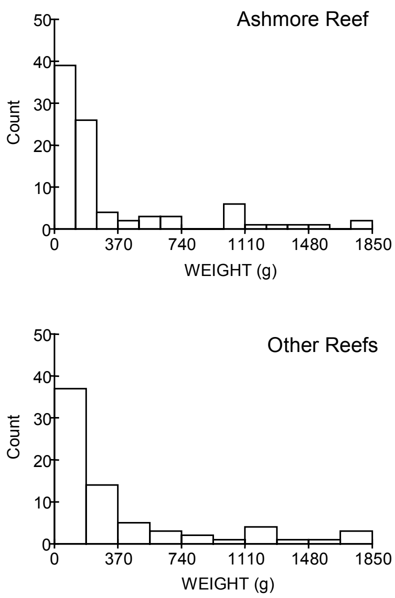


Figure 8. Size frequencies of *H. atra* on Ashmore Reef, and all other reefs combined.

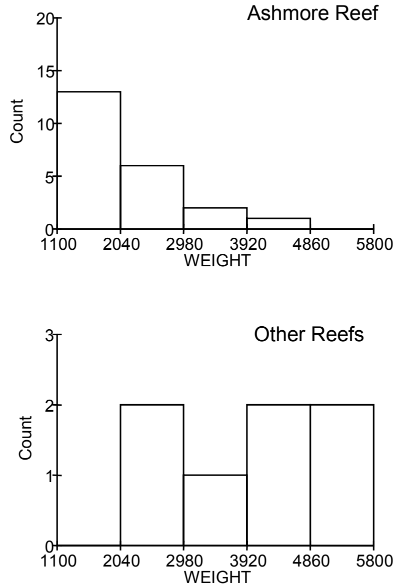


Figure 9. Size frequencies of *T. ananas* on Ashmore Reef, and all other reefs combined.

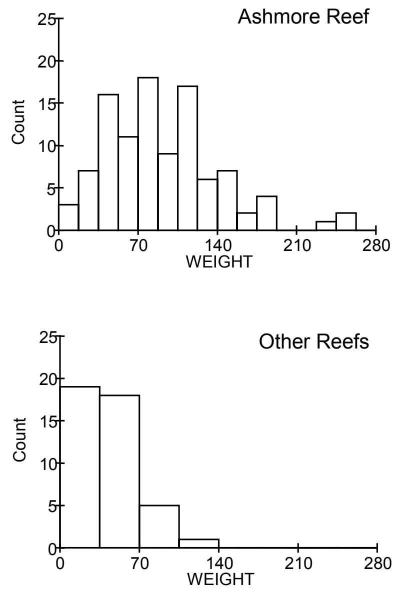


Figure 10. Size frequencies of *H.leucospilota* on Ashmore Reef, and all other reefs combined.

Given that Ashmore Reef is fished less than the other reefs in the MOU74 Box, we may expect to see differences in the population structure of the holothurians that live on the reefs, however, there was no clear pattern in differences between Ashmore Reef and the remaining reefs. The patterns ranged from no difference (e.g. *H. atra*, Fig. 8), to differences that are difficult to attribute to fishing pressure (e.g. *T. ananas*, Fig. 9). An unexploited species, *H. leucospilota* (Fig. 10), showed differences in its size frequency that can only be attributed to habitat differences between Ashmore Reef and the remaining reefs. It is likely that habitat differences may confound any fishing effect. However, this does not negate the usefulness of population structure data to assess fishing effects over time at the same location.

3.2.3 Stock status

The estimated total biomass of all beche-de-mer species on the reefs of the MOU74 Box excluding Ashmore Reef (about 200 t wet weight) is less than the estimated catch of beche-de-mer in the MOU74 Box in 1994 (340 t wet weight) (Wallner And McLouglin, 1996), indicating a severe depletion. Catch trends have declined steeply and the fishery moved to low-value species between 1991 and 1994 (Wallner and McLouglin, 1996).

The abundance of high-value species (*Holothuria nobilis*, *H. fuscogilva* and *Thelenota ananas*) on most reefs in the study area was very low, indicating heavy depletion. Even at the protected Ashmore Reef, the density of higher value holothurians was similar to or less than heavily fished populations of the same species at similar reefs in Torres Strait (Long *et al.*, 1996). For example, *H. nobilis* was found at densities of 4.1 to 12.5 per ha (by reef averages) in Torres Strait but 0.52 per ha on Ashmore Reef. Seringapatam Reef and Hibernia Reef in particular had extremely low densities of commercial holothurians (0.08 per ha and 1.54 per ha respectively).

The abundances of medium and low-value species on all reefs in the study area were generally lower than unfished populations on similar reefs in Torres Strait. A currently targeted species, *Holothuria atra*, was severely depleted on all reefs except Ashmore Reef, and Browse and Cartier Islands. Its abundance at Scott Reef, which is where most fishing for this species is currently happening, is very low (6.15 and 2.17 per ha at Scott Sth and Scott Nth respectively) compared to unfished populations on similar reefs in Torres Strait (approx 80 per ha) (Long *et al.*, 1996). Even Ashmore Reef, which had the highest densities of *H. atra*, averaging nearly 35 per ha, was a less than half the abundance of Torres Strait reefs.

It is possible that the reefs in the MOU74 Box have a lower carrying capacity to Torres Strait reefs; however, *H. leucospilota*, an unexploited species, was found in comparable densities or even higher densities on the reefs in the MOU74 Box than on reefs in Torres Strait. For example, in Torres Strait eastern reefs, which contain similar habitats to the reefs in the MOU74 Box (Skewes *et al.*, 1999), *H. leucospilota* density averaged 150 per ha with by-reef averages ranging from 0 to 1190 per ha (CSIRO, unpublished data). This compares well with *H. leucospilota* in the MOU74 Box, which averaged 610 per ha overall, and ranged from 0 per ha (several smaller reefs) to 1426 per ha (Ashmore Reef) (Appendix D).

Table 4. Total abundance, total wet weight and proportion of total commercial holothurians that are high-value species (*Holothuria nobilis*, *H. fuscogilva* and *Thelenota ananas*).

Reef	Total abundance	Weight (t)	Percent high-value spp. (*n*)	Percent high-value spp. (wt)
Ashmore	16567	32.5	1.5	5.3
Browse	0	0.0	0.0	0.0
Cartier	0	0.0	0.0	0.0
Hibernia	569	1.4	32.3	53.7
Scott Nth	438	0.7	0.2	0.7
Scott Sth	598	0.9	0.4	1.2
Seringapatam	0	0.0	0.0	0.0
Total area	**18172**	**35.5**	**1.2**	**4.3**

The proportion of higher value species in the holothurian population was lower on the fished reefs than the protected reefs (Table 4), indicating that the high-value species have been heavily depleted and fishing effort has switched to the medium- and low-value beche-de-mer species. Several Indonesian fishermen interviewed during the survey said that these species were previously abundant and fished in the southern reefs of the MOU74 Box, but had recently become very rare. The catch of two canoes at Scott Reef Sth observed during the survey in 1998 was mostly made up of *Holothuria anax* and *Bohadschia graeffei*, both low-value species (one canoe also had two trochus). We also observed that the Indonesian fishing vessels anchored at Scott Reef Sth were targeting *H. atra*, as the large boiling pots contained bright red water stained by boiling this species.

Historical catch-composition data provides further evidence of depletion. The catch in 1987 contained quantities of *H. timana* (previously *H. aculeata*) (11% of total) (Russell and Vail, 1988). Similarly, *H timana* was recorded during faunal surveys in 1986-87, as was *H. scabra*, a closely related species, in 1978. While significant populations of all other species listed in the catch records were seen during the recent survey, *H. timana* was not recorded, suggesting it is absent or very rare. Both *H. timana* and *H. scabra* are classified as high-value species and *H. scabra* is the target of a fishery in Torres Strait that was shown to be extremely susceptible to fishing effort (Skewes *et al.*, 1998).

While the holothurian resources on the shoals are currently being exploited by a few Indonesian fishers (*pers. obs.*), there were no signs of the severe depletion seen on the shallow reefs. The depth of the shoal areas (usually >20 m) currently offers some protection from fishing.

There is some evidence that the increased effort in the shoal areas is a recent phenomenon and that there may be a further increase in effort in this area, given the delpeted state of the shallow-reef fisheries, and particularly if protection of the shallow reefs in the MOU74 Box is extended. This effort should be monitored closely.

3.3 Trochus

3.3.1 Distribution and abundance

We observed trochus on three reefs: Ashmore Reef, Cartier Island and Scott Reef South. While 46 trochus were seen at 14 sites on Ashmore Reef, only 8 in total were observed on other reefs in the MOU74 Box: 7 on the Scott Reefs (4 off transect) and 1 at Cartier Island.

There was an estimated 4.5 tonnes (± 3.2 tonnes, 95% CI) of trochus (*Trochus niloticus*) on the shallow reefs of the MOU74 Box and Hibernia Reef (Table 5). Trochus were virtually absent from all the reefs in the study area with the exception of Ashmore Reef — Cartier Island and Scott Reef had small remnant populations.

Table 5. Stratified mean and standing stock estimates of *Trochus niloticus* for the reefs in the study area and for all reefs in the study area.

Reef	Sites	Abundance (per ha)	s^2	Total numbers	Weight (tonnes)	95% CI (%)
Ashmore	253	0.96	0.15	21767	4.4	78.8
Browse	26	0.00	0.00	0	0.0	
Cartier	33	0.20	0.06	222	0.0	234.9
Hibernia	40	0.00	0.00	0	0.0	
Scott Nth	157	0.00	0.00	0	0.0	
Scott Sth	214	0.05	0.00	718	0.1	179.9
Seringapatam	68	0.00	0.00	0	0.0	
Total area	**791**	**0.41**	**0.02**	**22706**	**4.6**	**75.6**

Population structure

The population consisted of two modal sizes ~60mm-100mm and >100mm (Fig. 11). Based on established growth curves for the Cairns area of the Great Barrier Reef (GBR) (Larcombe, 1993), the smaller mode is probably made up of 2- to 4-year-old animals, and the larger mode is probably made up of 5 year old and older animals. This larger mode at least is likely to represent a single year class as occurs on the GBR (Larcombe, 1993). Almost all trochus found were larger than the size at which trochus become sexually mature (<60 mm) (Castell, 1997, Chauvet *et al*, 1997).

The trochus that made up the two size modes were found in different zones on the reef edge. The smaller individuals were found, occasionally in high densities, close to the surf zone on areas of relatively smooth reef pavement with algal cover in water <2 m deep. The larger individuals were occasionally found in this area also, but were mostly found on the outer edge slope, or in deeper water off the reef edge slope in areas where the slope was gradual.

Very few trochus <60 mm were found; however it is likely they were present and not seen. Juvenile trochus are very difficult to sample as they are not only small, but also cryptic

(Larcombe, 1993; Castell, 1997). It is likely that the reef zone that these smaller trochus inhabit (Castell, 1997) was not thoroughly sampled because of the large swells and breaking waves.

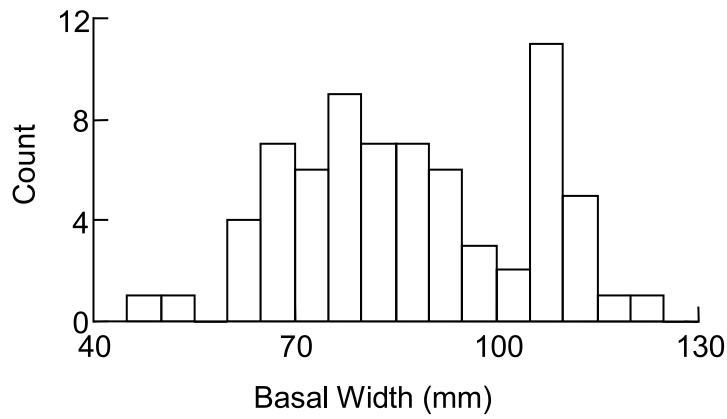


Figure 11. Size frequency for *Trochus niloticus*. All but nine specimens were of these were found at Ashmore Reef. (*n*=52)

3.3.2 Stock status

Trochus was targeted in the early 1980s by Indonesian fishers. Catch was estimated to have been as high as 20-30 t during the early 1980s (Wallner and McLouglin, 1996). However, by 1988 trochus was reported as being of low abundance on all reefs in the MOU74 Box including Ashmore Reef (Russell and Vail, 1988), and they were reported to be in low abundance on Ashmore Reef during a survey in 1986 (Wells, 1993).

The catch of trochus in the MOU74 Box (excluding Ashmore Reef) was estimated from catch data as being under 15 t in 1994 (Wallner and McLouglin, 1996), with the lower catch rates attributed to limited availability. The total biomass estimate from the current survey of under 5 tonnes, and certainly less than 1 tonne excluding Ashmore Reef, indicates a further severe depletion.

The current density observed at Ashmore Reef indicated that the population may have increased since the faunal surveys of the 1980s (see above). However, it still appears to be heavily depleted when compared to similar reefs in Torres Strait and the Great Barrier Reef (GBR). The highest densities seen during this study, on the Ashmore Reef front edge zone, averaged 29.9 trochus per ha (Appendix B) (range 0–400/ha). The reefs in Torres Strait average over 500 trochus per ha for similar habitat (algal pavement zone) (Long *et al.*, 1993). Even at these densities, the Torres Strait was considered heavily exploited and suffering from at least growth overfishing, based on an analysis of population size frequencies (Nash 1993). In the Swains complex of the GBR, fished reefs that had exposed reef front areas similar to the reef fronts of reefs in the MOU74 Box, had average densities of 761 per ha (range 500 per ha to 1100 per ha) (Nash, 1993). Even reefs that were inside the outer barrier, and had unsuitable habitat, had average densities of 191/ha on the reef edges. Based on these densities, and egg per recruit analysis, a reduction in the level of catch was recommended (Nash, 1993). Average densities on an unfished reef on the GBR (Orpheus Island) ranged from 1100/ha to 1800/ha (Castell, 1997). Average densities in trochus habitat in other South Pacific fisheries range from 65 to 1015 trochus per ha in Guam, to 8050 per ha in New Caledonia (for a summary, see Nash, 1993).

The depleted trochus population on Ashmore Reef may be the result of illegal fishing pressure (S. Tester, *pers comm.*), or of a slow recovery rate that caused by oligospermy (an over-dilution of the gametes, which prevents fertilisation in severely depleted populations) (Chauvet *et al*, 1997).

Despite the depletion of trochus in the study area, probably from unsustainable fishing effort, Indonesian fishers were still fishing for trochus at Scott Reef and Cartier Island during the survey (*pers. obs.*). Unless this fishing pressure is reduced drastically or removed altogether, this species will not recover.

3.4 Fin-fish and shark

3.4.1 Distribution and abundance

Shallow reefs

A total of 19557 fishes from 17 families and 104 species were recorded during the underwater visual count (UVC) surveys at 231 reef-edge sites (Appendix J, K). The most species-rich families were: Serranidae with 18 species; Lutjanidae with 16 species; Scaridae with 14 species; and Acanthuridae with 13 species (Appendix J, K). Of the species recorded, 89 were previously reported at Ashmore Reef and Cartier Island (Allen, 1993) or Scott and Seringapatam reefs (Allen and Russell, 1986). The heaviest species recorded were *Bolbometapon muricatum* (double-headed parrotfish; 11.2 kg), *Caranx ignobilis* (giant trevally; 7.1 kg), *Gymnosarda unicolor* (dog-tooth tuna; 6.6 kg) and *Cheilinus undulatus* (maori wrasse; 4.7 kg). However, these species were rarely observed and only *C. undulatus* made a significant contribution to the overall fish and shark biomass.

The species compositions were similar at each of the reefs surveyed with similar numbers of species recorded at Ashmore Reef (75), Scott Reef Nth (74), Scott Reef Sth (72), Seringapatam Reef (81) and Hibernia Reef (60), while fewer species were recorded at Cartier Island (49) and Browse Island reefs (27) due to the low number of sites sampled there. Ten species were ubiquitous and 8 species were only recorded at only one of the seven reefs surveyed (Appendix K). Allen (1983) also suggested that the faunal compositions of the Ashmore-Cartier reefs is similar to the Scott-Seringapatam reefs and that the overall species composition on these reefs is typical of coral reefs throughout the tropical Indo-Pacific region. Differences in the faunal compositions between the Ashmore-Cartier and Scott-Seringapatam reefs likely relate to the reef-edge habitats: Ashmore-Cartier reef-edges slope gradually to rubble/sand while the Scott-Seringapatam reefs drop steeply into oceanic water. Notably, the larger carangids and scombrids, including the dog-tooth tuna *Gymnosarda unicolor*, that prefer oceanic habitats were absent at Ashmore Reef and Cartier Island (Appendix K).

Fish communities on the exposed reef-edges consisted of more species than communities on the sheltered lagoon reef-edges (Table 6), particularly on Ashmore Reef, Hibernia Reef, Scott Reef Sth and Seringapatam Reef; reefs that have an enclosed lagoon.

Table 6. Numbers of fish families and species recorded at each strata of the shallow reefs surveyed by divers during the resource survey in September 1998.

Reef	Habitat Stratum	Families (*n*)	Species (*n*)
Ashmore	Back-reef	13	59
Ashmore	Front-reef	15	70
Ashmore	Lagoon	13	43
Browse	Front-reef	9	27
Cartier	Back-reef	10	35
Cartier	Front-reef	13	35
Hibernia	Back-reef	10	47
Hibernia	Front-reef	10	35
Hibernia	Lagoon	8	24
Scott Nth	Back-reef	14	49
Scott Nth	Front-reef	14	58
Scott Nth	Lagoon	15	56
Scott Sth	Back-reef	15	57
Scott Sth	Front-reef	16	62
Scott Sth	Lagoon	13	47
Seringapatam	Back-reef	12	53
Seringapatam	Front-reef	14	58
Seringapatam	Lagoon	12	48

The overall abundance and biomass estimated from strip-transect data was more precise (p: SE/mean = 0.057) than the estimates from stationary-point count data (p = 0.103; Appendix L). Strip-transect data also gave more precise density estimates by reef (Fig. 13). This result was expected given the larger area covered by strip transects and the greater likelihood of observing more species and individuals. Subsequent analyses of fish abundance and biomass were made from strip-transect data.

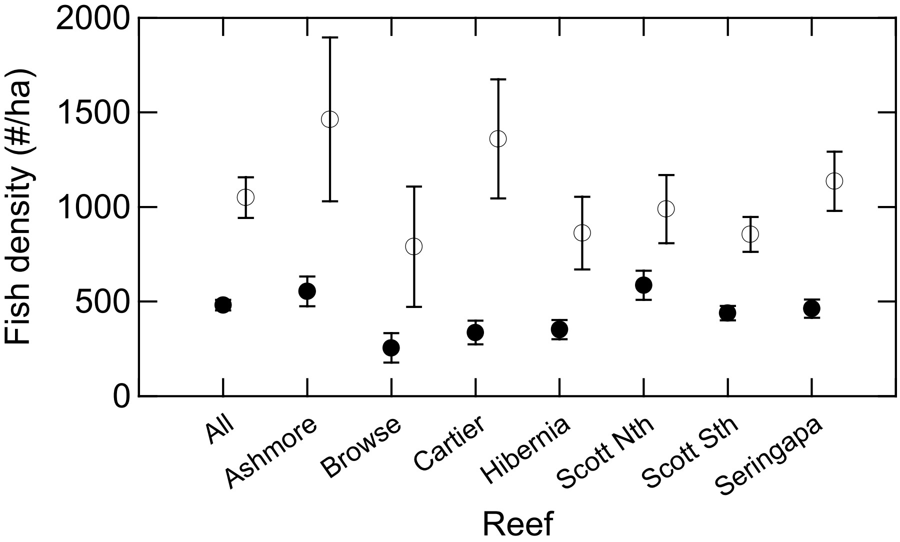


Figure 13. Mean densities of fish on the shallow reef-edges in the MOU74 Box, estimated from strip-transect data (filled circles) and stationary-point data (open circles) by reef and for all reefs. Error bars represent ± SE.

The estimated density of fish (all species) in the MOU74 Box was 481 per ha (Appendix L). By comparison, the density of "commercial" fish in the reef lagoon at New Caledonia has been estimated at 4800 to 6200 per ha (details in Labrosse *et al.*, 1998). The density of fish was highest and similar at Scott Reef Nth (586 per ha) and Ashmore Reef (554 per ha) reefs, slightly lower and similar at Seringapatam Reef (463 per ha) and Scott Reef Sth (439 per ha) reefs, while the smaller reefs (Hibernia Reef, Cartier and Browse islands) had the lowest densities (352 per ha, 336 per ha and 255 per ha respectively; Appendix L).

There was an estimated 1168 tonnes (± 132 tonnes, 95% CI) of fin-fish and reef shark on the shallow reef-edges of the MOU74 Box and Hibernia Reef (Appendix L). About 85% of this estimated fish biomass came from three reefs (Ashmore Reef, Scott Reef Nth and Scott Reef Sth) which also accounted for ~80% of the total area of reef-edge (Appendix L). The Ashmore Reef National Nature Reserve accounts for ~25% of the total fish biomass.

