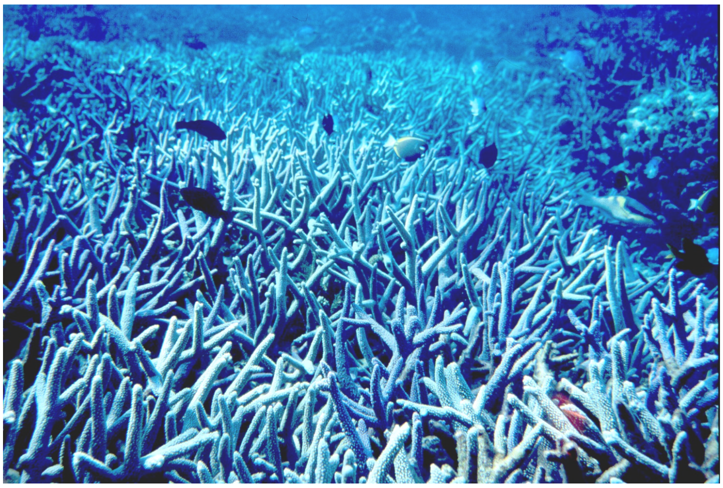

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SURVEY AND STOCK SIZE ESTIMATES OF THE SHALLOW REEF (0-15 M DEEP) AND SHOAL AREA (15-50 M DEEP) MARINE RESOURCES AND HABITAT MAPPING WITHIN THE TIMOR SEA MOU74 BOX

VOLUME 2: HABITAT MAPPING AND CORAL DIEBACK

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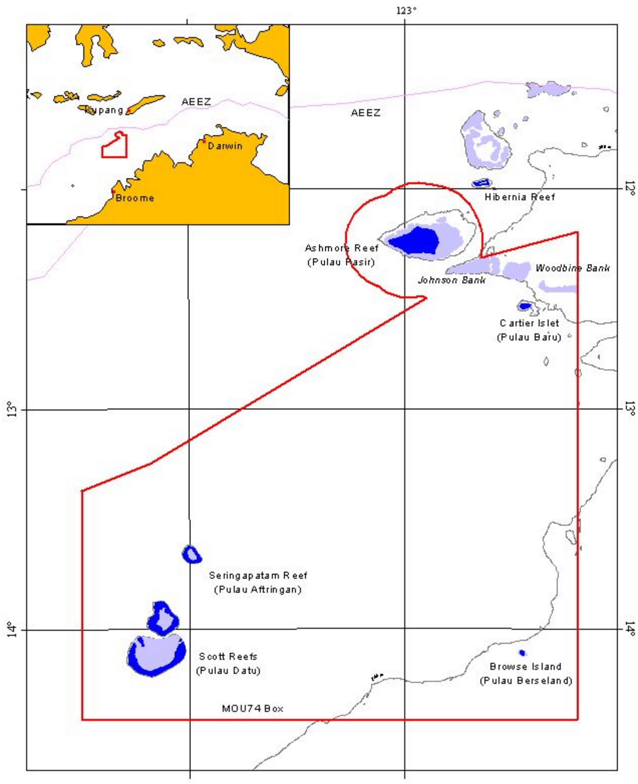

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July 1999

This report is part of a series produced by the CSIRO Division of Marine Research from a survey of the shallow reef and shoal fishery resources and habitat mapping of the MOU74 Box off northwestern Australia. The series also includes; Volume 1: Stock estimates and stock status; 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.

The authors wish to thank the captain and crew of the "MV James Kirby" for their dedication and assistance, and Des Pike (EA) and Tom Morris (WA Fisheries) for helpful information and encouragement.

CONTENTS

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.

In September and October 1998, CSIRO Division of Marine Research carried out a survey of 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. The purpose of the survey was to assess the status of the reef resources in the area, and the environment that supports them. Fieldwork for the survey was successfully completed on 10 October 1998.

The reefs in the study area show a wide variation in size and structure. The four largest reefs, Scott North Reef, Scott South Reef, Seringapatam Reef and Ashmore Reef make up over 95% of the shallow reef area in the study area. Ashmore Reef differed markedly from the Scott and Seringapatam Reefs. Generally, Ashmore Reef had more sandy habitats, and lacked the extensive shallow reef crest habitat of the southern reefs. It also lacked the deep lagoon and associated lagoon reef edge found on Scott and Seringapatam Reefs. However, several habitats were common to these larger reefs, including the reef flat, and front-reef and back-reef edges.

The shoals in the northern part of the study area are mostly made up of *Halimeda* sand with small areas of reef mainly on the southern margins. In contrast, the large shoal (or deep lagoon) associated with Scott Reef South had a high cover of hard substrate and live coral.

There has recently been a substantial mortality of hard corals on some of the shallow reefs in the study area, with up to 76% mortality on the large southern reefs, Scott and Seringapatam. In contrast, Ashmore Reef, and Browse and Cartier Islands had low or no coral mortality (0–5%). Hibernia Reef was intermediate (15%). We estimate that there were 2290 ha (+/- 14%, 95% CI) of live hard coral , and 2570 ha (+/- 13.5%, 95% CI) of recently dead coral on the shallow reefs in the study area (down to 15 m depth); an overall mortality rate of almost 53%.

The level of mortality was not the same for all corals in the study area: over 83% of branching coral (mostly *Acropora*), but only 22% of massive corals (mostly *Porites*) had died. The highest mortality rates were on the lagoon or protected reef edges; areas where branching *Acropora* corals flourish.

The effect of the coral mortality on the ecology of the reef is not known. However, it is unlikely to have a significant direct impact on commercial species of holothurians, or trochus, which do not rely on coral for food or shelter. One exception may be *Holothuria edulis*, a holothurian that is often associated with *Acropora* fields.

The coral most likely died during April/May 1998 coinciding with widespread coral bleaching and mortality in the Indo-Pacific region caused by above-average sea surface temperatures late last summer. The different mortality rates between reefs is probably due to differences in

maximum daily temperatures in the waters surrounding the two reefs during March 1998. The southern reefs including the Scott Reefs and Seringapatam Reef, were in a sea surface temperature hotspot that was hotter and lasted longer than the northern reefs.

In the shoals were large areas of what appear to be live foliose corals, probably dominated by *Montipora*, in the large (289 km^2) shoal (or deep lagoon, ~50 m deep) associated with Scott Reef South. We mapped the extent of this habitat with video and acoustics, and estimate that there is over 5000 ha of live coral in the area, with little evidence of mortality. This is over twice the amount of live coral estimated for the shallow reefs in the entire study area.

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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).

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**	

1.1 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. 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)

1.2 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 Marine Reserves (Ashmore Reef and Cartier Islands) for protecting the populations of the main target species of holothurians (beche-de-mer), trochus, fin-fish and reef shark.