The densities of fishes from each of ten of the most abundant families at each of the seven reefs surveyed were compared to examine their geographic distribution (Fig. 14). The acanthurids, balistids, labrids, scarids and serranids showed significant differences in density between reefs ($p = 0.004$, $p = 0.001$, $p = 0.022$, $p = 0.004$ and $p = 0.001$ respectively). The acanthurids were the only family showing greatest density in the Ashmore Reef National Nature Reserve (Fig. 14). However, pairwise comparisons showed that only Hibernia Reef and Scott Reef Sth were significantly different from Ashmore Reef (Tukey HSD; $p = 0.029$ and $p = 0.001$ respectively). Notably, the lethrinids and lutjanids, known to be harvested at Ashmore Reef, showed no significant differences between reefs ($p = 0.483$ and $p = 0.394$ respectively) and pairwise comparisons revealed no significant differences between individual reefs. The 2 labrid species showed greatest density at Scott Reef Nth, which was significantly different from Ashmore Reef ($p = 0.007$). This was likely due to habitat differences and preference exhibited by the maori wrasse *Cheilinus undulatus* for steeper, oceanic reef-edge. The serranids, including the cods and coral trout, showed greatest density at Seringapatam Reef, which was significantly (p

= 0.003) higher than that at Ashmore Reef. Again, this difference is likely related to the preference of this group for steeper, oceanic reef-edge habitat.

In general, the fish families show a relatively consistent geographic distribution across the MOU74 Box; differences between reefs probably relate to habitat differences. Only the acanthurids show greatest density in the Ashmore Reef National Nature Reserve. However, although it is known that this group is harvested by Indonesian fishers, it is not likely that density differences relate to fishing impact since many species in this group (particularly *Naso* spp.) inhabit oceanic waters not accessible to traditional divers.

Standing stock estimates for the common fin-fish species, calculated from stratified means, were reasonably precise (95% CI: 16.4 to 44.7%) given the large area of the MOU74 Box and the relatively limited sampling. The most abundant fish species was *Lutjanus gibbus* with an estimated population of 390000 (± 44.7%) of which 45% came from the Ashmore Reef (Appendix M). Although, not as abundant, *Lutjanus bohar* had greater biomass (158 t ±32.8%), due to a greater mean size (~42 cm cf. 25 cm; Appendix N). These two species probably represent the main target species of Indonesian fishers and they have been fished previously but given their current high abundance and biomass it is not likely the stocks are over-exploited. The coral cods (*Cephalopholis* spp.) have also been harvested and show greater abundance and biomass at Scott-Seringapatam reefs. The coral trouts *Plectropomus* spp., targeted throughout the Indo-Pacific, were also much more abundant at Scott-Seringapatam (16.8 t) than at Ashmore (0.8 t; Appendix M) probably because of the more suitable habitat at the latter reefs.

In general, most fin-fish species were more abundant at the Scott-Seringapatam reefs than at the Ashmore Reef National Nature Reserve, suggesting that current harvesting is not depleting the fish populations on the "open" reefs. The estimated size distributions (Appendix N) show no clear evidence of depletion of larger fish, which would occur at unsustainable levels of effort.

Reef-associated sharks were extremely rare (less than 1 per ha) throughout the study area and only two species *Carcharhinus amblyrhynchos* (3 times) and *Triaenodon obesus* (28 times) were observed during UVC surveys. The numbers precluded an accurate stratified estimate of total biomass. Nevertheless, the biomass of reef sharks was estimated at ~26 tonnes. By comparison, reef sharks of several species were observed at nearly all UVC sites surveyed in Torres Strait during a similar reef resource survey (Long, 1997a). Several *C. amblyrhynchos* were caught in gill-nets set overnight in shallow water at Seringapatam Reef: possibly the reef-sharks occupy deeper water by day and move to shallow water by night. Nevertheless, the low numbers of reef-sharks observed is atypical for oceanic reefs and it is probable that long-lining has impacted the stocks, particularly the carcharinids targeted for their fins. Long-lines were found close to the reefs during the 1998 survey.

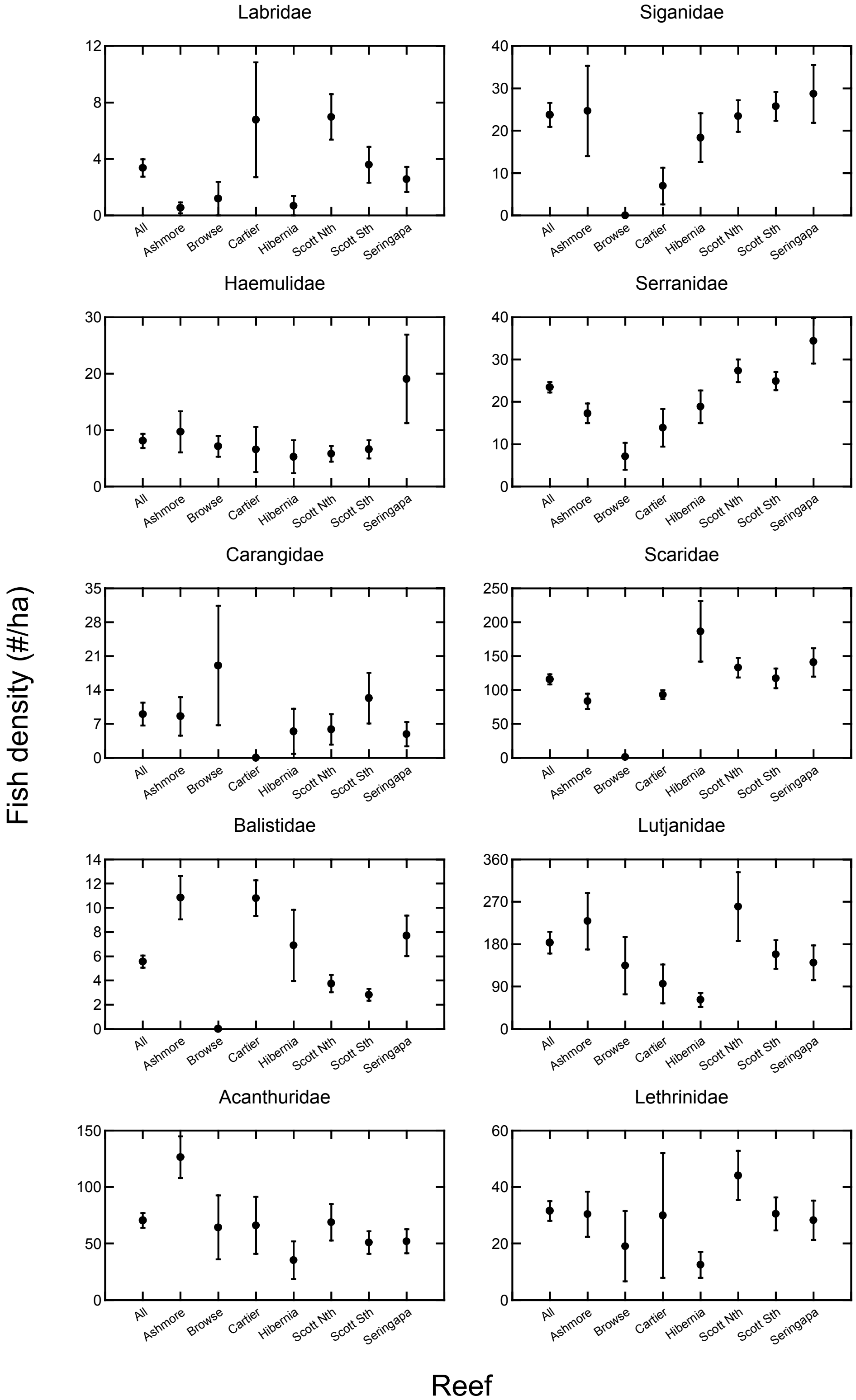


Figure 14. Densities of fishes from each of ten families at each of the seven reefs surveyed and for all reefs for comparison. Error bars represent ± se.

Shoal areas

There were few commercial and non-commercial fin-fish or sharks observed during video transects on the shoals and very few were caught during several hours of drop-line and long-line fishing. Overall, the mean density of commercial fish was estimated at 5 per ha (±78.58 %) (Appendix O) compared to 480 per ha (±11.35%) on the shallow reef-edges (Appendix L). However, most of the shoal areas were predominantly sand/algae; unsuitable habitat for most commercial fishes. Total abundance was estimated at 55000 (±78.58%), of which 73% came from the Scott Sth shoal, where much of the seabed was reef (Appendix O, Fig. 12.1-3). The species identified during video transects were also seen on the shallow reef-edges during the UVC surveys (Table 7). Assuming the shoal fish had similar mean weight to that of the reef-edge fish (0.508 kg), total commercial fish biomass on the shoals was estimated at 280 t.

Only four tawny sharks, (*Nebrius ferrugineus*) were observed, all at Scott Sth shoal, during the video transects. This species is not exploited commercially.

Overall, the estimated mean density of non-commercial fish (62.42 per ha ±48.52%) was 12 times that of the commercial fishes. Total abundance was estimated at 6830000 (±48.52%), but unlike the commercial fish, most (70%) came from Scott Sth shoal and Shoal B (Appendix O, Fig. 12.1). The species identified were also mainly coral-reef fishes.

Table 7. Table showing the composition of the commercial and non-commercial finfish species identified from the video transects in the MOU74 Box shoal areas.

Class	**Family**	**Species**	***n***	**%**
Commercial	Balistidae	?	1	1.2
Commercial	Serranidae	*Plectropomus* spp.	17	20.5
Commercial	Serranidae	*Epinephelus* spp.	3	3.6
Commercial	Haemulidae	*Diagramma pictum*	6	7.2
Commercial	Scaridae	?	1	1.2
Commercial	Serranidae	*Epinephelus fuscoguttatus*	1	1.2
Commercial	Serranidae	*Epinephelus polyphekadion*	2	2.4
Commercial	Lethrinidae	*Lethrinus* spp.	1	1.2
Commercial	Serranidae	*Variola albimarginata*	1	1.2
Commercial	Lutjanidae	?	50	60.2
Total			83	
Non-Commercial	Acanthuridae	?	82	48.5
Non-Commercial	Chaetodontidae	?	10	5.9
Non-Commercial	Serranidae	*Caesio* spp.	75	44.4
Non-Commercial	Pomacanthidae	*Pomacanthus sexstriatus*	2	1.2
Total			169	

Acoustic biomass index.

The broader-scale acoustic index reinforces the evidence of higher abundance of finfish in the Scott South shoal. Lower densities of finfish are confirmed for the remaining shoal areas. Not included in this analysis was intense acoustic marks (presumably finfish) that occurred on several occasions in deeper water (>50 m) on the steeper edges of the shoals.

More accurate indicators of finfish biomass from the acoustic echogram data may be estimated with intensive hand editing of the echogram worksheets in the ECHO software, using a mouse to redraw either the seabed acoustic bottom, the watercolumn integration layer boundary, classifications of watercolumn scatterers to exclude or include.

This hand editing would exclude water column scatterers that are not of interest (e.g. plankton, bait fish) from the analysis. This may be achieved by hand classifying finfish targets of interest (which may also allow limited species targeting using video data from sample sites as a cross-reference). Estimates for benthic fish species may also be improved by hand editing of the near bottom boundary of the echogram processing layer to include fish targets that exist between the 2 m data processing boundary and the actual seabed.

CPUE data

A total of 412 fin-fish and shark (total weight 787.88 kg) were caught during almost 80 hours of fishing effort on the reef edge and shoals of the MOU74 Box, using the four methods listed in Table 8. This equated to catch rates of 6.11 kg/hour/fisher for droplining, 8.37 kg/hour for gillnetting (though most of the catch was sharks), 3.9 kg/hour/fisher for spearfishing, and 8.63 kg/hour/fisher for trolling. These relatively low catch rates support the results of the UVC and video transects, which indicated fin-fish and shark abundance was low in the MOU74 Box compared to other fishing grounds in the Indo-West Pacific. The highest catch rates recorded — by trolling and gillnetting — were approximately half the rates Stehouwer (1981) recorded in NW Australia of 15.6 kg/hour/fisherman.

Table 8. Fishing methods, catch and catch per unit effort for experimental fishing carried out during the resource survey in September 1998.

Fishing method	Total catch (*n*)	Total catch (kg)	Fishing effort (hours)	CPUE (Kg/Fisher/Hour)
Dropline	293	347.79	38.25	6.11
Gillnet	29	123.49	14.75	8.37
Speargun	32	35.11	9.00	3.90
Trolling	58	281.49	17.57	8.63

3.4.2 Population structure

Shallow reefs

Size frequencies from estimated sizes indicated the population structure of many of the common fishes (Appendix N). Size distributions of the lethrinid, lutjanid and serranid species showed generally one main mode (eg. *L. gibbus*, *L. decussatus*, *M. niger*, *L. erythropterus*, *Plectropomus* spp.), representing the dominant size/age class of the reef edge population. In contrast, size distributions of the acanthurid and scarid species had several components. This contrast is likely due to many of the lethrinids, lutjanids and serranids occupying deeper shoal habitats as adults; with the reef-edge serving as nursery habitat, whereas all sizes/ages of the acanthurids and scarids probably live on the reef-edge. None of the size distributions showed truncation as would be expected where a species was being heavily exploited.

Figure 12.1. Two areas of the MOU74 Box, showing number of commercial finfish counted during 500 m video transects on shoals (15-50 m) during a survey in September 1998.

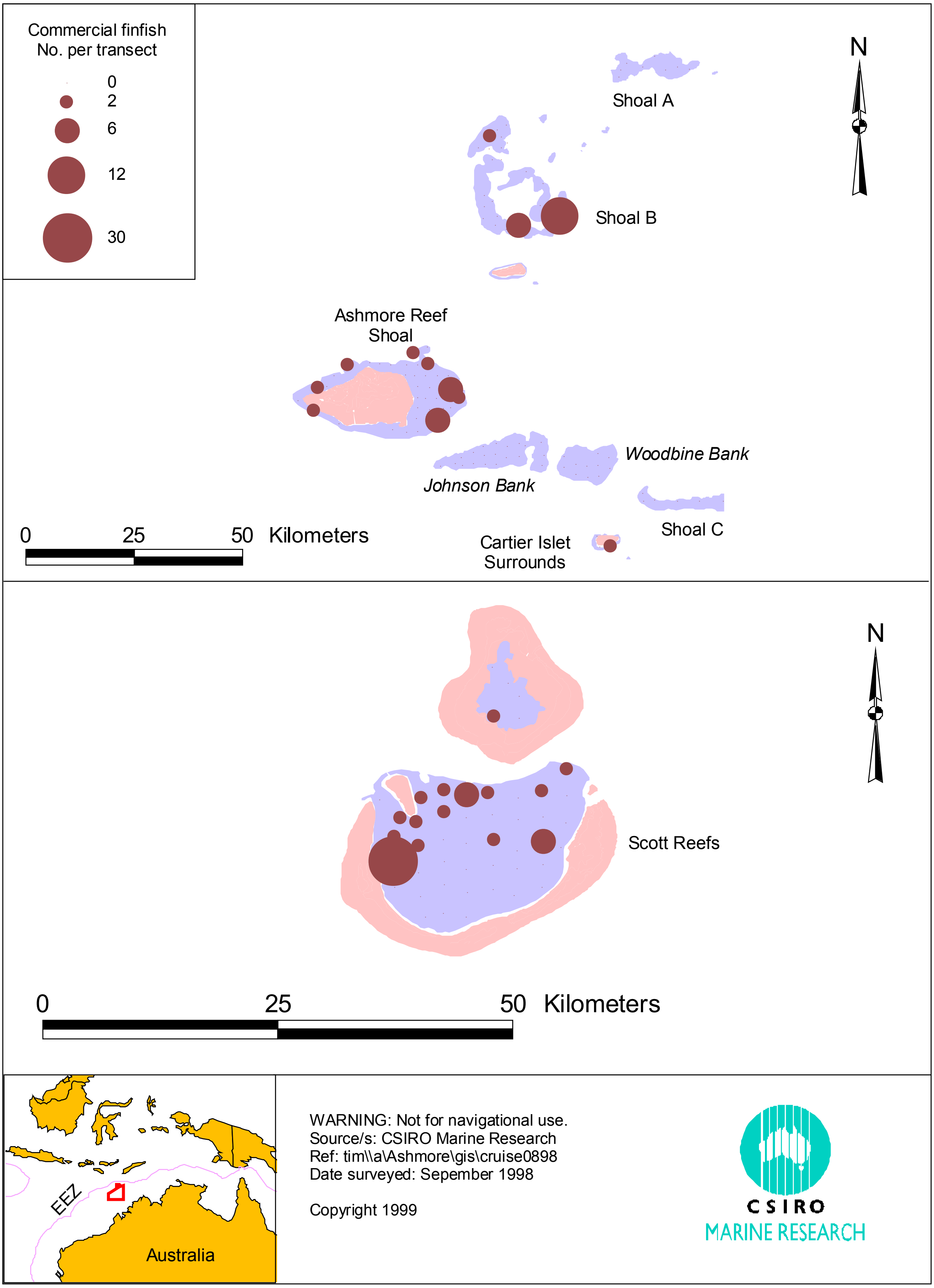


Figure 12.2. Two areas of the MOU74 Box, showing number of non-commercial finfish counted during 500 m video transects on shoals (15-50 m) during a survey in September 1998.

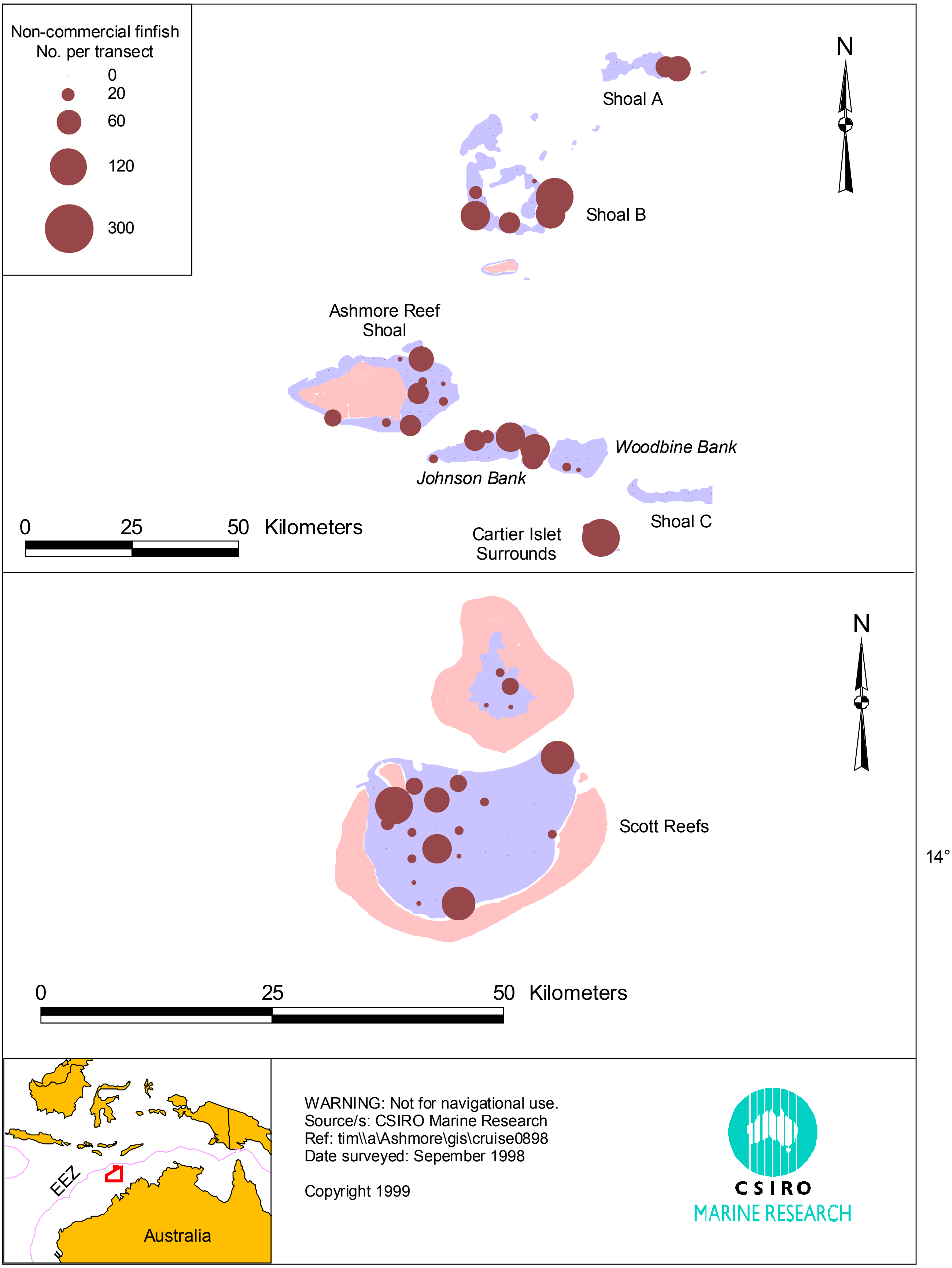
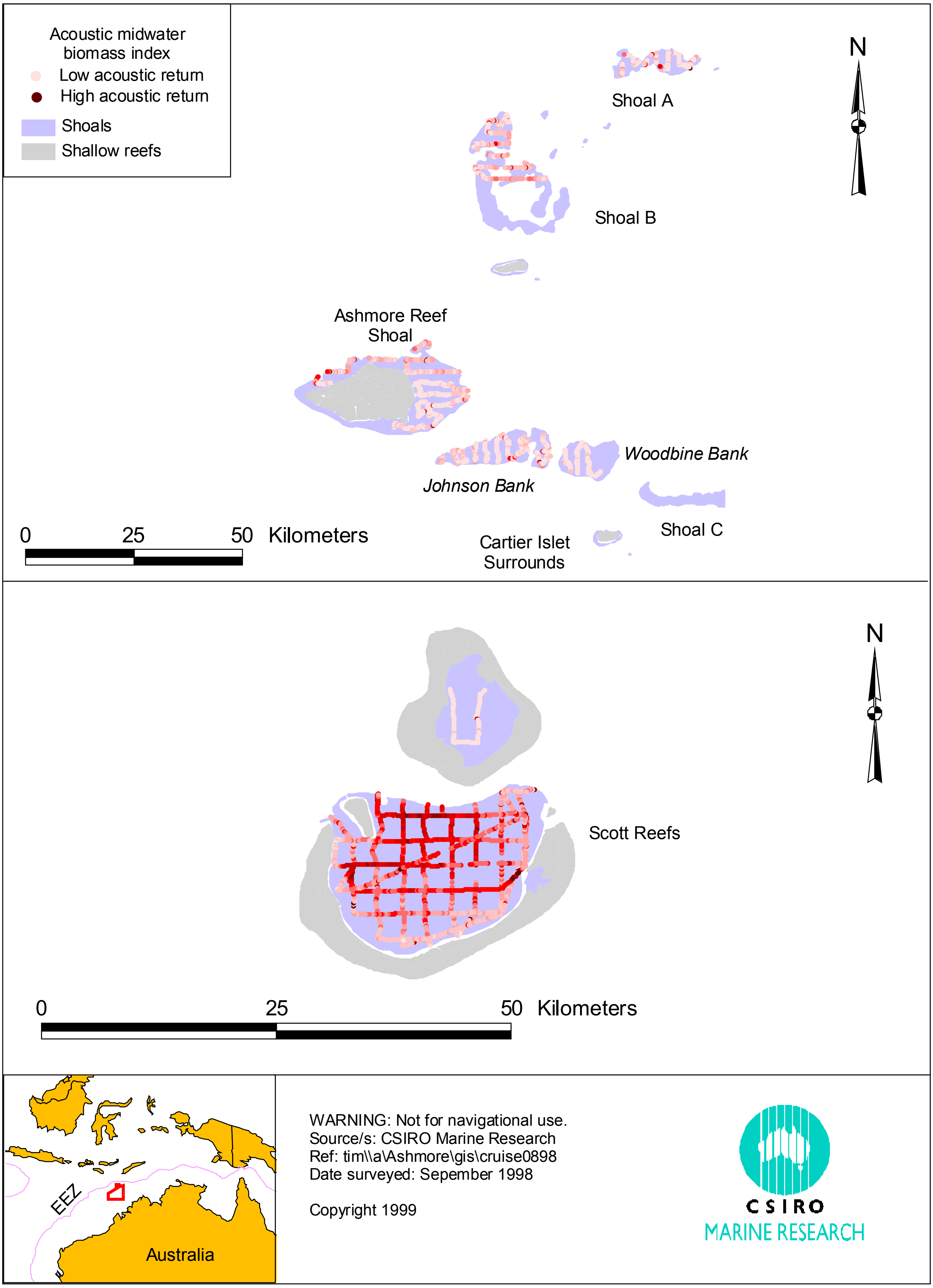