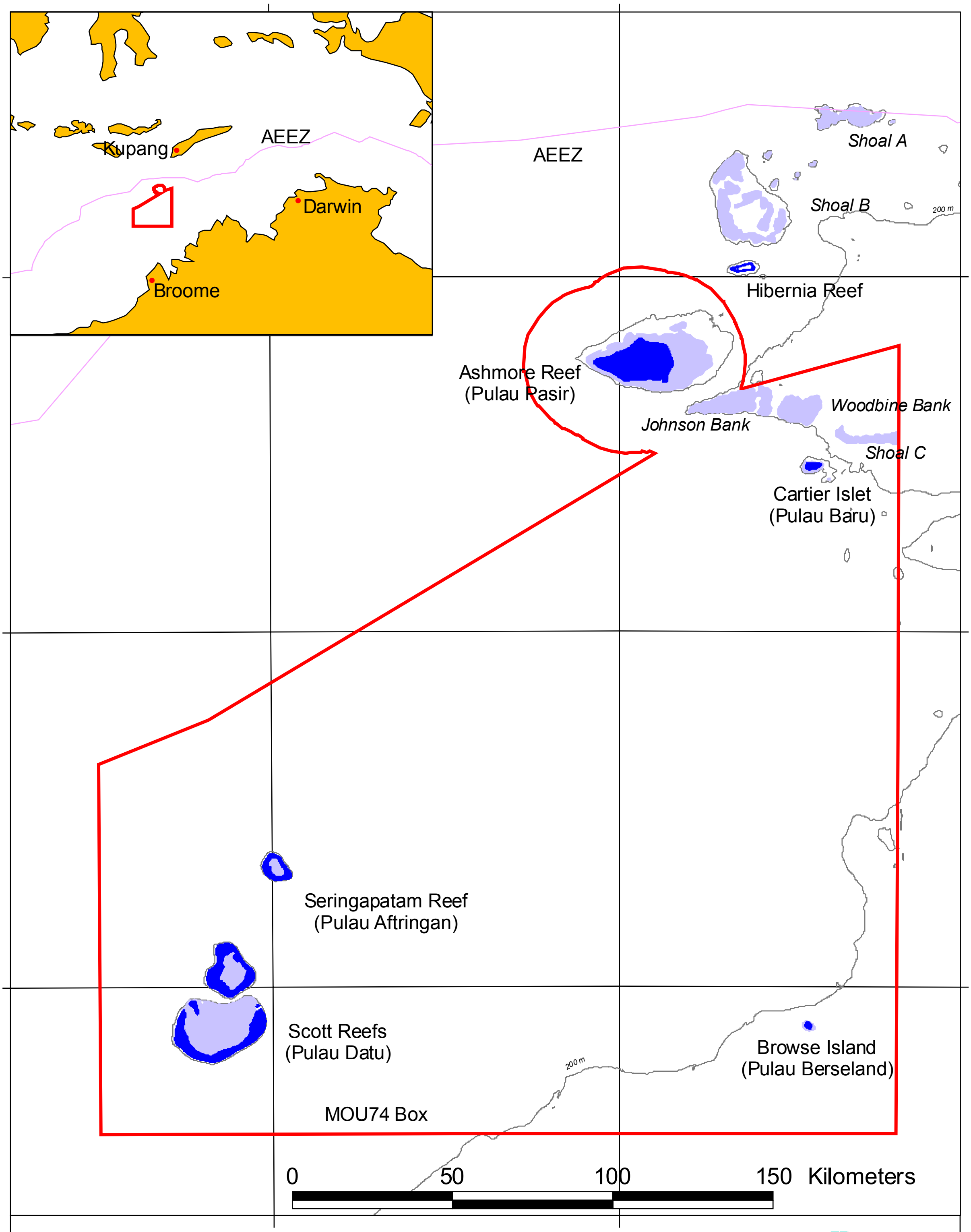
6. Provide information on the distribution and density of other conspicuous megafauna and quantifiable resources such as giant clams and spiny rock lobsters. This would include stock estimates where possible.

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 results of analysis relevant to objectives 7 and 8. The results of analysis relevant to objectives 1–6 are contained within Volume 1: Stock estimates and stock status (Skewes *et al.*, 1999). An additional volume, on the seabirds of East Island, Ashmore Reef, was also produced from data collected during fieldwork for the project (Milton, 1999).

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.



Shallow reef (0-15 m)
Shoal (15-50 m)

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Date surveyed: Sepember 1998

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2. METHODS

2.1 Sample design

2.1.1 Shallow reefs (0–15 m deep)

Initially, high-resolution Landsat satellite images 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 sampling density 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.The density of sampling was calculated to provide useful stock-size estimates (ie with 95% CI of ± 35%), and enable accurate habitat mapping (Long *et al.*, 1997*a*; Skewes *et al.*, 1998).

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.

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, and was a similar sampling intensity to previous surveys of Torres Strait and on the northern Great Barrier Reef (Long *et al.*, 1997*b*; Skewes *et al.*, 1996).

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.