Figure 12.3. Two areas of the MOU74 Box, showing the acoustic midwater biomass index collected from continous acoustic data collected during a survey of the shoals (15-50 m) in September 1998.
Note: the bottom of Shoal B, Shoal C and part of Woodbine Bank = missing data.



3.4.3 Stock status

These preliminary results suggest that the current level of fishing effort in the MOU Box has not caused a significant depletion of the fin-fish stocks on the reefs outside the Ashmore Reef marine reserve. However, it is not possible to measure the actual impact of fishing on the stocks as accurate current catch-data are not available for comparison with the estimated stock sizes. Nevertheless, given that the densities of most species are higher at reefs outside the marine reserve and size distributions show no signs of over-exploitation, current effort appears to be sustainable.

Annual catches of demersal fish by Indonesian fishers were estimated at less than 30 t during 1986-1994 (Wallner and McLoughlin, 1996) and it was suggested that the level of Indonesian fishing at that time did not constitute a threat to the sustainability of demersal fish stocks.

Much of the shoal habitat consists of sand/algae, which is generally unsuitable for commercial fish populations. The Scott Sth shoal supports the largest population (~400000 fish); however, the fish density (3.64 per per ha) was still very low on this shoal and it is unlikely that this area would support commercial fishing such as hand-lining or long-lining. In addition, all of the commercial fish identified from video transects were coral-reef fishes (eg. *Plectropomus* spp.), and these species are not targeted by long-line fishing. Target species in the Timor Sea include *Pristopomoides multidens*, *Lutjanus erythropterus*, *L. sebae* and *L. malabaricus*, none of which were observed during video transects on the shoals.

The non-commercial fish were more abundant than commercial fish; however, the estimated density was still low (62.42 per ha), highlighting that generally the shoal habitats were unsuitable for fish populations.

The low estimates of reef-shark abundance and biomass on the shallow reef-edges, particularly carcharhinids, suggest that current effort, particularly with long-lines, may be seriously depleting the reef-edge population. However, it is possible that reef sharks were not seen during the diver survey because they are predominantly nocturnal, and other methods may be more appropriate for monitoring their stock status.

No commercially exploited sharks, principally carcharhinids, were observed during video transects on the shoals. However, as for the commercial fish, the absence of sharks was likely due to the unsuitability of the shoal habitat. Also, since fish are the main prey item of sharks, the low abundance of commercial and non-commercial fish precludes a large shark population. Further, the shallow shoals are not the favoured long-line fishing areas, and are less productive than the offshore banks, such as the Sahul and Holothuria Banks (Wallner and McLoughlin, 1996). Nevertheless, even though shark abundance is likely to be naturally low, the absence of sharks on both the shoals and shallow reef-edges suggests fishing has depleted the shark population.

Uncertainties in the assessment

Although underwater visual census (UVC) is a method commonly used to estimate the abundance and biomass of fishes in shallow reef habitats, several factors can affect the accuracy of the estimates. The first disadvantage is the depth constraint imposed and the possibility that the full distribution is not covered. In this study we restricted the surveys to 15 m on the basis that most species of concern mainly occupy this depth range and that Indonesian fishers would be also restricted to this depth range. The experience and ability of each diver to identify species and estimate number and size of fishes may also lead to inaccuracies in the stock estimates. In this study, we used only two divers, each with previous experience in UVC surveys. Of the 52 most common species observed in this study, the difference in mean estimated sizes was less than 5 cm for 43 species (Fig. 15). However, there were large differences in the estimates for two large species *Cheilinus undulatus* and *Lutjanus rivulatus*, which will affect the accuracy of the estimated biomass.

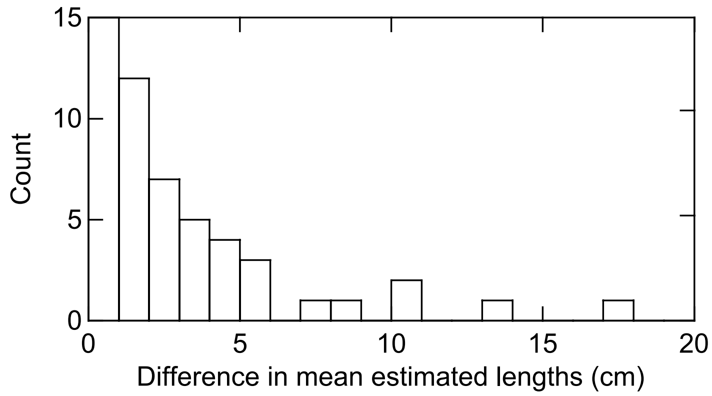


Figure 15. Distribution of the differences in mean estimated fish sizes for the two divers used to conduct UVC surveys in the MOU74 Box.

The greatest uncertainty in the current assessment of fish stock status is the absence of catch data for the Indonesian "fishery", both in terms of family/species composition and reliable tonnage. These data would be extremely difficult to obtain in this traditional fishery and would rely on extensive creel surveys to ensure the catch was estimated accurately.

3.5 Other reef fauna

The survey was able to produce abundance estimates for all species of giant clams (*Tridacna* spp) (Appendix E) although the results for *T. squamosa* and *T. maxima* were combined due to early inconsistencies in identifying these similar species. While the small burrowing clam *T. crocea* was the most abundant, the larger reef-flat species *Hippopus hippopus* was very common, particularly on Ashmore Reef and Cartier Island, with Ashmore Reef having about two-thirds the total stock of this species in the study area. *H. hippopus* had a far lower abundance on the remaining reefs in the study area reefs, probably due, at least in part, to fishing pressure.

The other larger species of giant clams all had higher abundances on larger reefs with deep inner lagoons such as Seringapatam Reef and Scott Nth Reef. These reefs provide excellent habitat for these species in the inner lagoon edge.

The blue starfish *Linkia laevigata* was very common throughout the study area (Appendix F), with over 2.7 million estimated on the reef flats. It was widespread throughout the study area with the exception of Seringapatam Reef and Browse Island.

Crown of thorns starfish *Acanthaster planci* were present but very rare throughout the study area (Appendix F).

4. DISCUSSION

In summary, the analysis of the effects of fishing on the sedentary marine living resources (beche-de-mer and trochus) on the shallow reefs suggests they are heavily depleted with the high-value species over-exploited and the lower-value species probably either fully or over-exploited. Despite the low abundance, there appears to be continued high fishing pressure by Indonesian fishers in the area.

The exception is Ashmore Reef, where there are still significant populations of most target species. There is evidence that the stocks of these species were heavily depleted before the reef was declared as a nature reserve in 1983, and enforced in the late 1980's. Since this time the populations have recovered to the current levels. This is a clear indication of the benefits of protecting the stocks of these species through the nature reserve. However a comparison of the density of the high-value resources (high-value beche-de-mer and trochus) to similar reefs in Torres Strait suggests that the stocks remain in a depleted state. This may be because the stocks are still in a recovery phase, or because of some illegal fishing.

It appears that the sedentary resources in the shoal areas are probably not heavily depleted, and are being exploited by a small number of Indonesian fishers. The depth of the shoal areas (usually >20 m) currently offers some protection from fishing. Management interventions that stabilise the fishing effort to current levels should be considered as an initial step towards managing these resources.

The survey suggests that the current level of fishing effort in the MOU74 Box has not caused a significant depletion of the fin-fish stocks on the shallow reefs outside the Ashmore Reef National Nature Reserve. The fin-fish stocks are naturally less susceptible to over-fishing, given their wide geographic and depth distribution and the difficulty in preserving fin-fish for later sale. The video transect surveys indicated that the shoal areas support a very low density of commercial fin-fish, likely as a result of predominantly unsuitable habitat (sand/algae). Given the combination of low fish density, lack of weather protection and water depth it is not likely that Indonesian fishers would concentrate effort in the shoal areas. Further, it is unlikely that the shoal area would support any form of commercial fishing on its own.

The very low estimates of shark abundance and biomass on the shallow reef-edges and shoals of the MOU74 Box, particularly carcharhinids, suggest that current effort, particularly with long-lines, may be seriously depleting the shark population. Sharks are susceptible to over-fishing because the high-value shark-fin can be easily dried and stored for later sale. Declining catches of shark recorded during 1991 to 1994 (Wallner and McLoughlin, 1995) suggested the stock was being over-fished. Further study is required to established the status of the population with greater precision.

The coral mortality observed on the shallow reefs during the survey (Skewes *et al.*, 1999) is unlikely to directly impact on the abundance of commercial species of holothurians, or trochus, which do not rely on live coral for food shelter. One exception may be *Holothuria edulis*, a holothurian that is often associated with staghorn (*Acropora*) fields. However, there may be some cascading environmental effects on the shallow reef habitats that may affect these populations in some way (both negative and positive impacts).

4.1 Management recommendations

The declaration of the marine reserve on Ashmore Reef has had the effect of concentrating fishing effort on the other reefs in the MOU74 Box (Wallner and McLouglin, 1996). Any management on a reef by reef basis would have a similar effect. All the reefs in the MOU74 Box have to be managed on a whole. There is little doubt that the resources in the MOU74 Box are heavily exploited, and for trochus and high-value beche-de-mer at least, are over-exploited. This is likely to be repeated for the shoal stocks of commercial species if the reefs are protected, as fishing effort will increasingly be directed at the shoals. Therefore management will need to consider including the shoal areas of the MOU74 Box in conjunction with the shallow reef areas to define an effective management plan for the whole area.

The high value beche-de-mer and trochus on the shallow reefs are extremely overexploited, and require immediate protection if they are to recover at all. The lower value species (e.g. *Holothuria atra*) on the reefs and shoals could probably be fished under limited effort management regime and yearly monitoring. However, given the difficulty in catch monitoring, surveillance and enforcement, management strategies that limit the catch to certain species will be difficult to implement.

The populations of exploited species should be allowed to recover to suitable benchmark densities, which will be established using data from fished and unfished populations of the same species on similar reefs in Torres Strait and the northern Great Barrier Reef. However, we are unable to accurately predict the recovery time for these fisheries. It will be variable between species and probably reefs and recruitment of beche-de-mer to depleted habitats has been shown to be sporadic and variable (Conand, 1990). It will therefore require monitoring to gauge recovery for any future opening of the fishery.

We suggest the populations be closed to fishing for at least three years which would allow, for most holothurian species and trochus, at least one unfished cohort to spawn, after which, small efficient stock surveys could be done to monitor the recovery. The results of the current survey could form the basis of an extremely cost effective monitoring program. This would be achieved by targeted sampling and repeated measures techniques which allows changes in the abundance of selected species to be quantified with a high precision with reduced sampling effort (Skewes *et al.*, 1998). These surveys could also be carried out each year after the commencement of fishing if necessary.

If the recovered stocks are to be fished in the future, a range of management regimes could be developed that primarily limits effort but vary in complexity, efficiency and risk. The management regimes would primarily depend on limited fishing areas and/or limited seasons, with some catch monitoring. We suggest that the smaller reefs (Hibernia Reef, Cartier Island and Browse Island) be closed to fishing permanently. They provide little economic advantage if fished, can be depleted very easily, and provide easily identifiable refuges.

It should be emphasized that the reef invertebrate fisheries have a relatively high potential sustainable yields if the populations are allowed to recover. The value of the fisheries in the future, if exploited sustainably, would far out-weigh the value of the fisheries currently. For example, up to a third the virgin biomass of most holothurian species could probably be fished annually. The current population levels of high value beche-de-mer would be a small fraction of virgin biomass levels. For example, if the density of *Holothuria nobilis* (black teatfish) was allowed to recover to the minimum densities seen on reefs in Torres Strait (4 per ha) (Long *et al.*, 1996), then the sustainable yield of that species would be approximately 50 tonnes per year (wet weight) for Scott Reef alone.

The nature of these fisheries and the depleted state of the other reefs in the MOU74 Box suggest that the remaining resources on Ashmore Reef could be quickly depleted if the protection currently given to the reef was reduced. It is important that these populations are protected. Year-round protection of the resources on Ashmore Reef should be considered.

1. Include all reefs and shoals in an integrated management plan for the whole area.
2. Cease fishing effort on at least the high-value beche-de-mer, trochus and shark in the MOU74 Box for at least three years.
3. Reduce and regulate effort/catch on the lower value beche-de-mer species on the shallow reefs (especially *H. atra* on Scott Reefs and *H. edulis* on Scott Reef North).
4. Regulate effort (probably to current levels) on the shoal beche-de-mer.
5. Stop illegal fishing effort on Ashmore Reef.
6. Establish a cost effective monitoring program.

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APPENDIX A

Average density of holothurians (*n* per ha) for reef-top strata of the shallow reefs in the study area.

Reef	Strata	Comm-ercial	High-value	*H. atra*	*H. nobilis*	*H. fusco-gilva*	*H. edulis*	*H. leuc-ospilota*	*H. graeff-ei*	*H. argus*	*H. fusco-puncata*	*H. chloro-notus*	*H. ananas*	*H. anax*	*H. varieg-atus*	*Actinop-yga spp.*
Ashmore	Deep lagoon	41.67	0.00	0.00	0.00	0.00	13.89	0.00	0.00	13.89	0.00	0.00	0.00	0.00	13.89	0.00
Ashmore	Sand	14.53	0.00	11.63	0.00	0.00	0.00	2889.53	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.91
Ashmore	Shallow	100.77	1.28	86.73	1.28	0.00	2.55	1776.79	0.00	0.00	0.00	10.20	0.00	0.00	0.00	0.00
Ashmore	Shallow lagoon	0.00	0.00	0.00	0.00	0.00	0.00	2.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Browse	Shallow	18.75	0.00	18.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cartier	Shallow	25.00	0.00	25.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hibernia	Shallow	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hibernia	Shallow lagoon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scott Nth	Shallow	6.15	0.00	2.05	0.00	0.00	4.10	215.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scott Nth	Shallow lagoon	42.79	0.00	2.25	0.00	0.00	33.78	0.00	0.00	3.38	0.00	0.00	0.00	0.00	3.38	0.00
Scott Sth	Deep lagoon	12.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	12.50	0.00	0.00
Scott Sth	Shallow	7.21	0.00	7.21	0.00	0.00	0.00	62.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scott Sth	Shallow lagoon	6.94	0.00	0.00	0.00	0.00	4.17	0.00	2.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Seringapatam	Deep lagoon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Seringapatam	Shallow	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Seringapatam	Shallow lagoon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX A (cont.)

Average density of clams, trochus and starfish (*n* per ha) for reef-top strata of the shallow reefs in the study area.

Reef	Zone	*Tridacna gigas*	*T. crocea*	*T. spp*	*T. derasa*	*Hippopus hippopus*	*Acanthaster planci*	*Trochus niloticus*	*Linkia laevigata*
Ashmore	Deep lagoon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ashmore	Sand	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ashmore	Shallow	2.55	6.38	1.28	1.28	131.38	0.00	0.00	109.69
Ashmore	Shallow lagoon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	11.11
Browse	Shallow	0.00	0.00	6.25	0.00	6.25	0.00	0.00	6.25
Cartier	Shallow	0.00	12.50	0.00	0.00	75.00	0.00	0.00	98.68
Hibernia	Shallow	0.00	463.54	15.63	0.00	31.25	0.00	0.00	88.54
Hibernia	Shallow lagoon	0.00	0.00	62.50	0.00	0.00	0.00	0.00	62.50
Scott Nth	Shallow	0.00	182.38	12.30	0.00	14.34	0.00	0.00	84.02
Scott Nth	Shallow lagoon	13.51	145.27	77.70	10.14	3.38	0.00	0.00	20.27
Scott Sth	Deep lagoon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scott Sth	Shallow	1.20	75.32	1.20	0.00	17.63	0.00	0.00	76.92
Scott Sth	Shallow lagoon	6.94	48.61	6.94	4.17	16.67	0.00	0.00	25.00
Seringapatam	Deep lagoon	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Seringapatam	Shallow	5.68	39.77	5.68	0.00	22.73	0.00	0.00	0.00
Seringapatam	Shallow lagoon	0.00	0.00	27.78	6.94	0.00	0.00	0.00	6.94

APPENDIX B

Average density of holothurians (*n* per ha) for reef-edge strata of the shallow reefs in the study area.

Reef	Zone	Commercial	High-value	*H. atra*	*H. nobilis*	*H. fuscogilva*	*H. edulis*	*H. leucospilota*	*H. graeffei*	*H. argus*	*H. fuscopuncata*	*H. chloronotus*	*H. ananas*	*H. anax*	*H. variegatus*	*Actinopyga spp.*
Ashmore	Back edge	50.00	0.00	0.00	0.00	0.00	46.43	0.00	3.57	0.00	0.00	7.14	0.00	0.00	0.00	0.00
Ashmore	Front edge	27.62	4.63	5.56	1.85	0.00	9.26	0.00	4.63	0.77	0.93	1.85	2.78	0.93	0.00	0.93
Ashmore	Lagoon edge	68.18	15.91	4.55	0.00	9.09	43.18	0.00	4.55	0.00	0.00	29.55	6.82	0.00	0.00	0.00
Browse	Front edge	25.00	0.00	20.83	0.00	0.00	0.00	0.00	4.17	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cartier	Back edge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cartier	Front edge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hibernia	Back edge	16.15	5.21	2.60	0.00	2.60	4.17	0.00	0.00	4.17	0.00	7.58	2.60	0.00	0.00	0.00
Hibernia	Front edge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.50	0.00	0.00	0.00	0.00
Hibernia	Lagoon edge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scott Nth	Back edge	5.09	0.00	0.00	0.00	0.00	0.00	0.00	2.78	0.00	0.00	0.00	0.00	2.31	0.00	0.00
Scott Nth	Front edge	7.84	1.32	1.32	1.32	0.00	2.63	0.00	2.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scott Nth	Lagoon edge	33.33	0.00	4.17	0.00	0.00	25.00	0.00	2.08	2.08	0.00	0.00	0.00	0.00	0.00	0.00
Scott Sth	Back edge	34.83	0.00	2.00	0.00	0.00	26.83	0.00	1.00	1.00	0.00	0.00	0.00	2.00	0.00	2.00
Scott Sth	Front edge	0.81	0.00	0.81	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Scott Sth	Lagoon edge	58.33	1.04	36.46	1.04	0.00	18.75	0.00	0.00	1.04	0.00	0.00	0.00	0.00	1.04	0.00
Seringapatam	Back edge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Seringapatam	Front edge	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Seringapatam	Lagoon edge	2.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.27	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX B (cont.)