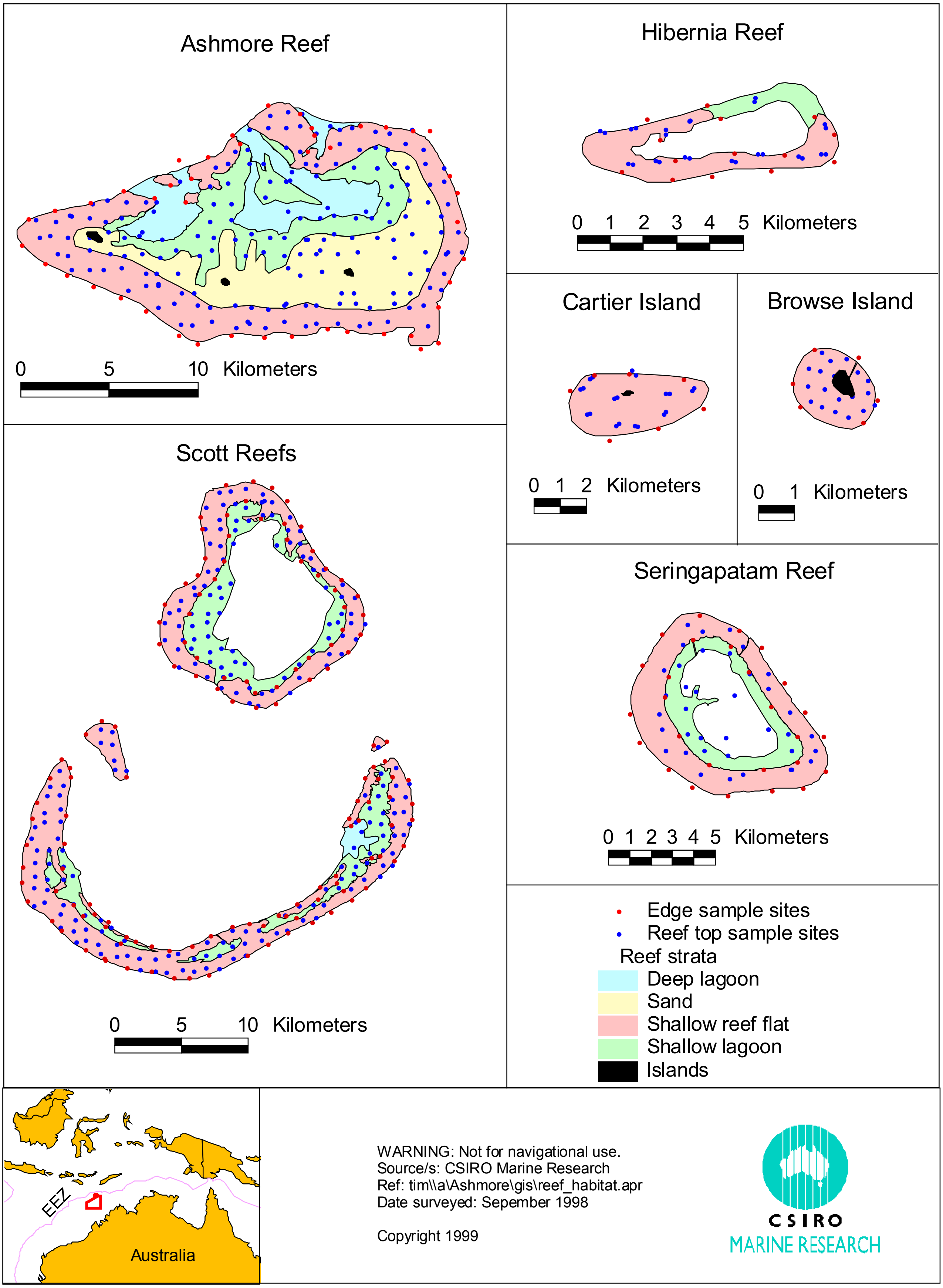