Average density of clams, trochus and starfish (*n* per ha) for reef-edge strata of the shallow reefs in the study area.

Reef	Zone	*Tridacna gigas*	*T. crocea*	*T. spp*	*T. derasa*	*Hippopus hippopus*	*Acanthaster planci*	*Trochus niloticus*	*Linkia laevigata*
Ashmore	Back edge	0.00	46.43	7.14	0.00	0.00	0.00	7.50	14.29
Ashmore	Front edge	0.00	21.72	9.43	0.00	0.00	0.00	29.86	11.11
Ashmore	Lagoon edge	0.00	29.55	9.09	0.00	2.27	0.00	0.00	70.45
Browse	Front edge	0.00	45.83	4.17	0.00	0.00	0.00	0.00	0.00
Cartier	Back edge	0.00	0.00	0.00	0.00	0.00	0.00	6.25	0.00
Cartier	Front edge	0.00	12.50	6.25	0.00	0.00	0.00	0.00	12.50
Hibernia	Back edge	4.17	99.70	67.39	0.00	0.00	0.00	0.00	18.51
Hibernia	Front edge	0.00	17.71	5.21	0.00	0.00	0.00	0.00	5.27
Hibernia	Lagoon edge	19.23	12.50	57.69	0.00	50.00	0.00	0.00	0.00
Scott Nth	Back edge	0.00	401.60	113.89	0.00	0.00	0.00	0.00	5.56
Scott Nth	Front edge	0.00	195.15	109.21	6.66	0.00	0.00	0.00	0.00
Scott Nth	Lagoon edge	0.00	155.71	45.83	18.75	7.29	1.04	0.00	35.42
Scott Sth	Back edge	2.00	199.30	8.00	2.00	2.30	2.67	0.00	7.00
Scott Sth	Front edge	0.81	43.19	0.81	0.00	0.00	0.00	0.00	0.00
Scott Sth	Lagoon edge	6.25	55.21	18.75	1.04	2.08	0.00	1.25	14.58
Seringapatam	Back edge	0.00	269.97	0.00	0.00	0.00	0.00	0.00	0.00
Seringapatam	Front edge	0.00	78.41	96.47	2.50	0.00	0.00	0.00	0.00
Seringapatam	Lagoon edge	0.00	65.00	66.52	11.36	0.00	0.00	0.00	23.94

APPENDIX C

Strata mean abundance and variance estimates for the calculation of standing stock estimates for *Holothuria atra* by reef and for the total study area. Column headings correspond to the formula in Appendix R.

REEF	ZONE	Sites n_h	Area (ha)	Reef W_h	Total W_h	H_ATRA Y_h	H_ATRA S^2_h	Reef Y_{st}	Reef $v(Y_{st})$	Total Y_{st}	Total $v(Y_{st})$
Ashmore	Back edge	7	160.25	0.007	0.003	0.00	0.00	0.00	0.00	0.00	0.00
Ashmore	Deep lagoon	9	3183.85	0.140	0.057	0.00	0.00	0.00	0.00	0.00	0.00
Ashmore	Front edge	27	688.68	0.030	0.012	5.56	160.26	0.17	0.01	0.07	0.00
Ashmore	Lagoon edge	11	179.30	0.008	0.003	4.55	102.27	0.04	0.00	0.01	0.00
Ashmore	Sand	43	6123.30	0.270	0.110	11.63	3581.81	3.14	6.06	1.27	1.00
Ashmore	Shallow	98	8252.84	0.364	0.148	86.73	39113.45	31.54	52.77	12.80	8.70
Ashmore	Shallow lagoon	45	4108.87	0.181	0.073	0.00	0.00	0.00	0.00	0.00	0.00
Browse	Front edge	6	101.73	0.223	0.002	20.83	1604.17	4.66	13.36	0.04	0.00
Browse	Shallow	20	353.45	0.789	0.006	18.75	2097.04	14.79	65.23	0.12	0.00
Cartier	Back edge	3	35.52	0.033	0.001	0.00	0.00	0.00	0.00	0.00	0.00
Cartier	Front edge	4	111.29	0.103	0.002	0.00	0.00	0.00	0.00	0.00	0.00
Cartier	Shallow	20	938.66	0.865	0.017	25.00	4276.32	21.62	159.89	0.42	0.06
Hibernia	Back edge	6	109.23	0.095	0.002	2.60	40.69	0.25	0.06	0.01	0.00
Hibernia	Front edge	6	161.25	0.140	0.003	0.00	0.00	0.00	0.00	0.00	0.00
Hibernia	Lagoon edge	2	11.00	0.010	0.000	0.00	0.00	0.00	0.00	0.00	0.00
Hibernia	Shallow	24	675.92	0.589	0.012	0.00	0.00	0.00	0.00	0.00	0.00
Hibernia	Shallow lagoon	2	190.33	0.166	0.003	0.00	0.00	0.00	0.00	0.00	0.00
Scott Nth	Back edge	9	131.96	0.012	0.002	0.00	0.00	0.00	0.00	0.00	0.00
Scott Nth	Front edge	19	332.59	0.031	0.006	1.32	32.89	0.04	0.00	0.01	0.00
Scott Nth	Lagoon edge	24	444.40	0.042	0.008	4.17	144.93	0.17	0.01	0.03	0.00
Scott Nth	Shallow	61	5673.40	0.535	0.101	2.05	256.15	1.10	1.20	0.21	0.04
Scott Nth	Shallow lagoon	37	4030.76	0.380	0.072	2.25	187.69	0.86	0.73	0.16	0.03
Scott Sth	Back edge	25	648.10	0.045	0.012	2.00	47.92	0.09	0.00	0.02	0.00
Scott Sth	Deep lagoon	2	419.03	0.029	0.007	0.00	0.00	0.00	0.00	0.00	0.00
Scott Sth	Front edge	31	679.60	0.047	0.012	0.81	20.16	0.04	0.00	0.01	0.00
Scott Sth	Lagoon edge	24	574.20	0.040	0.010	36.46	23259.74	1.45	1.54	0.37	0.10
Scott Sth	Shallow	104	9116.75	0.633	0.163	7.21	3891.66	4.57	15.00	1.18	0.99
Scott Sth	Shallow lagoon	30	2962.67	0.206	0.053	0.00	0.00	0.00	0.00	0.00	0.00
Seringapatam	Back edge	6	93.18	0.017	0.002	0.00	0.00	0.00	0.00	0.00	0.00
Seringapatam	Deep lagoon	5	1330.04	0.241	0.024	0.00	0.00	0.00	0.00	0.00	0.00
Seringapatam	Front edge	10	119.46	0.022	0.002	0.00	0.00	0.00	0.00	0.00	0.00
Seringapatam	Lagoon edge	11	189.20	0.034	0.003	0.00	0.00	0.00	0.00	0.00	0.00
Seringapatam	Shallow	22	2561.94	0.464	0.046	0.00	0.00	0.00	0.00	0.00	0.00
Seringapatam	Shallow lagoon	12	1225.60	0.222	0.022	0.00	0.00	0.00	0.00	0.00	0.00

Standing stock estimates and 95% confidence intervals by reef and for all reefs in the study area for *Holothuria atra*.

Reef	*n*	Area (ha)	yst (*n*/ha)	$v(Y_{st})$	Total Abundance	Weight (t)	95% CI (%)
Ashmore	240	22697.09	34.88	58.84	791650	281.6	43.3
Browse	26	455.18	19.22	76.58	8747	3.1	93.6
Cartier	27	1085.47	21.62	159.89	23467	8.3	120.0
Hibernia	40	1147.73	0.25	0.06	284	0.1	202.1
Scott Nth	150	10613.11	2.17	1.94	22993	8.2	127.2
Scott Sth	216	14400.34	6.15	16.54	88524	31.5	130.4
Seringapatam	66	5519.43	0.00	0.00	0	0.0	
Total area	765	55918.37	16.73	10.93	935666	332.8	38.8

APPENDIX D

Standing stock estimates and 95% confidence intervals by reef and for all reefs in the study area for large holothurians. Also included is an estimate of total standing stock of commercial holothurians (excluding *H. leucospilota*).

Species	Reef	Mean density (*n*/ha)	s^2 (mean)	Total numbers	Weight (tonnes)	95% CI (%)
Commercial	Ashmore	48.13	80.16	1092523	560.4	36.6
species	Browse	20.15	75.71	9171	3.4	88.8
	Cartier	21.62	159.89	23467	8.3	120.0
	Hibernia	1.54	0.95	1764	2.6	127.9
	Scott Nth	21.24	41.22	225459	99.5	59.7
	Scott Sth	10.29	17.98	148171	78.1	81.2
	Seringapatam	0.08	0.01	430	0.6	199.7
	All reefs	26.84	15.95	1500985	752.9	29.2
High-value	Ashmore	0.73	0.22	16567	29.5	126.8
	Browse	0.00	0.00	0	0.0	0.0
	Cartier	0.00	0.00	0	0.0	0.0
	Hibernia	0.50	0.25	569	1.4	202.1
	Scott Nth	0.04	0.00	438	0.7	197.6
	Scott Sth	0.04	0.00	598	0.9	197.1
	Seringapatam	0.00	0.00	0	0.0	0.0
	Total area	0.32	0.04	18172	32.5	115.6
Holothuria atra	Ashmore	34.88	58.84	791650	281.6	43.3
	Browse	19.22	76.58	8747	3.1	93.6
	Cartier	21.62	159.89	23467	8.3	120.0
	Hibernia	0.25	0.06	284	0.1	202.1
	Scott Nth	2.17	1.94	22993	8.2	127.2
	Scott Sth	6.15	16.54	88524	31.5	130.4
	Seringapatam	0.00	0.00	0	0.0	0.0
	All reefs	16.73	10.93	935666	332.8	38.8
Thelenota ananas	Ashmore	0.14	0.00	3136	7.9	77.6
	Browse	0.00	0.00	0	0.0	
	Cartier	0.00	0.00	0	0.0	
	Hibernia	0.25	0.06	284	0.7	202.1
	Scott Nth	0.00	0.00	0	0.0	
	Scott Sth	0.00	0.00	0	0.0	
	Seringapatam	0.00	0.00	0	0.0	
	All reefs	0.06	0.00	3420	8.6	72.7
Holothuria nobilis	Ashmore	0.52	0.22	11802	17.8	176.3
	Browse	0.00	0.00	0	0.0	
	Cartier	0.00	0.00	0	0.0	
	Hibernia	0.00	0.00	0	0.0	
	Scott Nth	0.04	0.00	438	0.7	197.6
	Scott Sth	0.04	0.00	598	0.9	197.1
	Seringapatam	0.00	0.00	0	0.0	
	All reefs	0.23	0.04	12838	19.4	161.9

APPENDIX D (cont.)

Species	Reef	Mean density (n/ha)	s^2 (mean)	Total numbers	Weight (tonnes)	95% CI (%)
Holothuria edulis	Ashmore	3.83	4.32	86833	16.7	107.0
	Browse	0.00	0.00	0	0.0	
	Cartier	0.00	0.00	0	0.0	
	Hibernia	0.40	0.16	455	0.1	202.1
	Scott Nth	16.15	38.62	171411	33.0	76.0
	Scott Sth	2.81	1.02	40497	7.8	71.0
	Seringapatam	0.00	0.00	0	0.0	
	All reefs	5.35	2.17	299195	57.5	54.0
Bohadschia argus	Ashmore	1.97	3.80	44751	58.5	194.7
	Browse	0.00	0.00	0	0.0	
	Cartier	0.00	0.00	0	0.0	
	Hibernia	0.40	0.16	455	0.6	202.1
	Scott Nth	1.37	1.65	14543	19.0	185.2
	Scott Sth	0.09	0.00	1246	1.6	139.5
	Seringapatam	0.08	0.01	430	0.6	199.7
	All reefs	1.10	0.69	61426	80.3	147.9
Holothuria fuscogilva	Ashmore	0.07	0.00	1630	3.8	82.4
	Browse	0.00	0.00	0	0.0	
	Cartier	0.00	0.00	0	0.0	
	Hibernia	0.25	0.06	284	0.7	202.1
	Scott Nth	0.00	0.00	0	0.0	
	Scott Sth	0.00	0.00	0	0.0	
	Seringapatam	0.00	0.00	0	0.0	
	All reefs	0.03	0.00	1914	4.5	75.8
Stichopus chloronotus	Ashmore	4.05	2.04	91930	30.7	69.5
	Browse	0.00	0.00	0	0.0	
	Cartier	0.00	0.00	0	0.0	
	Hibernia	1.07	0.64	1230	0.4	151.2
	Scott Nth	0.00	0.00	0	0.0	
	Scott Sth	0.00	0.00	0	0.0	
	Seringapatam	0.00	0.00	0	0.0	
	All reefs	1.67	0.34	93160	31.1	68.4
Thelenota anax	Ashmore	0.03	0.00	638	2.6	197.0
	Browse	0.00	0.00	0	0.0	
	Cartier	0.00	0.00	0	0.0	
	Hibernia	0.00	0.00	0	0.0	
	Scott Nth	0.03	0.00	305	1.2	197.6
	Scott Sth	0.45	0.14	6534	26.5	160.3
	Seringapatam	0.00	0.00	0	0.0	
	All reefs	0.13	0.01	7477	30.3	140.7
Holothuria fuscopunctata	Ashmore	0.03	0.00	638	0.9	197.0
	Browse	0.00	0.00	0	0.0	
	Cartier	0.00	0.00	0	0.0	
	Hibernia	0.00	0.00	0	0.0	
	Scott Nth	0.00	0.00	0	0.0	
	Scott Sth	0.00	0.00	0	0.0	
	Seringapatam	0.00	0.00	0	0.0	
	All reefs	0.01	0.00	638	0.9	196.3

APPENDIX D (cont.)

Species	Reef	Mean density (*n*/ha)	s^2 (mean)	Total numbers	Weight (tonnes)	95% CI (%)
Stichopus variegatus	Ashmore	1.95	3.80	44220	116.8	197.0
	Browse	0.00	0.00	0	0.0	
	Cartier	0.00	0.00	0	0.0	
	Hibernia	0.00	0.00	0	0.0	
	Scott Nth	1.28	1.65	13617	36.0	197.6
	Scott Sth	0.04	0.00	598	1.6	197.1
	Seringapatam	0.00	0.00	0	0.0	
	All reefs	1.05	0.68	58436	154.4	155.4
Bohadschia graeffei	Ashmore	0.20	0.01	4576	3.2	76.9
	Browse	0.93	0.87	424	0.3	205.6
	Cartier	0.00	0.00	0	0.0	
	Hibernia	0.00	0.00	0	0.0	
	Scott Nth	0.20	0.01	2151	1.5	86.8
	Scott Sth	0.62	0.33	8878	6.3	183.3
	Seringapatam	0.00	0.00	0	0.0	
	All reefs	0.29	0.02	16028	11.4	104.2
Actinopyga spp.	Ashmore	0.81	0.62	18438	19.8	190.3
	Browse	0.00	0.00	0	0.0	
	Cartier	0.00	0.00	0	0.0	
	Hibernia	0.00	0.00	0	0.0	
	Scott Nth	0.00	0.00	0	0.0	
	Scott Sth	0.09	0.00	1296	1.4	136.4
	Seringapatam	0.00	0.00	0	0.0	
	All reefs	0.35	0.10	19734	21.2	177.4
Holothuria leucospilota	Ashmore	1426.11	271581.33	32368451	2749.1	72.0
	Browse	0.00	0.00	0	0.0	
	Cartier	0.00	0.00	0	0.0	
	Hibernia	0.00	0.00	0	0.0	
	Scott Nth	115.02	7251.68	1220712	103.7	146.3
	Scott Sth	39.57	612.70	569797	48.4	123.3
	Seringapatam	0.00	0.00	0	0.0	
	All reefs	610.87	45045.52	34158959	2901.2	68.2

APPENDIX E

Standing stock estimates and 95% confidence intervals by reef and for all reefs in the study area for giant clams (*Tridacna* spp.). *T. maxima* and *T. squamosa* combined.

Species	Reef	Mean density (*n*/ha)	s^2 (mean)	Total numbers	95% CI (%)
Tridacna crocea	Ashmore	3.54	1.56	80325	69.5
	Browse	10.24	54.98	4663	148.8
	Cartier	12.09	55.89	13124	126.9
	Hibernia	285.09	11318.99	327202	75.4
	Scott Nth	170.29	4798.61	1807347	80.4
	Scott Sth	70.90	193.75	1020921	38.7
	Seringapatam	26.94	80.90	148716	66.6
	Total area	60.84	191.55	3402298	44.7
Tridacna spp	Ashmore	0.87	0.23	19796	108.6
(*T. maxima and T. sqamosa*)	Browse	5.78	24.42	2633	175.6
	Cartier	0.64	0.41	696	205.2
	Hibernia	27.26	149.92	31292	90.8
	Scott Nth	42.84	156.59	454675	57.7
	Scott Sth	3.34	1.67	48031	76.3
	Seringapatam	13.17	34.12	72710	88.5
	Total area	11.26	6.19	629832	43.4
Tridacna derasa	Ashmore	0.46	0.22	10527	197.0
	Browse	0.00	0.00	0	
	Cartier	0.00	0.00	0	
	Hibernia	0.00	0.00	0	
	Scott Nth	4.84	5.02	51401	91.4
	Scott Sth	0.99	0.74	14239	171.5
	Seringapatam	1.99	2.43	10960	156.6
	Total area	1.56	0.29	87126	67.7
Hippopus hippopus	Ashmore	47.79	86.65	1084646	38.4
	Browse	4.85	23.55	2209	205.6
	Cartier	64.86	1254.52	70400	112.1
	Hibernia	18.88	83.68	21673	97.9
	Scott Nth	9.26	9.23	98239	64.8
	Scott Sth	14.78	21.07	212776	61.2
	Seringapatam	10.55	38.42	58226	117.3
	Total area	27.69	16.89	1548168	29.1
Tridacna gigas	Ashmore	0.93	0.43	21053	138.6
	Browse	0.00	0.00	0	
	Cartier	0.00	0.00	0	
	Hibernia	0.58	0.19	667	152.2
	Scott Nth	5.13	9.42	54470	118.2
	Scott Sth	2.57	1.63	36965	98.2
	Seringapatam	2.64	6.96	14556	199.7
	Total area	2.28	0.59	127711	65.8

APPENDIX F

Standing stock estimates and 95% confidence intervals by reef and for all reefs in the study area for Crown of Thorns starfish (*Acanthaster planci*), and the blue starfish (*Linckia laevigata*).

Species	Reef	Mean density (*n*/ha)	s^2 (mean)	Total numbers	95% CI (%)
Acanthaster planci	Ashmore	0.00	0.00	0	
	Browse	0.00	0.00	0	
	Cartier	0.00	0.00	0	
	Hibernia	0.00	0.00	0	
	Scott Nth	0.04	0.00	463	197.6
	Scott Sth	0.12	0.01	1728	141.0
	Seringapatam	0.00	0.00	0	
	Total area	0.04	0.00	2191	118.3
Linkia laevigata	Ashmore	42.89	49.86	973514	32.4
	Browse	4.85	23.55	2209	205.6
	Cartier	86.62	493.61	94022	52.6
	Hibernia	65.01	294.59	74615	53.4
	Scott Nth	54.16	113.85	574836	38.9
	Scott Sth	54.74	79.18	788266	32.0
	Seringapatam	2.36	2.45	13040	132.2
	Total area	45.07	17.90	2520503	18.4

APPENDIX G

Standing stock estimates and 95% confidence intervals by shoal and for all shoals in the study area for commercial holothurians.