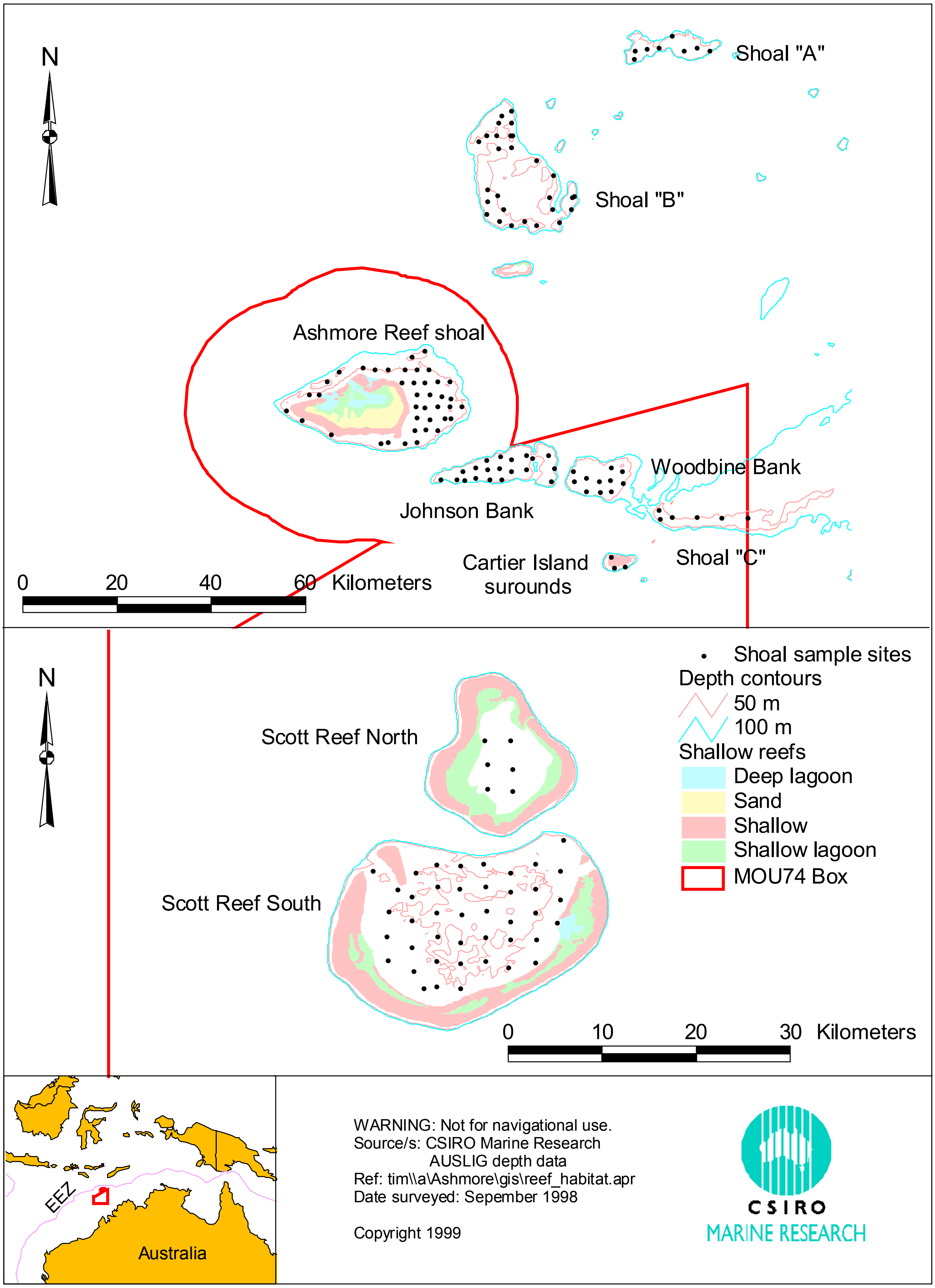