SHOAL	Sites n^h	Area (ha)	Shoal W_h	Total W_h	HOLO_H Y_h	HOLO_H s^2_h	Shoal Y_{st}	Shoal $v(Y_{st})$	Total Y_{st}	Total $v(Y_{st})$	Total abundance	Weight (t)	95% CI (%)
Ashmore Rf	39	30382.7		0.25	5.56	127.57			1.38	0.20	169050	256.2	65.7
Browse Is	4	541.9		0.00	0.00	0.00			0.00	0.00	0	0.0	
Cartier Is	3	867.4		0.01	1.71	14.81			0.01	0.00	1479	3.2	414.8
Johnson Bk "sand"	17	12196.9	0.89	0.10	3.01	78.10	2.67	3.63	0.30	0.05	36709	53.8	150.3
Johnson Bk “hard”	9	1526.5	0.11	0.01	5.03	25.74	0.56	0.04	0.06	0.00	7681	11.3	76.0
Johnson Bk total	26	13723.4					3.23	3.66			44390	65.1	121.6
Scott Nth Rf	5	3309.8		0.03	0.00	0.00			0.00	0.00	0	0.0	
Scott Sth Rf	42	28895.5		0.24	2.68	126.26			0.63	0.17	77427	105.4	130.6
Shoal A	8	7585.2		0.06	0.00	0.00			0.00	0.00	0	0.0	
Shoal B	27	22516.6		0.18	2.08	31.66			0.38	0.04	46939	73.4	106.6
Shoal C	6	5458.4		0.04	1.71	29.63			0.08	0.01	9311	17.0	318.8
Woodbine Bk "sand"	12	8348.4	0.89	0.07	1.07	30.86	0.95	2.05	0.07	0.01	8899	16.2	327.8
Woodbine Bk “hard”	4	1005.2	0.11	0.01	5.42	26.04	0.58	0.08	0.04	0.00	5445	10.0	130.8
Woodbine Bk total	16	9353.6					1.53	2.12			14344	26.2	201.5
Total shoal area	176	122634.4							2.96	0.48	362940	546.4	46.0

APPENDIX H

Standing stock estimates and 95% confidence intervals by shoal and for all shoals in the study area for large holothurians.

Species	Shoal	Mean density (*n*/ha)	s^2 (mean)	Total numbers	Weight (tonnes)	95% CI (%)
Thelenota ananas	Ashmore Rf	0.00	0.00	0	0.0	
	Browse Is	0.00	0.00	0	0.0	
	Cartier Is	1.71	8.72	1479	0.0	318.2
	Scott Nth Rf	0.00	0.00	0	0.0	
	Scott Sth Rf	0.00	0.00	0	0.0	
	Shoal A	0.00	0.00	0	0.0	
	Shoal B	0.00	0.00	0	0.0	
	Shoal C	0.85	4.36	4653	10.1	244.7
	Johnson Bk	0.13	0.01	1735	3.8	140.8
	Woodbine Bk	0.88	0.33	8218	17.8	138.3
	Total area	0.13	0.00	16085	34.9	90.2
Bohadschia argus	Ashmore Rf	0.13	0.65	3885	5.1	204.8
	Browse Is	0.00	0.00	0	0.0	
	Cartier Is	0.00	0.00	0	0.0	
	Scott Nth Rf	0.00	0.00	0	0.0	
	Scott Sth Rf	0.00	0.00	0	0.0	
	Shoal A	0.00	0.00	0	0.0	
	Shoal B	0.00	0.00	0	0.0	
	Shoal C	0.00	0.00	0	0.0	
	Johnson Bk	0.00	0.00	0	0.0	
	Woodbine Bk	0.00	0.00	0	0.0	
	Total area	0.03	0.00	3885	5.1	199.9
Stichopus variegatus	Ashmore Rf	0.26	1.27	7771	20.5	143.0
	Browse Is	0.00	0.00	0	0.0	
	Cartier Is	0.00	0.00	0	0.0	
	Scott Nth Rf	0.00	0.00	0	0.0	
	Scott Sth Rf	0.00	0.00	0	0.0	
	Shoal A	0.00	0.00	0	0.0	
	Shoal B	0.19	0.97	4266	11.3	205.2
	Shoal C	0.00	0.00	0	0.0	
	Johnson Bk	0.00	0.00	0	0.0	
	Woodbine Bk	0.00	0.00	0	0.0	
	Total area	0.10	0.00	12036	31.8	114.0
Holothuria fuscopunctata	Ashmore Rf	4.03	78.13	122419	181.0	71.1
	Browse Is	0.00	0.00	0	0.0	
	Cartier Is	0.00	0.00	0	0.0	
	Scott Nth Rf	0.00	0.00	0	0.0	
	Scott Sth Rf	0.24	1.22	7045	10.4	140.9
	Shoal A	0.00	0.00	0	0.0	
	Shoal B	1.33	17.31	29872	44.2	123.8
	Shoal C	0.85	4.37	4658	6.9	244.7
	Johnson Bk	2.46	2.00	33750	49.9	118.1
	Woodbine Bk	0.48	0.30	4451	6.6	244.8
	Total area	1.65	0.17	202195	299.0	50.0

APPENDIX H (cont.)

Species	Shoal	Mean density (*n*/ha)	s^2 (mean)	Total numbers	Weight (tonnes)	95% CI (%)
Holothuria fuscogilva	Ashmore Rf	0.00	0.00	0	0.0	
	Browse Is	0.00	0.00	0	0.0	
	Cartier Is	0.00	0.00	0	0.0	
	Scott Nth Rf	0.00	0.00	0	0.0	
	Scott Sth Rf	0.00	0.00	0	0.0	
	Shoal A	0.00	0.00	0	0.0	
	Shoal B	0.00	0.00	0	0.0	
	Shoal C	0.00	0.00	0	0.0	
	Johnson Bk	0.03	0.00	347	0.8	227.2
	Woodbine Bk	0.00	0.00	0	0.0	
	Total area	0.00	0.00	347	0.8	218.2
Holothuria atra	Ashmore Rf	0.64	4.99	19426	26.2	113.1
	Browse Is	0.00	0.00	0	0.0	
	Cartier Is	0.00	0.00	0	0.0	
	Scott Nth Rf	0.00	0.00	0	0.0	
	Scott Sth Rf	2.44	100.25	70382	95.0	128.0
	Shoal A	0.00	0.00	0	0.0	
	Shoal B	0.38	3.17	8531	11.5	185.4
	Shoal C	0.00	0.00	0	0.0	
	Johnson Bk	0.37	0.14	5090	6.9	210.1
	Woodbine Bk	0.00	0.00	0	0.0	
	Total area	0.84	0.15	103430	139.6	89.4
Actinopyga echinites	Ashmore Rf	0.00	0.00	0	0.0	
	Browse Is	0.00	0.00	0	0.0	
	Cartier Is	0.00	0.00	0	0.0	
	Scott Nth Rf	0.00	0.00	0	0.0	
	Scott Sth Rf	0.00	0.00	0	0.0	
	Shoal A	0.00	0.00	0	0.0	
	Shoal B	0.00	0.00	0	0.0	
	Shoal C	0.00	0.00	0	0.0	
	Johnson Bk	0.25	0.03	3469	3.7	136.7
	Woodbine Bk	0.18	0.02	1675	1.8	164.2
	Total area	0.04	0.00	5145	5.5	101.6

APPENDIX I

Size Frequencies (grams) for all holothurian species collected and weighed on reefs in the study area.

Species	*n*	Min (g)	Max (g)	Range	Mean (g)	Std.Error
Actinopyga echinites	1	1100	1100		1100	
Actinopyga mauritiana	3	590	1400	810	930	242.69
Bohadschia argus	15	900	2250	1350	1306.67	89.03
Bohadschia graeffei	22	425	1250	825	709.09	46.92
Holothuria atra	160	25	1800	1775	344.95	34.65
Holothuria coluber	3	145	350	205	235	60.48
Holothuria edulis	164	20	1625	1605	192.25	12.92
Holothuria fuscopunctata	9	625	2750	2125	1478.89	234.45
Holothuria fuscogilva	3	1600	3625	2025	2341.67	644.26
Holothuria hilla	3	10	25	15	18.33	4.41
Holothuria leucospilota	147	5	1400	1395	84.93	9.92
Holothuria nobilis	7	450	2250	1800	1510	213.60
Stichopus chloronotus	39	85	850	765	334.36	34.41
Stichopus variegatus	3	2300	3125	825	2641.67	248.47
Thelenota ananas	29	1200	5750	4550	2607.76	238.13
Thelenota anax	5	3350	5000	1650	4050	301.66

Size frequencies (grams) for all holothurian species collected and weighed on shoals in the study area.

Species	No.	Min (g)	Max (g)	Range	Mean (g)	Std.Error
Actinopyga echinites	12	800	1675	875	1070.83	77.11
Holothuria atra	1	1350	1350		1350	
Thelenota ananas	12	700	3300	2600	2167.50	259.02

Size frequencies-basal width (mm) for all *Trochus niloticus* collected and measured in the study area.

Species	No.	Min (g)	Max (g)	Range	Mean (g)	Std.Error
Trochus niloticus	71	46.7	120	73.3	86.54	2.05

APPENDIX J

Summary table listing families and species observed during UVC surveys in the MOU74 Box and their mean length and weight, estimated density (*n* per hectare), abundance and biomass (kg). Note: density, abundance and biomass figures are unstratified estimates.

Family	Species	Mean Length	MeanWt	Mean._Ha	SE	Max._Ha	Totalnum	Biomass
Acanthuridae	*Acanthurus bariene*	28.87	130.57	0.62	0.21	28.57	2950.49	385.24
Acanthuridae	*Acanthurus dussumieri*	30.99	152.43	2.20	1.14	242.86	10474.23	1596.60
Acanthuridae	*Acanthurus lineatus*	20.37	225.59	1.58	0.41	57.14	7523.75	1697.30
Acanthuridae	*Acanthurus olivaceus*	22.53	306.23	4.27	1.45	264.29	20358.37	6234.30
Acanthuridae	*Acanthurus xanthopterus*	25.08	71.73	26.96	3.45	371.43	128641.3	9228.04
Acanthuridae	*Naso annulatus*	26.86	465.88	1.02	0.47	85.71	4868.31	2268.03
Acanthuridae	*Naso brachycentron*	33.66	715.60	4.33	1.75	371.43	20653.42	14779.60
Acanthuridae	*Naso brevirostris*	28.48	465.44	7.02	1.94	250.00	33488.05	15586.81
Acanthuridae	*Naso hexacanthus*	38.02	996.92	13.39	3.64	535.71	63878.08	63681.45
Acanthuridae	*Naso lituratus*	25.59	539.16	2.78	0.47	35.71	13277.20	7158.57
Acanthuridae	*Naso tuberosus*	43.75	1856.27	2.44	1.62	357.14	11654.43	21633.82
Acanthuridae	*Naso unicornis*	35.07	870.47	1.05	0.29	35.71	5015.83	4366.13
Acanthuridae	*Naso vlamingi*	32.12	622.47	2.81	0.79	100.00	13424.72	8356.43
Balistidae	*Balistapus undulatus*	17.98	142.14	1.79	0.31	28.57	8556.42	1216.17
Balistidae	*Balistoides conspicillum*	31.73	455.05	0.49	0.12	14.29	2360.39	1074.10
Balistidae	*Balistoides viridescens*	41.51	846.28	3.00	0.40	50.00	14309.87	12110.17
Balistidae	*Pseudobalistes flavimarginatus*	41.17	839.78	0.28	0.12	14.29	1327.72	1114.99
Carangidae	*Carangoides ferdau*	36.33	1162.04	1.30	0.86	142.86	6196.03	7200.05
Carangidae	*Carangoides fulvoguttatus*	44.50	1510.28	0.84	0.62	129.87	4023.39	6076.45
Carangidae	*Carangoides plagiotaenia*	30.00	720.24	0.25	0.21	50.00	1180.20	850.03
Carangidae	*Caranx ignobilis*	64.61	7123.85	0.53	0.24	50.00	2507.92	17866.00
Carangidae	*Caranx lugubris*	36.40	721.83	0.49	0.32	71.43	2360.39	1703.81
Carangidae	*Caranx melampygus*	37.92	1249.15	1.82	0.57	92.86	8703.94	10872.57
Carangidae	*Caranx sexfasciatus*	41.00	1920.18	0.06	0.04	7.14	295.05	566.55
Carangidae	*Elegatis bipinnulata*	36.14	549.77	1.61	0.78	142.86	7671.27	4217.41
Carangidae	*Scomberoides lysan*	42.50	781.82	2.50	1.58	357.14	11949.48	9342.34
Carcharhinidae	*Carcharhinus amblyrhynchos*	96.67	13075.01	0.09	0.05	7.14	442.57	5786.65
Dasyatididae	*Dasyatis kuhlii*	31.74	1106.48	0.71	0.16	14.29	3393.06	3754.37
Haemulidae	*Diagramma pictum*	31.56	512.76	0.25	0.19	42.86	1180.20	605.15
Haemulidae	*Plectorhinchus chaetodontoides*	36.31	531.03	6.03	1.06	164.29	28767.26	15276.19
Haemulidae	*Plectorhinchus gibbosus*	45.00	2585.77	0.06	0.06	14.29	295.05	762.93
Haemulidae	*Plectorhinchus goldmanni*	32.82	374.43	1.67	0.61	100.00	7966.32	2982.86
Haemulidae	*Plectorhinchus orientalis*	39.58	699.52	0.37	0.16	21.43	1770.29	1238.36
Hemigaleidae	*Triaenodon obesus*	73.07	6037.93	0.71	0.14	14.29	3393.06	20487.07
Holocentridae	*Sargocentron*	26.53	390.22	1.39	0.45	71.43	6638.60	2590.54
Kyphosidae	*Kyphosus cinerascens*	30.61	580.80	3.68	1.23	171.43	17555.41	10196.19
Labridae	*Cheilinus fasciatus*	23.20	424.72	0.77	0.39	85.71	3688.11	1566.43
Labridae	*Cheilinus undulatus*	52.57	4726.02	2.78	0.53	85.71	13277.20	62748.31
Lethrinidae	*Gnathodentex aurolineatus*	15.78	89.09	3.28	1.37	214.29	15637.59	1393.12
Lethrinidae	*Gymnocranius grandoculus*	27.50	63.97	0.25	0.19	42.86	1180.20	75.50
Lethrinidae	*Lethrinus atkinsoni*	25.67	362.41	0.28	0.12	21.43	1327.72	481.18
Lethrinidae	*Lethrinus erythropterus*	22.79	289.55	4.98	0.83	142.86	23751.43	6877.33
Lethrinidae	*Lethrinus harak*	19.07	128.57	0.43	0.26	50.00	2065.34	265.54
Lethrinidae	*Lethrinus obsoletus*	26.53	502.05	1.45	0.61	135.71	6933.65	3481.03
Lethrinidae	*Lethrinus olivaceus*	39.47	787.46	4.45	1.87	321.43	21243.52	16728.41
Lethrinidae	*Lethrinus xanthochilus*	37.35	1281.98	2.84	0.90	150.00	13572.25	17399.41
Lethrinidae	*Monotaxis grandoculis*	27.93	564.61	14.25	2.12	228.57	68008.76	38398.58
Lutjanidae	*Aphareus furca*	26.92	248.44	0.62	0.16	21.43	2950.49	733.02
Lutjanidae	*Aprion virescens*	42.70	1058.27	1.55	0.29	28.57	7376.22	7806.05
Lutjanidae	*Lutjanus bohar*	35.12	1078.36	24.46	3.86	678.57	116691.8	125835.8
Lutjanidae	*Lutjanus decussatus*	21.00	183.37	19.45	2.05	321.43	92792.87	17015.10

APPENDIX J (cont.)

Family	Species	Mean Length	MeanWt	Mean._Ha	SE	Max._Ha	Totalnum	Biomass
Lutjanidae	*Lutjanus fulvus*	21.00	211.58	0.19	0.18	42.86	885.15	187.28
Lutjanidae	*Lutjanus gibbus*	25.29	377.84	83.52	19.74	3571.43	398463.48	150556.1
Lutjanidae	*Lutjanus kasmira*	18.69	128.16	22.05	10.08	1928.57	105184.92	13480.93
Lutjanidae	*Lutjanus lutjanus*	19.50	147.81	0.15	0.11	21.43	737.62	109.03
Lutjanidae	*Lutjanus monostigma*	33.26	747.66	0.80	0.31	64.29	3835.64	2867.76
Lutjanidae	*Lutjanus rivulatus*	46.65	2028.73	1.67	0.76	157.14	7966.32	16161.52
Lutjanidae	*Lutjanus vitta*	20.00	140.85	0.56	0.55	129.87	2682.26	377.81
Lutjanidae	*Macolor macularis*	21.40	252.56	0.19	0.15	35.71	885.15	223.55
Lutjanidae	*Macolor niger*	30.00	616.41	28.39	5.03	571.43	135427.42	83478.23
Lutjanidae	*Symphorichthys spilurus*	26.25	539.79	0.99	0.26	35.71	4720.78	2548.24
Lutjanidae	*Symphorus nematophorus*	20.00	205.05	0.03	0.03	7.14	147.52	30.25
Scaridae	*Bolbometopon muricatum*	71.25	11170.25	0.25	0.12	14.29	1180.20	13183.08
Scaridae	*Cetoscarus bicolor*	32.32	782.65	3.12	0.51	57.14	14899.97	11661.41
Scaridae	*Hipposcarus longiceps*	23.98	374.36	24.55	3.35	392.86	117134.40	43850.16
Scaridae	*Scarus bleekeri*	23.67	335.08	2.35	0.69	107.14	11211.86	3756.92
Scaridae	*Scarus flavipectoralis*	28.44	525.73	2.72	0.92	178.57	12982.15	6825.05
Scaridae	*Scarus frenatus*	18.86	203.16	7.95	1.78	214.29	37913.78	7702.38
Scaridae	*Scarus ghobban*	21.30	211.45	0.68	0.27	50.00	3245.54	686.28
Scaridae	*Scarus microrhinos*	31.49	986.59	10.17	1.62	250.00	48535.54	47884.70
Scaridae	*Scarus niger*	24.01	357.12	2.57	1.74	400.00	12244.53	4372.80
Scaridae	*Scarus oviceps*	22.05	234.66	0.62	0.24	35.71	2950.49	692.35
Scaridae	*Scarus rubroviolaceus*	28.11	751.37	1.58	0.89	178.57	7523.75	5653.11
Scaridae	*Scarus schlegeli*	18.44	229.92	4.67	1.46	257.14	22276.19	5121.70
Scaridae	*Scarus sordidus*	13.30	68.33	28.23	4.31	500.00	134689.80	9203.41
Scaridae	*Scarus sp.*	21.41	271.06	27.95	4.02	550.00	133362.08	36148.86
Scombridae	*Grammatorcynus bilineatus*	45.00	913.88	0.28	0.28	64.94	1341.13	1225.63
Scombridae	*Gymnosarda unicolor*	70.00	6642.23	0.25	0.09	14.29	1180.20	7839.12
Serranidae	*Aethaloperca rogga*	25.52	386.07	2.04	0.28	21.43	9736.61	3759.05
Serranidae	*Anyperodon leucogrammicus*	28.71	435.34	0.25	0.09	14.29	1180.20	513.79
Serranidae	*Cephalopholis argus*	24.41	286.15	5.84	0.61	71.43	27882.12	7978.53
Serranidae	*Cephalopholis miniata*	24.09	518.26	1.27	0.29	42.86	6048.50	3134.70
Serranidae	*Cephalopholis urodeta*	17.94	195.98	0.71	0.19	28.57	3393.06	664.96
Serranidae	*Epinephelus fasciatus*	23.00	265.02	0.09	0.05	7.14	442.57	117.29
Serranidae	*Epinephelus fuscoguttatus*	50.30	2287.75	0.40	0.14	21.43	1917.82	4387.48
Serranidae	*Epinephelus maculatus*	20.00	150.74	0.03	0.03	7.14	147.52	22.24
Serranidae	*Epinephelus merra*	14.51	90.41	0.77	0.27	50.00	3688.11	333.44
Serranidae	*Epinephelus polyphekadion*	35.67	976.54	0.87	0.16	14.29	4130.68	4033.77
Serranidae	*Epinephelus spilotoceps*	11.75	20.78	0.25	0.08	7.14	1180.20	24.53
Serranidae	*Gracila albimarginata*	27.22	467.39	0.34	0.12	14.29	1622.77	758.47
Serranidae	*Plectropomus areolatus*	29.46	366.77	0.99	0.21	21.43	4720.78	1731.45
Serranidae	*Plectropomus laevis*	37.74	761.84	1.11	0.20	14.29	5310.88	4046.05
Serranidae	*Plectropomus leopardus*	25.28	282.21	5.07	0.67	71.43	24194.01	6827.77
Serranidae	*Plectropomus oligocanthus*	30.63	418.02	3.15	0.44	42.86	15047.49	6290.16
Serranidae	*Variola albimarginata*	27.90	442.72	0.53	0.15	21.43	2507.92	1110.30
Serranidae	*Variola louti*	25.67	309.22	0.12	0.07	14.29	590.10	182.47
Siganidae	*Siganus argenteus*	19.83	143.76	3.53	2.03	428.57	16817.78	2417.67
Siganidae	*Siganus doliatus*	23.08	281.30	4.58	0.79	85.71	21833.62	6141.76
Siganidae	*Siganus fuscescens*	21.00	201.35	0.12	0.09	14.29	590.10	118.82
Siganidae	*Siganus puellus*	21.51	224.09	4.17	0.68	71.43	19915.80	4462.93
Siganidae	*Siganus punctatissimus*	26.52	432.56	3.59	0.56	71.43	17112.83	7402.37
Siganidae	*Siganus vulpinis*	19.94	194.53	7.82	0.95	100.00	37323.68	7260.44
Sphyraenidae	*Sphyraena barracuda*	56.67	1488.63	0.19	0.07	7.14	885.15	1317.66

APPENDIX K

Summary table listing species observed during UVC surveys in the MOU74 Box and their occurrence at each of the seven reefs visited. (+) = present, (-) = absent.

		REEF						
Family	Species	Ashmore	Browse	Cartier	Hibernia	Scott Nth	Scott Sth	Seringapatam
Acanthuridae	*Acanthurus bariene*	+	-	+	+	-	-	+
Acanthuridae	*Acanthurus dussumieri*	+	-	-	-	+	-	+
Acanthuridae	*Acanthurus lineatus*	+	-	+	-	+	+	+
Acanthuridae	*Acanthurus olivaceus*	+	+	+	+	-	+	+
Acanthuridae	*Acanthurus xanthopterus*	+	+	+	+	+	+	+
Acanthuridae	*Naso annulatus*	-	-	-	-	+	-	+
Acanthuridae	*Naso brachycentron*	+	+	+	+	+	+	+
Acanthuridae	*Naso brevirostris*	+	+	+	+	+	+	+
Acanthuridae	*Naso hexacanthus*	-	+	+	-	+	+	+
Acanthuridae	*Naso lituratus*	+	-	+	+	-	-	+
Acanthuridae	*Naso tuberosus*	+	-	-	-	-	-	-
Acanthuridae	*Naso unicornis*	+	-	+	+	-	+	+
Acanthuridae	*Naso vlamingi*	+	-	+	+	+	+	+
Balistidae	*Balistapus undulatus*	+	-	+	+	+	-	+
Balistidae	*Balistoides conspicillum*	+	-	+	+	+	+	+
Balistidae	*Balistoides viridescens*	+	-	+	+	+	+	+
Balistidae	*Pseudobalistes flavimarginatus*	-	-	+	+	+	+	+
Carangidae	*Carangoides ferdau*	+	+	-	-	+	-	-
Carangidae	*Carangoides fulvoguttatus*	-	+	-	+	-	-	-
Carangidae	*Carangoides plagiotaenia*	-	-	-	-	-	-	+
Carangidae	*Caranx ignobilis*	+	-	+	+	+	+	+
Carangidae	*Caranx lugubris*	-	-	-	-	+	+	+
Carangidae	*Caranx melampygus*	+	+	+	+	+	+	+
Carangidae	*Caranx sexfasciatus*	-	+	-	-	-	-	+
Carangidae	*Elegatis bipinnulata*	-	-	-	-	+	+	-
Carangidae	*Scomberoides lysan*	+	-	-	-	-	+	-
Carcharhinidae	*Carcharhinus amblyrhynchos*	+	-	-	-	-	+	+
Dasyatididae	*Dasyatis kuhlii*	+	-	+	+	+	+	+
Haemulidae	*Diagramma pictum*	+	-	-	-	-	+	+
Haemulidae	*Plectorhinchus chaetodontoides*	+	+	-	+	+	+	+
Haemulidae	*Plectorhinchus gibbosus*	-	+	-	-	-	-	-
Haemulidae	*Plectorhinchus goldmanni*	+	+	+	+	+	-	+
Haemulidae	*Plectorhinchus orientalis*	+	-	+	+	-	-	-
Hemigaleidae	*Triaenodon obesus*	+	+	+	+	+	+	+
Holocentridae	*Sargocentron*	+	-	-	-	+	+	+
Kyphosidae	*Kyphosus cinerascens*	+	-	+	-	+	+	+
Labridae	*Cheilinus fasciatus*	-	-	+	+	-	+	-
Labridae	*Cheilinus undulatus*	+	+	-	-	+	+	+
Lethrinidae	*Gnathodentex aurolineatus*	+	-	-	-	+	+	+
Lethrinidae	*Gymnocranius grandoculus*	-	-	-	-	+	-	-
Lethrinidae	*Lethrinus atkinsoni*	+	-	+	-	-	-	-
Lethrinidae	*Lethrinus erythropterus*	-	-	-	+	+	+	+
Lethrinidae	*Lethrinus harak*	-	-	-	-	+	+	-
Lethrinidae	*Lethrinus obsoletus*	+	-	-	-	+	+	+
Lethrinidae	*Lethrinus olivaceus*	+	+	-	+	+	+	+
Lethrinidae	*Lethrinus xanthochilus*	+	-	-	+	+	+	+
Lethrinidae	*Monotaxis grandoculis*	+	-	+	+	+	+	+
Lutjanidae	*Aphareus furca*	-	-	-	+	+	+	+
Lutjanidae	*Aprion virescens*	+	-	+	+	+	+	+
Lutjanidae	*Lutjanus bohar*	+	+	+	+	+	+	+
Lutjanidae	*Lutjanus decussatus*	+	+	+	+	+	+	+
Lutjanidae	*Lutjanus fulviflamma*	+	+	-	-	+	-	-
Lutjanidae	*Lutjanus fulvus*	+	-	-	-	-	-	-

APPENDIX K (cont.)

Family	Species	Ashmore	Browse	Cartier	REEF Hibernia	Scott Nth	Scott Sth	Seringapatam
Lutjanidae	*Lutjanus gibbus*	+	+	+	+	+	+	+
Lutjanidae	*Lutjanus kasmira*	+	-	+	-	+	+	+
Lutjanidae	*Lutjanus lutjanus*	+	-	-	-	-	-	-
Lutjanidae	*Lutjanus monostigma*	+	-	+	+	+	+	+
Lutjanidae	*Lutjanus rivulatus*	+	+	-	+	-	+	+
Lutjanidae	*Lutjanus vitta*	-	+	-	-	-	-	-
Lutjanidae	*Macolor macularis*	+	-	-	+	-	-	-
Lutjanidae	*Macolor niger*	+	+	+	+	+	+	+
Lutjanidae	*Symphorichthys spilurus*	-	-	-	-	+	+	+
Lutjanidae	*Symphorus nematophorus*	-	-	-	-	+	+	-
Scaridae	*Bolbometopon muricatum*	-	-	-	-	+	-	+
Scaridae	*Cetoscarus bicolor*	+	-	+	+	+	+	+
Scaridae	*Hipposcarus longiceps*	+	-	+	+	+	+	+
Scaridae	*Scarus bleekeri*	+	-	+	-	+	+	+
Scaridae	*Scarus flavipectoralis*	+	+	-	+	+	+	+
Scaridae	*Scarus frenatus*	+	-	-	+	+	+	+
Scaridae	*Scarus ghobban*	+	-	+	-	-	-	-
Scaridae	*Scarus microrhinos*	+	-	+	+	+	+	+
Scaridae	*Scarus niger*	-	-	+	+	-	-	+
Scaridae	*Scarus oviceps*	-	-	+	+	-	-	+
Scaridae	*Scarus rubroviolaceus*	+	-	+	+	-	-	+
Scaridae	*Scarus schlegeli*	+	-	+	+	+	-	+
Scaridae	*Scarus sordidus*	+	-	+	+	+	+	+
Scaridae	*Scarus sp.*	+	-	+	+	+	+	+
Scombridae	*Grammatorcynus bilineatus*	-	-	-	-	-	+	-
Scombridae	*Gymnosarda unicolor*	-	-	+	+	+	+	-
Serranidae	*Aethaloperca rogga*	+	-	+	+	+	+	+
Serranidae	*Anyperodon leucogrammicus*	+	-	-	-	+	+	+
Serranidae	*Cephalopholis argus*	+	+	+	+	+	+	+
Serranidae	*Cephalopholis miniata*	+	-	+	+	+	+	+
Serranidae	*Cephalopholis urodeta*	-	-	+	+	+	+	+
Serranidae	*Epinephelus fasciatus*	+	+	-	-	-	-	-
Serranidae	*Epinephelus fuscoguttatus*	+	-	-	-	+	+	+
Serranidae	*Epinephelus maculatus*	+	-	-	-	-	-	-
Serranidae	*Epinephelus merra*	+	-	-	-	+	+	+
Serranidae	*Epinephelus polyphekadion*	+	-	-	+	+	+	+
Serranidae	*Epinephelus spilotoceps*	-	-	-	-	+	+	+
Serranidae	*Gracila albimarginata*	-	-	-	-	+	+	+
Serranidae	*Plectropomus areolatus*	-	-	-	-	+	+	+
Serranidae	*Plectropomus laevis*	+	-	-	+	+	+	+
Serranidae	*Plectropomus leopardus*	+	-	-	+	+	+	+
Serranidae	*Plectropomus oligocanthus*	-	-	-	+	+	+	+
Serranidae	*Variola albimarginata*	+	+	+	+	-	-	+
Serranidae	*Variola louti*	-	+	-	+	-	-	-
Siganidae	*Siganus argenteus*	+	-	-	+	+	+	+
Siganidae	*Siganus doliatus*	+	-	-	-	+	+	+
Siganidae	*Siganus fuscescens*	+	-	-	-	-	-	+
Siganidae	*Siganus puellus*	+	+	-	+	+	+	+
Siganidae	*Siganus punctatissimus*	+	-	+	+	+	+	+
Siganidae	*Siganus vulpinis*	+	-	-	+	+	+	+
Sphyraenidae	*Sphyraena barracuda*	+	-	-	-	+	+	+

APPENDIX L

Stock size estimates by reef and zone in the Box MOU74 for fin-fish and reef sharks combined, using strip transect data.

REEF	ZONE	Sites N_h	Area_Ha	Reef W_h	Total W_h	Y_h	Var S^2_h	Reef Y_{st}	Reef $v(Y_{st})$	Total Y_{st}	Total $v(Y_{st})$
Ashmore	Back edge	7	160.25	0.156	0.034	1088.78	1363466.96	169.68	4730.96	36.57	219.75
Ashmore	Front edge	27	688.68	0.670	0.144	438.89	69031.92	293.96	1146.95	63.35	53.27
Ashmore	Lagoon edge	11	179.30	0.174	0.038	516.88	139370.13	90.13	385.26	19.43	17.89
Browse	Front edge	6	101.73	1.000	0.021	254.76	36544.22	254.76	6090.70	5.43	2.77
Cartier	Back edge	3	35.52	0.242	0.007	438.10	132874.15	105.99	2592.30	3.26	2.45
Cartier	Front edge	4	111.29	0.758	0.023	303.57	9336.73	230.13	1341.40	7.08	1.27
Hibernia	Back edge	6	109.23	0.388	0.023	307.14	21000.00	119.19	527.08	7.03	1.83
Hibernia	Front edge	6	161.25	0.573	0.034	360.71	35974.49	206.64	1967.59	12.19	6.85
Hibernia	Lagoon edge	2	11.00	0.039	0.002	671.43	117959.18	26.24	90.07	1.55	0.31
Scott Nth	Back edge	9	131.96	0.145	0.028	675.40	74350.91	98.06	174.13	18.68	6.32
Scott Nth	Front edge	19	332.59	0.366	0.070	722.93	718172.22	264.52	5060.65	50.40	183.69
Scott Nth	Lagoon edge	24	444.40	0.489	0.093	456.55	68615.42	223.21	683.41	42.53	24.81
Scott Sth	Back edge	25	648.10	0.341	0.136	582.29	186416.33	198.42	865.87	79.10	137.60
Scott Sth	Front edge	31	679.60	0.357	0.142	386.87	86085.36	138.24	354.56	55.11	56.35
Scott Sth	Lagoon edge	24	574.20	0.302	0.120	339.29	58775.51	102.43	223.22	40.83	35.47
Seringapatam	Back edge	6	93.18	0.232	0.020	615.48	113926.87	142.72	1021.01	12.02	7.24
Seringapatam	Front edge	10	119.46	0.297	0.025	441.43	7038.55	131.23	62.20	11.05	0.44
Seringapatam	Lagoon edge	11	189.20	0.471	0.040	401.30	64692.02	188.95	1303.76	15.91	9.25

Stock size estimates and 95% confidence intervals by reef and for the Box MOU74 for all fin-fish and sharks.

Reef	*n*	Area	y_{st} (kg/Ha)	$v(Y_{st})$	$se(Y_{st})$	Total Abundance	Biomass (t)	95%CI (%)
Ashmore	45	1028.23	553.77	6263.17	79.14	569407	289.4	28.78
Browse	6	101.73	254.76	6090.70	78.04	25918	13.2	74.96
Cartier	7	146.81	336.12	3933.70	62.72	49345	25.1	44.12
Hibernia	14	281.48	352.07	2584.74	50.84	99100	50.4	30.97
Scott Nth	52	908.95	585.79	5918.18	76.93	532455	270.6	26.35
Scott Sth	80	1901.90	439.09	1443.66	38.00	835110	424.5	17.22
Seringapatam	27	401.84	462.89	2386.97	48.86	186008	94.5	21.66
Totals	231	4770.94	481.53	767.5744	27.71	2297343	1167.7	11.34

APPENDIX M

Standing stock estimates and 95% confidence intervals by reef and for all reefs in the MOU74 Box for the most common fish species.

Species	Reef	Mean abundance (*n*/Ha)	Variance (Mean)	Total numbers	Total weight (t)	95% CI (%)
Acanthurus xanthopterus	Ashmore	52.48	139.71	53960	3.2	45.4
	Browse	41.67	440.19	4239	0.3	123.2
	Cartier	16.96	55.37	2490	0.1	103.7
	Hibernia	2.35	2.46	661	0.0	143.4
	Scott Nth	25.02	54.76	22740	1.4	59.4
	Scott Sth	21.59	18.08	41059	2.5	39.2
	Seringapatam	17.95	80.75	7212	0.4	102.7
	Total area	27.74	12.18	132360	7.9	24.8
Plectorhinchus chaetodontoides	Ashmore	3.68	3.81	3789	2.5	106.6
	Browse	1.19	1.42	121	0.1	244.7
	Cartier	0.00	0.00	0	0.0	0.0
	Hibernia	3.89	7.60	1096	0.7	151.9
	Scott Nth	5.80	1.94	5272	3.5	48.2
	Scott Sth	6.51	2.67	12376	8.1	50.0
	Seringapatam	13.89	55.30	5582	3.7	109.8
	Total area	5.92	1.09	28235	18.6	34.8
Plectropomus spp.	Ashmore	2.05	0.68	2112	0.8	81.1
	Browse	0.00	0.00	0	0.0	0.0
	Cartier	0.00	0.00	0	0.0	0.0
	Hibernia	4.98	2.92	1402	0.5	73.6
	Scott Nth	13.56	4.21	12328	4.6	30.4
	Scott Sth	14.15	3.07	26916	10.0	24.7
	Seringapatam	14.92	5.59	5997	2.2	32.5
	Total area	10.22	0.72	48753	18.1	16.4
Epinephelus spp.	Ashmore	1.77	0.36	1820	1.4	68.6
	Browse	1.19	1.42	121	0.1	244.7
	Cartier	0.00	0.00	0	0.0	0.0
	Hibernia	0.46	0.21	130	0.1	214.5
	Scott Nth	4.04	1.31	3676	2.8	56.8
	Scott Sth	1.99	0.19	3788	2.9	43.3
	Seringapatam	3.72	1.03	1497	1.1	56.0
	Total area	2.31	0.10	11032	8.4	27.3
Cephalopholis spp.	Ashmore	8.77	3.16	9018	2.9	40.8
	Browse	1.19	1.42	121	0.0	244.7
	Cartier	8.67	11.12	1273	0.4	91.0
	Hibernia	9.27	4.84	2609	0.8	50.9
	Scott Nth	6.74	1.03	6126	2.0	30.3
	Scott Sth	6.92	1.23	13158	4.2	31.9
	Seringapatam	11.02	8.26	4430	1.4	53.5
	Total area	7.70	0.47	36735	11.7	17.5
Scarus microrhinus	Ashmore	2.82	3.93	2900	2.8	141.6
	Browse	0.00	0.00	0	0.0	0.0
	Cartier	5.99	29.65	880	0.9	214.9
	Hibernia	1.34	0.52	378	0.4	114.8
	Scott Nth	13.11	11.09	11916	11.6	51.0
	Scott Sth	11.78	13.70	22397	21.8	62.5
	Seringapatam	15.93	9.36	6403	6.2	39.4
	Total area	9.41	2.86	44874	43.6	35.4

APPENDIX M (cont.)

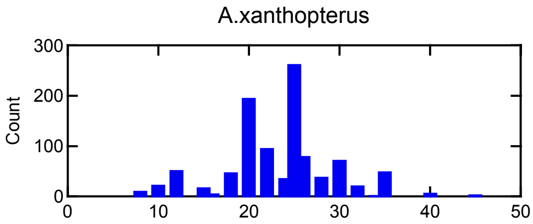
Species	Reef	Mean abundance (*n*/Ha)	Variance (Mean)	Total numbers	Total weight (t)	95% CI (%)
Hipposcarus longiceps	Ashmore	6.52	3.18	6706	1.8	55.1
	Browse	0.00	0.00	0	0.0	0.0
	Cartier	4.44	8.33	651	0.2	153.8
	Hibernia	17.66	17.29	4972	1.3	50.5
	Scott Nth	34.71	67.71	31553	8.3	47.6
	Scott Sth	32.92	39.58	62603	16.5	38.0
	Seringapatam	25.41	76.95	10213	2.7	70.8
	Total area	24.46	9.51	116697	30.8	24.8
Cetoscarus bicolor	Ashmore	1.38	0.27	1415	1.1	76.3
	Browse	0.00	0.00	0	0.0	0.0
	Cartier	5.41	14.66	795	0.6	167.2
	Hibernia	3.19	3.09	898	0.7	118.2
	Scott Nth	3.35	0.89	3047	2.3	56.5
	Scott Sth	1.11	0.23	2107	1.6	85.7
	Seringapatam	9.90	5.12	3980	3.0	46.9
	Total area	2.57	0.14	12242	9.4	28.9
Macolor niger	Ashmore	6.27	3.28	6447	4.1	58.2
	Browse	11.90	22.68	1211	0.8	97.9
	Cartier	3.08	1.83	452	0.3	103.9
	Hibernia	6.30	7.17	1773	1.1	91.1
	Scott Nth	34.75	82.55	31591	20.1	52.5
	Scott Sth	34.39	113.69	65415	41.7	61.7
	Seringapatam	48.69	347.47	19564	12.5	78.6
	Total area	26.50	23.72	126453	80.6	36.2
Lutjanus gibbus	Ashmore	170.73	3151.81	175553	57.9	66.2
	Browse	3.57	12.76	363	0.1	244.7
	Cartier	57.40	1171.66	8427	2.8	141.0
	Hibernia	8.37	47.91	2356	0.8	177.4
	Scott Nth	122.70	4727.77	111528	36.8	112.4
	Scott Sth	37.46	126.01	71243	23.5	59.6
	Seringapatam	49.98	616.18	20082	6.6	101.9
	Total area	81.65	343.68	389551	128.5	44.7
Lutjanus decussatus	Ashmore	16.26	4.10	16720	3.1	25.1
	Browse	1.19	1.42	121	0.0	244.7
	Cartier	14.49	31.48	2127	0.4	91.6
	Hibernia	12.85	29.98	3616	0.7	91.4
	Scott Nth	21.08	18.62	19161	3.6	41.1
	Scott Sth	25.65	22.76	48786	9.2	37.0
	Seringapatam	10.67	3.69	4287	0.8	36.9
	Total area	19.87	4.64	94818	17.8	21.4
Lutjanus bohar	Ashmore	18.81	35.22	19343	26.2	63.5
	Browse	11.90	19.27	1211	1.6	90.2
	Cartier	16.22	119.63	2381	3.2	159.5
	Hibernia	20.53	78.95	5780	7.8	92.8
	Scott Nth	26.09	46.10	23712	32.1	52.2
	Scott Sth	29.56	78.08	56214	76.2	59.5
	Seringapatam	18.96	50.80	7620	10.3	77.1
	Total area	24.37	16.47	116261	157.6	32.8
Monotaxis grandoculus	Ashmore	12.39	28.92	12738	8.2	87.4
	Browse	0.00	0.00	0	0.0	0.0
	Cartier	29.38	486.11	4313	2.8	177.5
	Hibernia	10.38	22.32	2921	1.9	97.7
	Scott Nth	19.21	32.06	17462	11.3	59.1
	Scott Sth	12.73	8.87	24208	15.6	46.6
	Seringapatam	12.15	15.07	4881	3.2	65.6
	Total area	13.94	4.56	66523	43.0	30.2

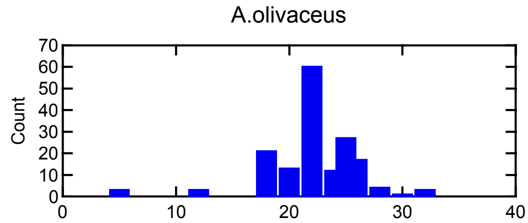
APPENDIX M (cont.)