Figure 3. Shoal areas (<50 m deep) of the MOU74 Box and areas north and video transect sample sites.



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.

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 at about 20 sites. 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.*, 1997*b*). 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.

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.

2.3 Data analysis

2.3.1 Satellite data habitat mapping

Two satellite images, one covering the northern reefs and the other the southern reefs, were rectified by using reef-edge location data collected during the survey as control points in the image analysis program ER Mapper. An isodata clustering algorithm was used to group pixels in bands 2-4 into 9 spectral classes. The field data was then appended onto the classified image and the discriminating capacity of the satellite image classes was tested by discriminant function analysis and ANOVA. The results of the discriminant function analysis and the mean values for each image class were then used to characterise and label the satellite classes. Satellite classes that did not discriminate well (ie had high error rates, >50%) were merged until well-defined classes were produced. Maps of the final image with several habitat types were then produced.

2.3.2 Acoustic habitat mapping

High-density acoustic echogram data were collected from the seabed in the Scott Reef South shoal area (deep lagoon, ~50 m deep) for analysis as a habitat indicator. Acoustic echogram data were recorded over the entire study area with the Simrad EY500 portable scientific echosounder. The EY500 transmits a pulse of high frequency sound that is reflected back by the seabed targets including 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 with GPS.

The CSIRO developed software ECHO (Waring et.al., 1984), was used to process the digitised acoustic echogram data. 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). The seabed layer was automatically defined from the EY500 bottom pick and checked for quality. Bad data were edited out of the echogram.

Two indices — one equivalent to seabed acoustic hardness and one to roughness — were calculated from the echogram data. Once calibrated over known seabed type and with appropriate “ground truthing”, the indices provided continuous classification of basic physical seabed habitat types.

A false-colour acoustic image of the study area was produced. This was done by thin-moving-plate-spline interpolation of the roughness and hardness values to a 100 m grid; colouring increases roughness values in blue (min = 0, max = 255) and hardness values in red (min = 0, max = 255) and decreasing softness/smoothness in green (ie. min roughness & hardness = 255 blue, max roughness & hardness = 0 blue) and displaying the mixed colour result in 100 m scale cells.

The acoustic hardness and roughness values were then classified, based on benthic code data, from the survey video data, using a discriminant function analysis that maximally separated the substrate types based on roughness and hardness values. To predict substratum type from echo signals the acoustic data were first merged by location with the coded video transect data. This matched up areas where both acoustic and video data were available. The discriminant function analysis, which was based on a 5 point classification system, indicated that the acoustic data were able to discriminate satisfactorily among five substrate types. The discriminant function was then applied to the remaining unclassified acoustic hardness and roughness data to classify the substrate in areas where we had acoustic data only.

3. RESULTS

3.1 Bathymetry

A digital elevation model (DEM) of the MOU74 Box and surrounding area is shown in Fig. 4. It was constructed from depth data collected during the survey, and from data supplied by the Australian Geological Survey Organisation (AGSO). The reefs and shoals of the MOU74 Box are all on or close to the edge of the shallow Australian continental shelf (the Sahul Shelf), and form part of a chain of reefs and shoals that stretch for another 400 km to the northeast of Ashmore Reef. Most shallow features in the area are generally deeper than 25 m; Hibernia Reef is the northernmost emergent reef in the series (Fig. 5, 6). The islands of Timor and Sumba, which form part of the Indonesian Archapelago, are separated by a deep channel, the Timor Trough, which is mostly over two kilometers deep (Fig. 4).

The Scott Reefs and Seringapatam Reef differ from this pattern in that they are somewhat removed from the shallow continental shelf edge and are more in the form of true “shelf atolls” (Fig 4) (Berry and Marsh, 1986). Scott Reef and Seringapatam are 65 km and 100 km outside the 200m depth contour line of the Sahul Shelf respectively. Their bases stand in about 600 m of water (Fig. 7) compared to Ashmore Reef which stands in about 150 m (Fig. 6).

3.2 Marine habitats

3.2.1 Shallow reefs (0–15 m deep)

Substrate types

The substrate of the reef tops of the shallow reefs shows some variability throughout the study area (Fig. 8, Appendix A). Ashmore Reef was the most sandy of the shallow reefs (70% sand cover) while Hibernia Reef was the least sandy (16% sand cover). The three large southern reefs (Scott and Seringapatam) had similar substrate proportions (34%–44% sand cover).

On the reef edges (Fig. 9, Appendix B), there were also differences between reefs in substrate cover. Ashmore Reef, Cartier Island and Browse Island had high cover of hard substrate such as pavement (18%–33% cover) or consolidated rubble 27% - 32% cover). For the three southern reefs and Hibernia Reef, dead coral was a significant proportion of the substrate (15%–36% cover). These differences between reefs were mostly caused by different proportions of lagoon reef edge on each of the reefs (Appendix B)

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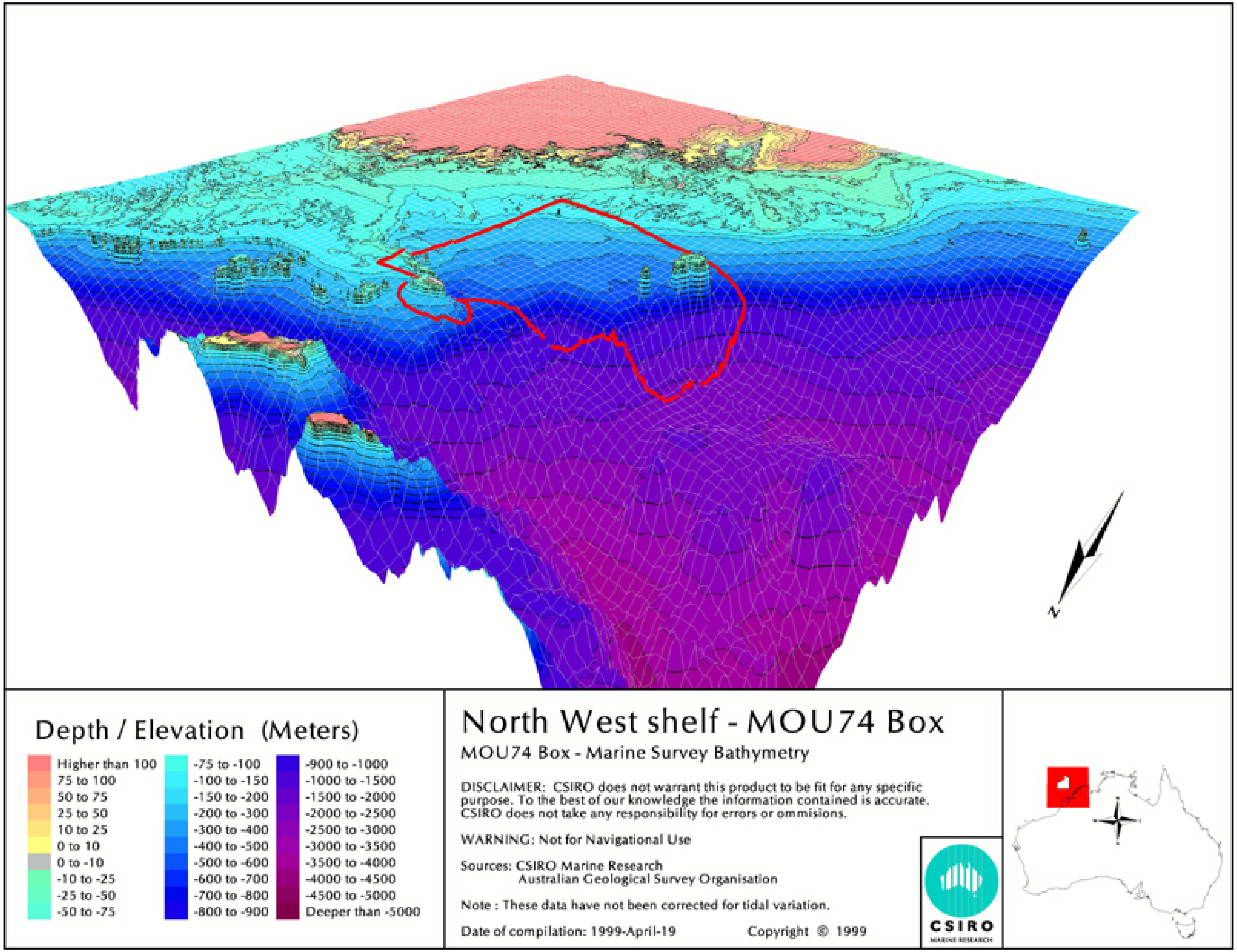


Figure 4. DEM of the MOU74 Box and surrounds Including the Australian mainland and the southern Indonesian Islands of Timor and Sumba (aspect; southeast).