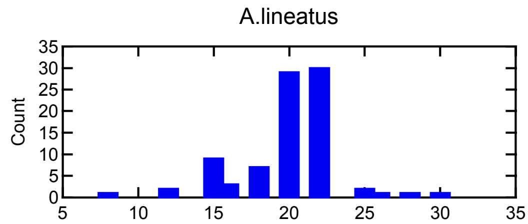
Species	Reef	Mean abundance (*n*/Ha)	Variance (Mean)	Total numbers	Total weight (t)	95% CI (%)
Lethrinus erythropterus	Ashmore	0.00	0.00	0	0.0	0.0
	Browse	0.00	0.00	0	0.0	0.0
	Cartier	0.00	0.00	0	0.0	0.0
	Hibernia	1.06	0.36	299	0.1	121.2
	Scott Nth	6.55	1.65	5951	1.6	39.4
	Scott Sth	6.87	1.70	13060	3.5	37.8
	Seringapatam	10.75	34.53	4321	1.2	112.1
	Total area	4.95	0.58	23630	6.3	30.2
Cheilinus undulatus	Ashmore	0.53	0.15	547	2.4	147.8
	Browse	1.19	1.42	121	0.5	244.7
	Cartier	0.00	0.00	0	0.0	0.0
	Hibernia	0.00	0.00	0	0.0	0.0
	Scott Nth	6.97	2.59	6339	28.2	46.3
	Scott Sth	1.78	0.27	3389	15.1	57.7
	Seringapatam	2.56	0.80	1027	4.6	71.6
	Total area	2.39	0.15	11423	50.9	31.8

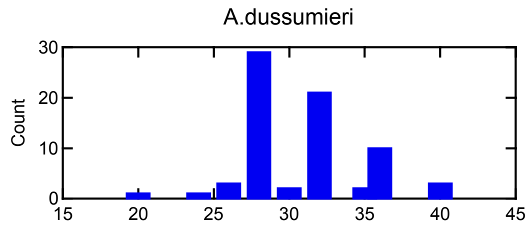
APPENDIX N

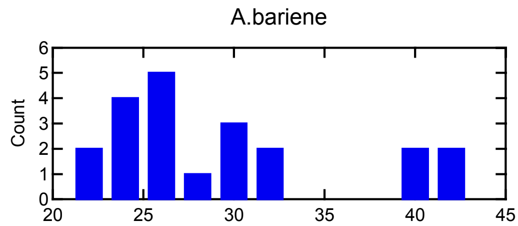
Size frequency distributions for fish species recorded during the UVC surveys and comparative size frequencies for fish caught during the MOU74 Box survey ("Catch").

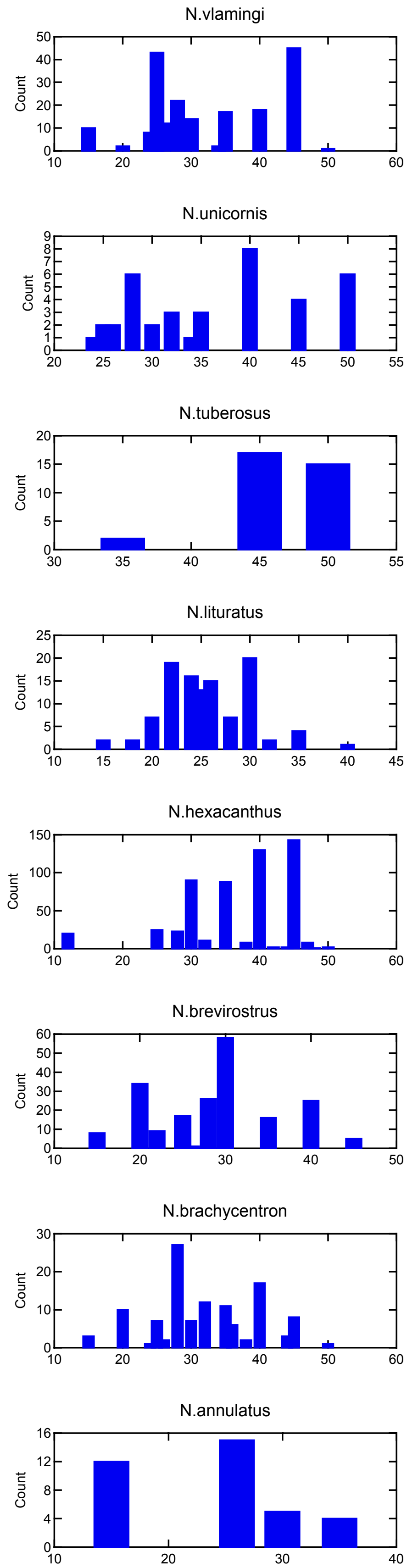








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N.unicornis
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N.tuberosus
Count
0 5 10 15 20
30 35 40 45 50 55
N.lituratus
Count
0 5 10 15 20 25
10 15 20 25 30 35 40 45
N.hexacanthus
Count
0 50 100 150
10 20 30 40 50 60
N.brevirostrus
Count
0 10 20 30 40 50 60
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N.brachycentron
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10 20 30 40 50 60
N.annulatus
Count
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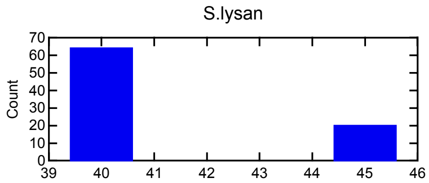
10 20 30 40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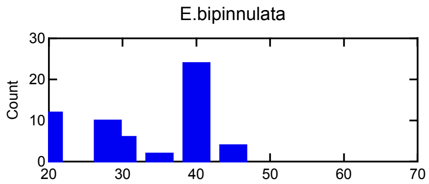
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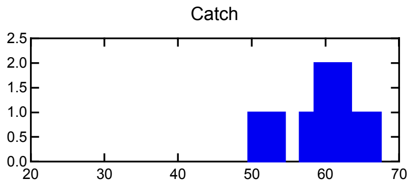
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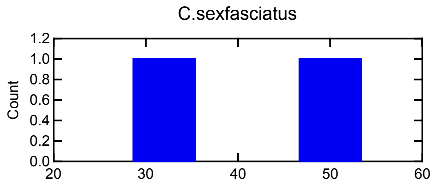
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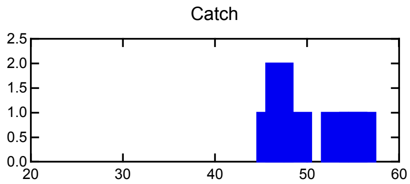
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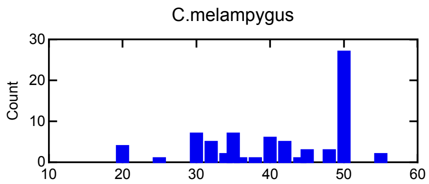
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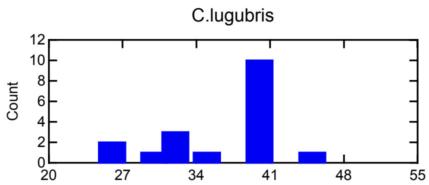
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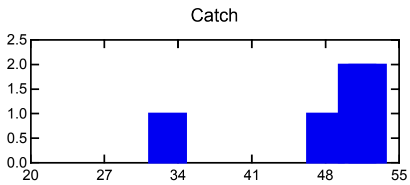
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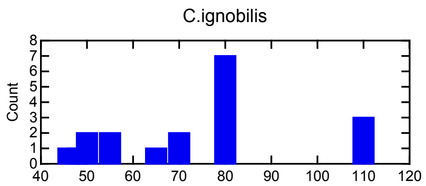
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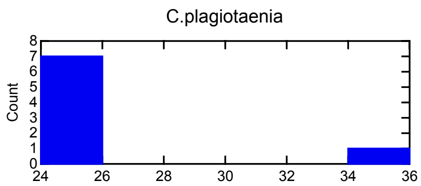
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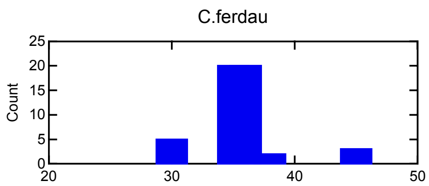
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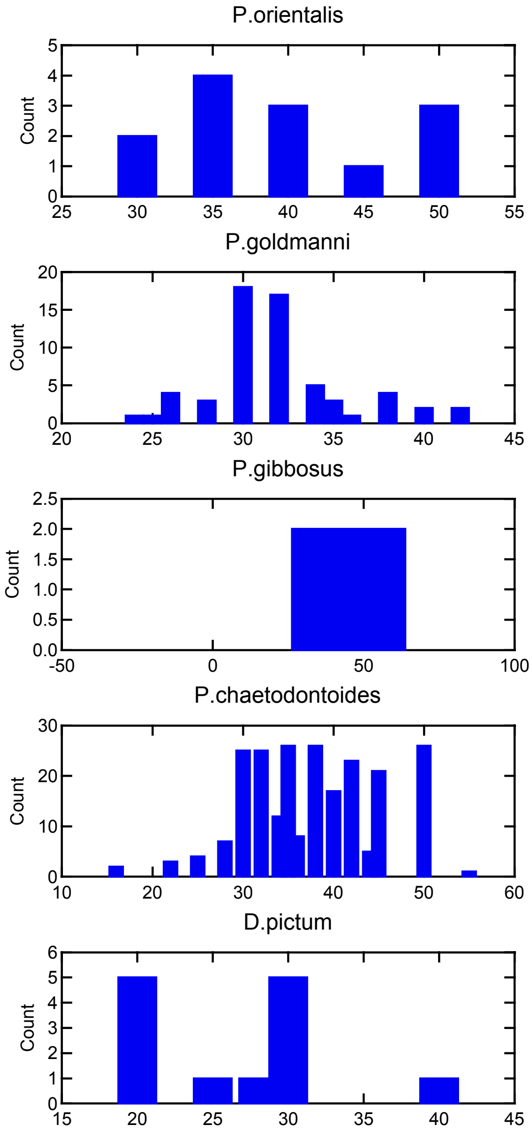
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10
15
20
20
25
30
35
40
45
P.gibbosus
Count
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0.5
1.0
1.5
2.0
2.5
-50
0
50
100
P.chaetodontoides
Count
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10
20
30
10
20
30
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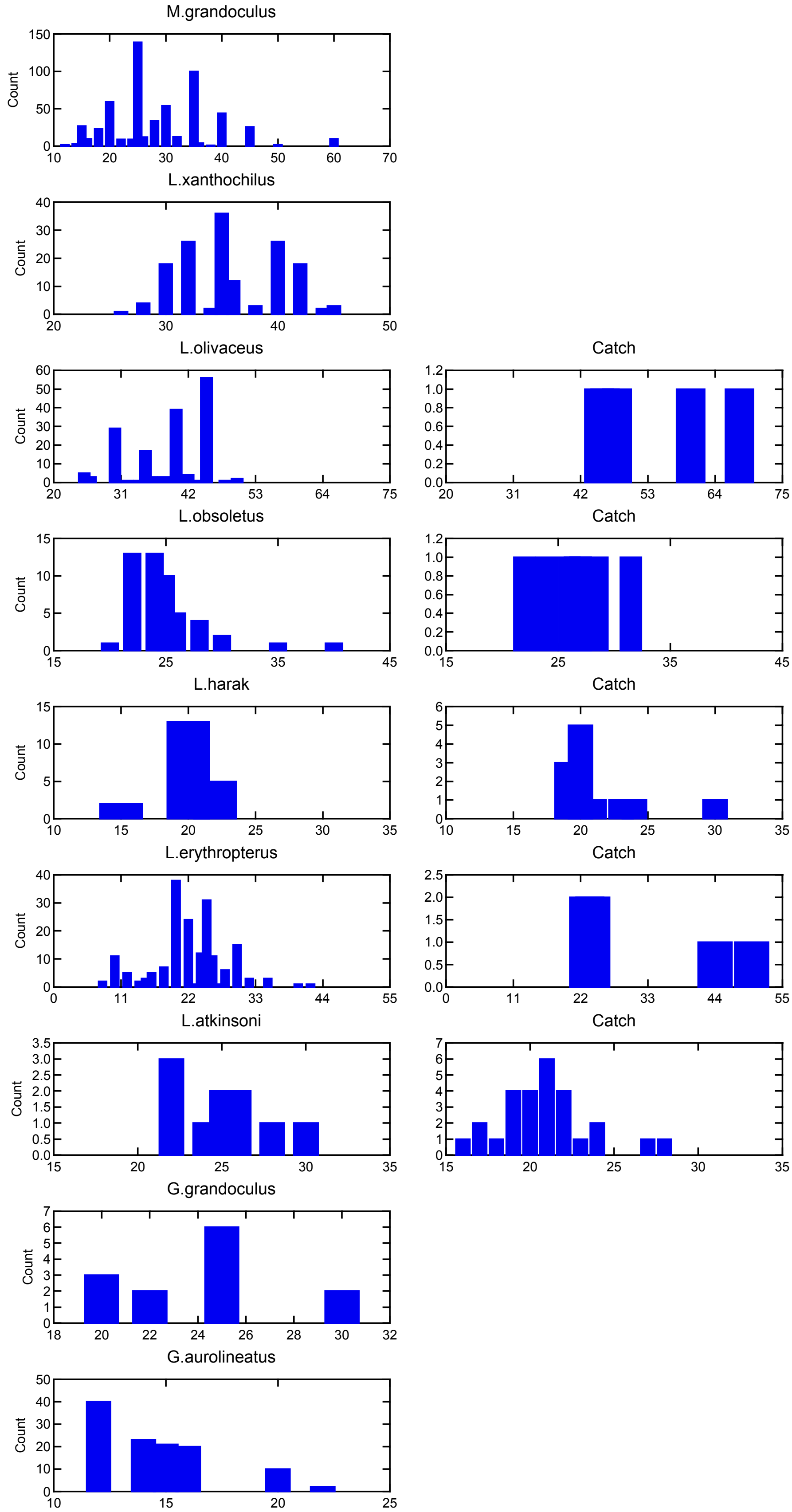
40
45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Catch
L.harak
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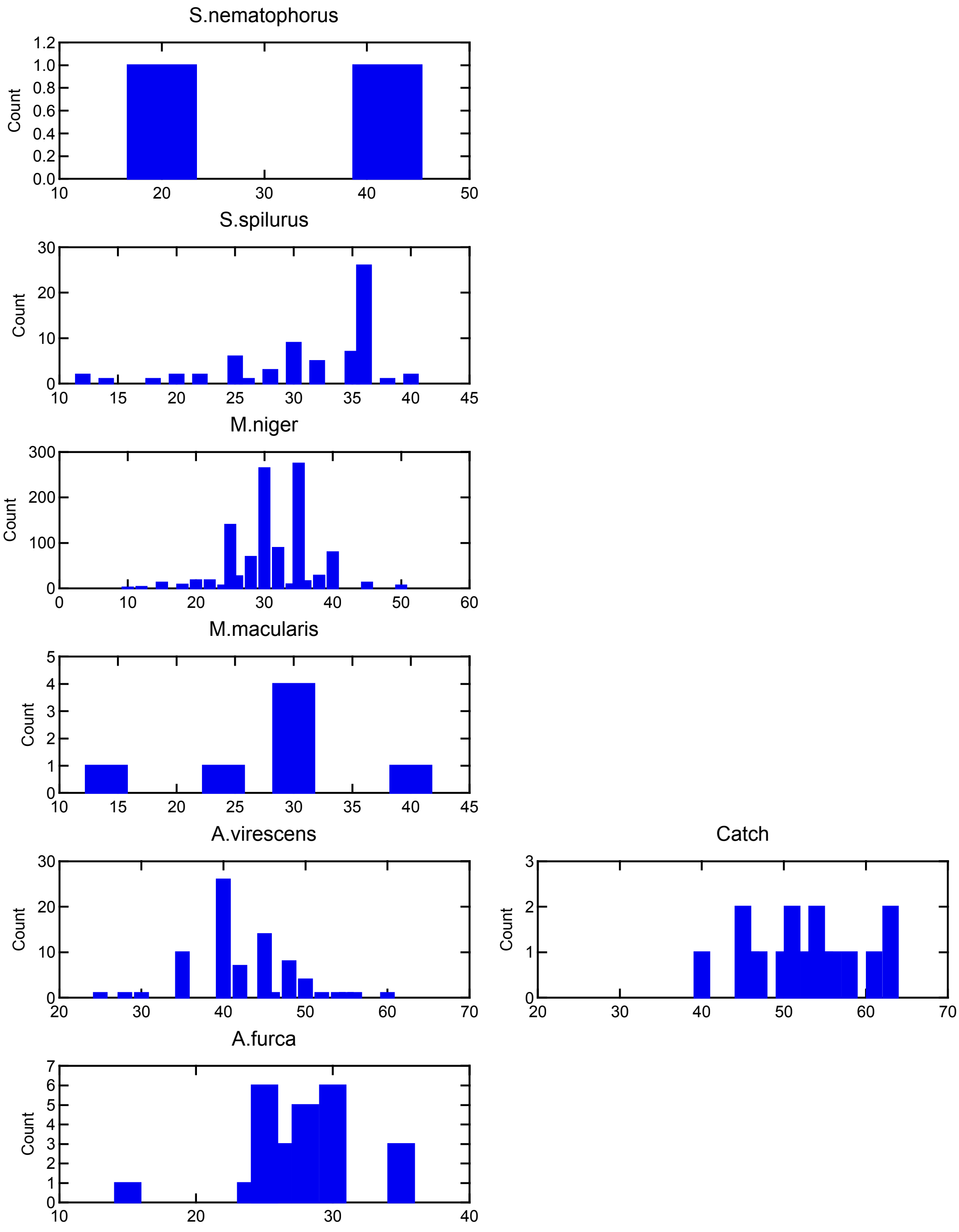
Catch
L.erythropterus
Count
Catch
L.atkinsoni
Count
Catch
G.grandoculus
Count
G.aurolineatus
Count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M.niger
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M.macularis
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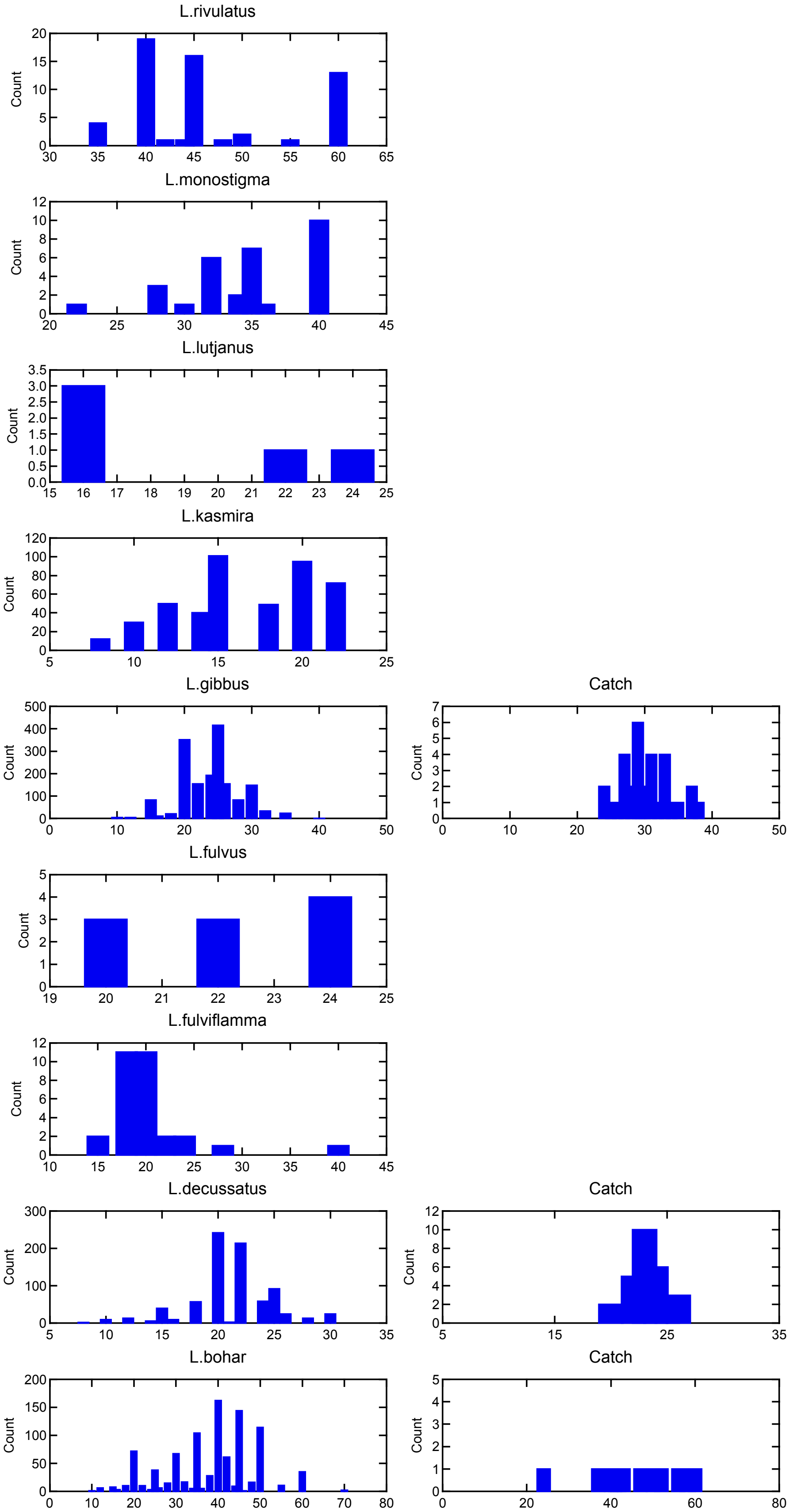
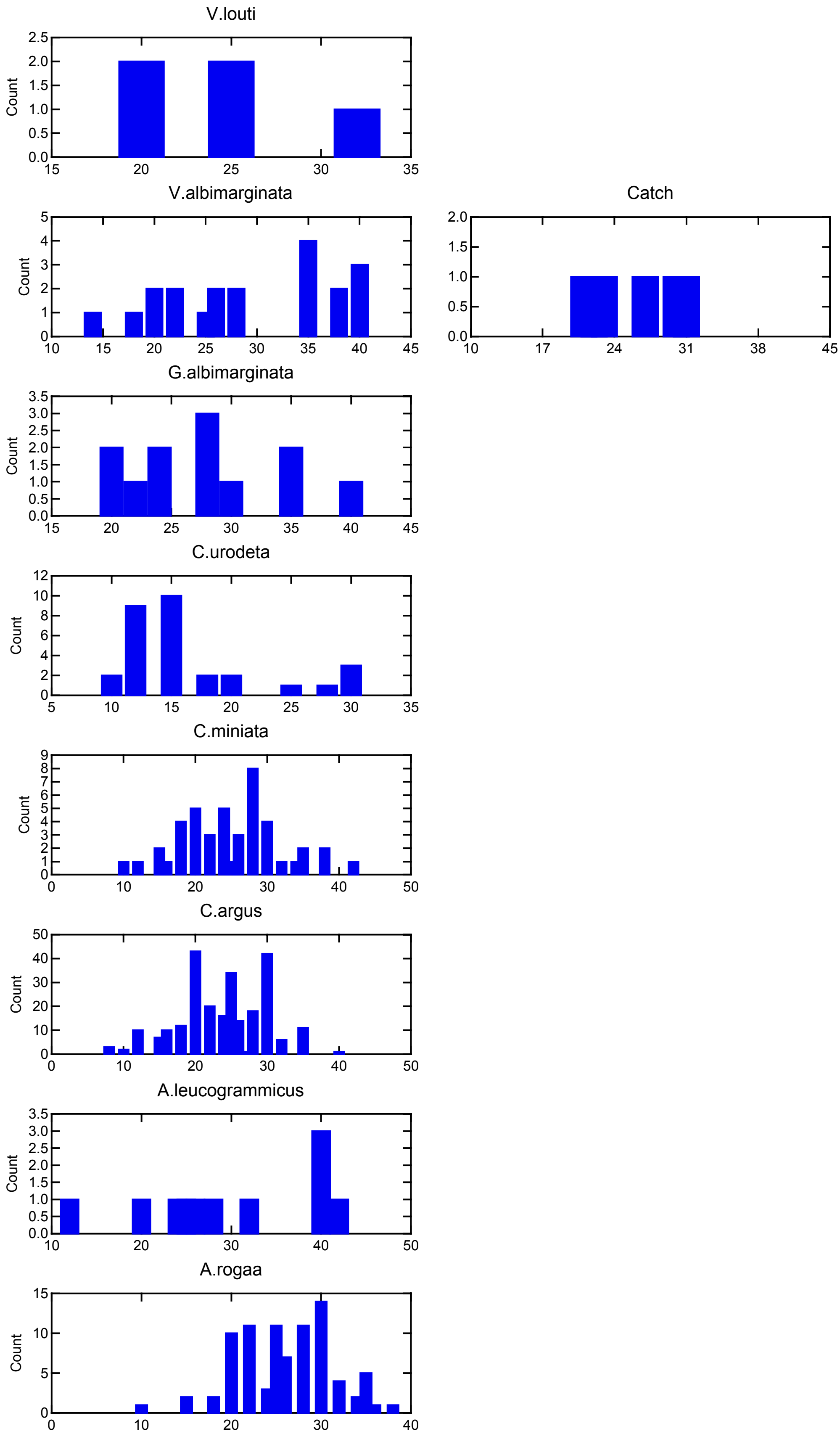
A.virescens
Count
Catch
Count
A.furca
Count


L.rivulatus
Count
20 15 10 5 0
30 35 40 45 50 55 60 65
L.monostigma
Count
12 10 8 6 4 2 0
20 25 30 35 40 45
L.lutjanus
Count
3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0
15 16 17 18 19 20 21 22 23 24 25
L.kasmira
Count
120 100 80 60 40 20 0
5 10 15 20 25
L.gibbus
Count
500 400 300 200 100 0
0 10 20 30 40 50
Catch
Count
7 6 5 4 3 2 1 0
0 10 20 30 40 50
L.fulvus
Count
5 4 3 2 1 0
19 20 21 22 23 24 25
L.fulviflamma
Count
12 10 8 6 4 2 0
10 15 20 25 30 35 40 45
L.decussatus
Count
300 200 100 0
5 10 15 20 25 30 35
Catch
Count
12 10 8 6 4 2 0
5 15 25 35
L.bohar
Count
200 150 100 50 0
0 10 20 30 40 50 60 70 80
Catch
Count
5 4 3 2 1 0
0 20 40 60 80



V.louti
Count
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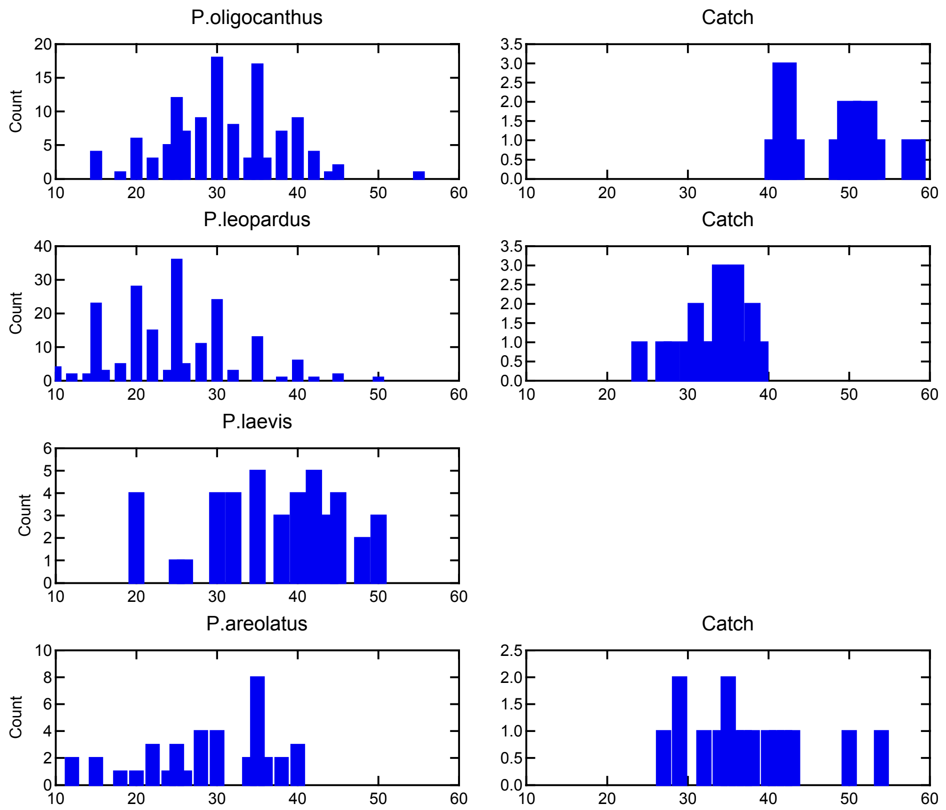
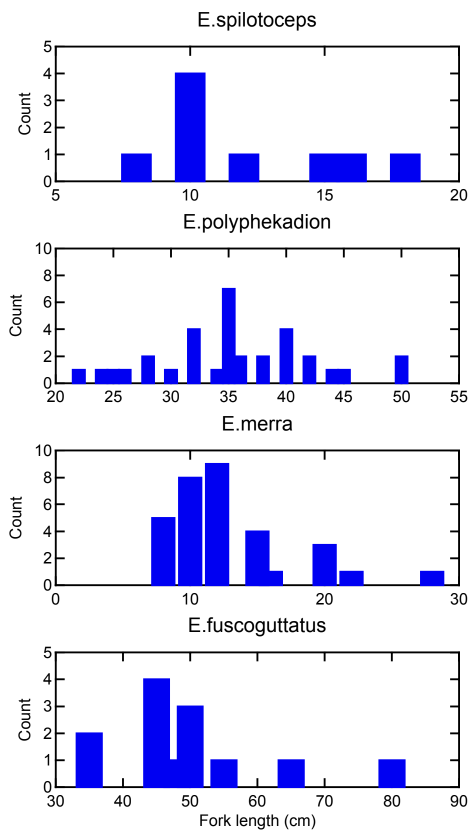
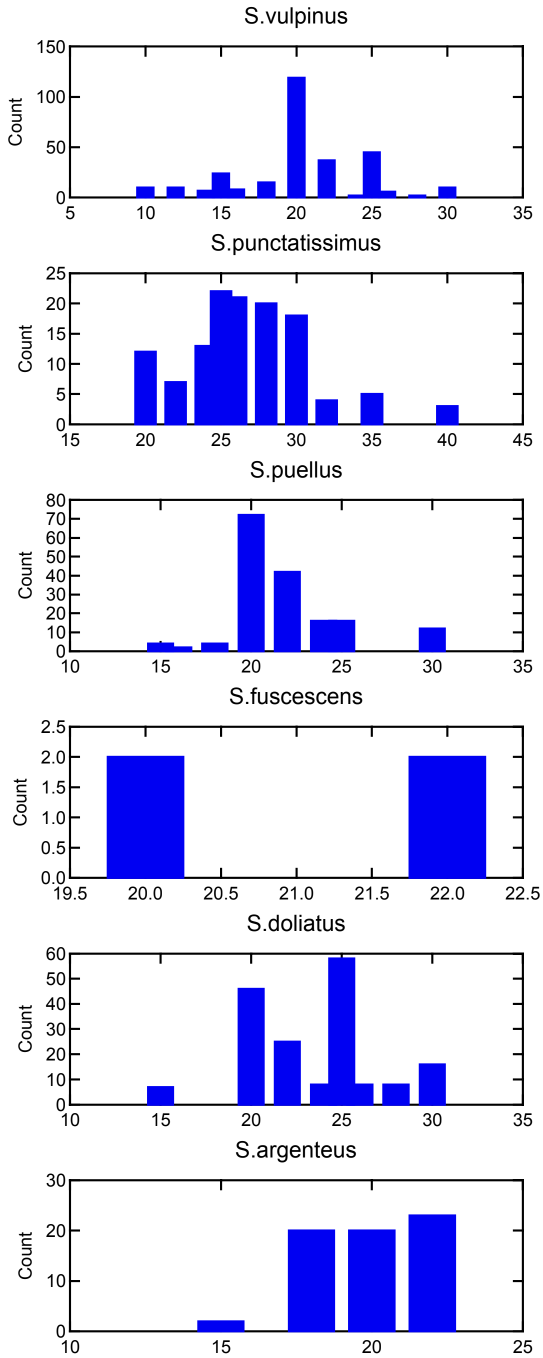
0.5
1.0
1.5
2.0
2.5
15
20
25
30
35
V.albimarginata
Count
0
1
2
3
4
5
10
15
20
25
30
35
40
45
Catch
0.0
0.5
1.0
1.5
2.0
10
17
24
31
38
45
G.albimarginata
Count
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
15
20
25
30
35
40
45
C.urodeta
Count
0
2
4
6
8
10
12
5
10
15
20
25
30
35
C.miniata
Count
0
1
2
3
4
5
6
7
8
9
0
10
20
30
40
50
C.argus
Count
0
10
20
30
40
50
0
10
20
30
40
50
A.leucogrammicus
Count
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
10
20
30
40
50
A.rogaa
Count
0
5
10
15
0
10
20
30
40


P.oligocanthus
Catch
P.leopardus
Catch
P.laevis
P.areolatus
Catch
Count


E.spilotoceps
E.polyphekadion
Catch
E.merra
E.fuscoguttatus
Count
Fork length (cm)


S.vulpinus
Count
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5 10 15 20 25 30 35
S.punctatissimus
Count
0 5 10 15 20 25
15 20 25 30 35 40 45
S.puellus
Count
0 10 20 30 40 50 60 70 80
10 15 20 25 30 35
S.fuscescens
Count
0.0 0.5 1.0 1.5 2.0 2.5
19.5 20.0 20.5 21.0 21.5 22.0 22.5
S.doliatus
Count
0 10 20 30 40 50 60
10 15 20 25 30 35
S.argenteus
Count
0 10 20 30
10 15 20 25

APPENDIX O

Standing stock estimates and 95% confidence intervals by shoal and for all shoals in the study area for commercial finfish.

SHOAL	Sites nh	Area (ha)	Total W_h	HOLO_H Y_h	HOLO_H s^2_h	Total Y_{st}	Total $v(Y_{st})$	Total abundance	95% CI (%)
Ashmore Rf	40	30382.7	0.28	2.56	44.28	0.71	0.09	77705	83.14
Browse Is	5	541.9	0.00	0.00	0.00	0.00	0.00	0	#DIV/0!
Cartier Is	3	867.4	0.01	1.71	8.72	0.01	0.00	1479	318.24
Johnson Bk total	21	1526.5	0.01	0.00	0.00	0.00	0.00	0	#DIV/0!
Scott Nth Rf	6	3309.8	0.03	1.71	17.44	0.05	0.00	5643	244.69
Scott Sth Rf	42	28895.5	0.26	13.80	2234.35	3.64	3.71	398833	106.64
Shoal A	8	7585.2	0.07	0.00	0.00	0.00	0.00	0	#DIV/0!
Shoal B	27	22516.6	0.21	2.84	109.35	0.58	0.17	63986	145.31
Shoal C	6	5458.4	0.05	0.00	0.00	0.00	0.00	0	#DIV/0!
Woodbine Bk total	14	8348.4	0.08	0.00	0.00	0.00	0.00	0	#DIV/0!
Total shoal area	172	109432.3				5.00	3.97	547646	78.58

APPENDIX P

Standing stock estimates and 95% confidence intervals by shoal and for all shoals in the study area for non-commercial finfish.

SHOAL	Sites nh	Area (ha)	Total W_h	HOLO_H Y_h	HOLO_H s^2_h	Total Y_{st}	Total $v(Y_{st})$	Total abundance	95% CI (%)
Ashmore Rf	40	30382.7	0.28	25.96	5313.85	7.21	10.24	788706	89.74
Browse Is	5	541.9	0.00	218.93	71878.13	1.08	0.35	118633	140.78
Cartier Is	3	867.4	0.01	528.56	759632.22	4.19	15.91	458451	302.98
Johnson Bk total	21	1526.5	0.01	73.32	24707.67	1.02	0.23	111920	97.29
Scott Nth Rf	6	3309.8	0.03	31.54	1720.73	0.95	0.26	104400	131.37
Scott Sth Rf	42	28895.5	0.26	95.36	65600.29	25.18	108.90	2755467	83.64
Shoal A	8	7585.2	0.07	63.94	14764.05	4.43	8.87	484990	154.94
Shoal B	27	22516.6	0.21	86.96	57790.55	17.89	90.62	1957965	109.17
Shoal C	6	5458.4	0.05	0.85	4.36	0.04	0.00	4653	244.69
Woodbine Bk total	14	8348.4	0.08	5.48	227.28	0.42	0.09	45753	157.68
Total shoal area	172	109432.3				62.42	235.47	6830939	48.52

APPENDIX Q

Size frequencies–length (mm) for all fish species caught and measured in the study area.

Species	*n*	Min (g)	Max (g)	Range	Mean (g)	Std.Error
Acanthurus bariene	2	240	240		240	
Acanthurus dussumieri	1	460	460		460	
Acanthurus olivaceus	1	200	200		200	
Naso annulatus	1	260	260		260	
Naso brachycentron	1	210	210		210	
Naso brevirostris	1	300	300		300	
Balistapus undulatus	2	210	230	20	220	10.00
Balistoides viridescens	2	470	530	60	500	30.00
Odonus niger	1	130	130		130	
Sufflamen fraenatus	1	290	290		290	
Tylosurus crocodilus	4	650	950	300	825	75.00
Carangoides fulvoguttatus	2	360	380	20	370	10.00
Caranx ignobilis	3	800	1000	200	906.67	58.12
Caranx lugubris	6	330	520	190	478.33	30.27
Caranx melampygus	4	500	620	120	560	29.44
Carangoides plagiotaenia	1	310	310		310	
Caranx sexfasciatus	7	460	560	100	504.29	15.71
Elegatis bipinnulata	5	520	650	130	596	21.35
Scomberoides lysan	1	500	500		500	
Carcharinhus albimarginatus	1	790	790		790	
Carcharinhus amblyrhynchos	24	560	1270	710	750.83	27.09
Nebrius ferrugineus	1	570	570		570	
Plectorhynchus chaetodontoides	1	340	340		340	
Triaenodon obesus	11	730	1200	470	903.64	40.32
Sargocentron sp	1	260	260		260	
Sargocentron rubrum	1	315	315		315	
Cheilinus undulatus	2	500	600	100	550	50.00
Halichoeres chrysus	1	210	210		210	
Gymnocranius grandoculus	1	360	360		360	
Lethrinus atkinsoni	27	160	280	120	208.89	5.29
Lethrinus erythropterus	6	230	500	270	313.33	50.18
Lethrinus sp	4	290	380	90	325	20.21
Lethrinus harak	12	190	300	110	212.5	9.14
Lethrinus miniatus	4	230	470	240	302.5	56.48
Lethrinus obsoletus	7	220	315	95	265	11.55
Lethrinus olivaceus	5	450	680	230	534	45.34
Lethrinus rubrioperculatus	14	210	350	140	296.43	10.93
Lethrinus xanthochilus	1	390	390		390	
Aprion virescens	18	400	760	360	537.78	19.98
Lutjanus bohar	12	240	600	360	458.33	29.44
Lutjanus decussatus	27	200	260	60	232.22	2.89
Lutjanus gibbus	33	240	380	140	301.67	6.23
Lutjanus kasmira	1	200	200		200	
Lutjanus monostigma	1	300	300		300	

APPENDIX Q (cont.)

Species	*n*	Min (g)	Max (g)	Range	Mean (g)	Std.Error
Pempheris analis	1	210	210		210	
Cetoscarus bicolor	5	375	460	85	419	18.47
Hipposcarus longiceps	1	360	360		360	
Scarus frenatus	1	160	160		160	
Scarus microrhinus	4	370	510	140	422.50	30.92
Scarus niger	1	260	260		260	
Scarus oviceps	3	200	330	130	280	40.42
Scarus sordidus	1	187	187		187	
Scarus spinus	1	196	196		196	
Euthynnus affinis	2	570	600	30	585	15.00
Grammatorcynus bilineatus	1	510	510		510	
Gymnosarda unicolor	14	550	1070	520	790	44.40
Scomberomorus commerson	4	600	1150	550	845	136.41
Anyperodon leucogrammicus	1	370	370		370	
Cephalopholis argus	1	300	300		300	
Cephalopholis miniata	4	270	320	50	292.50	11.09
Cephalopholis spiloparaea	1	210	210		210	
Epinephelus fasciatus	2	225	280	55	252.50	27.50
Epinephelus fuscoguttatus	1	410	410		410	
Epinephelus maculatus	2	260	380	120	320	60.00
Epinephelus merra	1	170	170		170	
Epinephelus ongus	1	230	230		230	
Epinephelus polyphekadion	26	200	470	270	340.96	13.70
Plectropomus areolatus	16	270	540	270	376.25	18.37
Plectropomus laevis	2	540	600	60	570	30.00
Plectropomus leopardus	22	240	620	380	359.55	19.37
Plectropomus oligocanthus	12	410	580	170	478.33	16.23
Variola albimarginata	6	210	310	100	256.67	17.45
Sphyraena barracuda	8	600	1100	500	753.75	62.65
Sphyraena bleekeri	1	560	560		560	
Sphyraena nautipinnis	1	400	400		400	
Sphyraena putnamiae	3	350	1000	650	673.33	187.65

APPENDIX R

Stratified sampling techniques. In stratified sampling the population of N units is divided into subpopulations of N1, N2, N3,... NL units respectively. If each stratum is homogenous in that the measurements vary little from one unit to another, a precise estimate of any stratum mean can be obtained in that stratum. These estimates can then be combined to give a precise estimate for the whole population. The notation of terms used for stratified sampling follows below:

N	total number of possible sampling units in the study area;
N_h	total number of possible sampling units in stratum *h;*
n_h	actual number of samples taken in stratum *h;*
y_{hi}	value obtained from *i*th unit in stratum *h;*
$W_h = \frac{N_h}{N}$	stratum *h* weight;
$f_h = \frac{n_h}{N_h}$	sampling fraction in stratum *h;*
$\bar{y}_h = \frac{\sum_{i=1}^{n_h} y_{hi}}{n_h}$	stratum *h* mean;
$\bar{y}_{st} = \sum_{h=1}^{L} W_h \bar{y}_h$	stratified mean over all strata;
s_h^2	sample estimate of stratum *h* variance;
$v(\bar{y}_{st}) = \sum_{h=1}^{L}\left(\frac{W_h^2 s_h^2}{n_h}\right) - \sum_{h=1}^{L}\left(\frac{W_h s_h^2}{N}\right)$	estimated strata variance.

Samples were allocated randomly to reefs and strata. For future sampling, samples will be allocated to strata in proportion to variance and strata size. The estimated sample size required for fixed variance $v(\bar{y}_{st})$ is:

$$n = \frac{n_o}{\left(1+\frac{n_o}{N}\right)}$$

where $n_o = \frac{N}{v(\bar{y}_{st})} \sum_{h=1}^{L} N_h s_h^2$