Figure 5. DEM of the northern section of the study area showing the northern shoals (aspect; southeast).

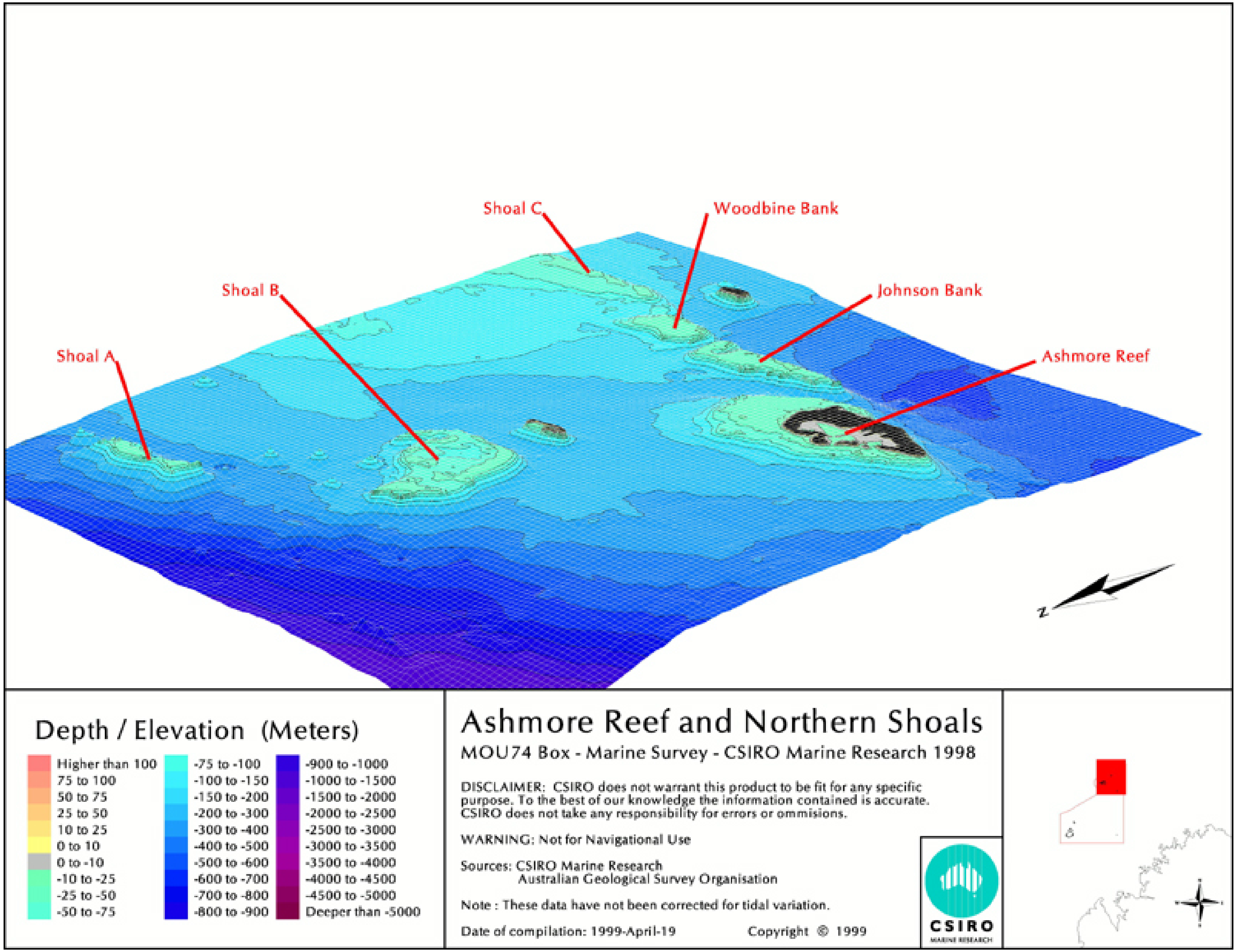


Figure 6. DEM of a northern section of the study area showing the northern shallow reefs (aspect; southeast).

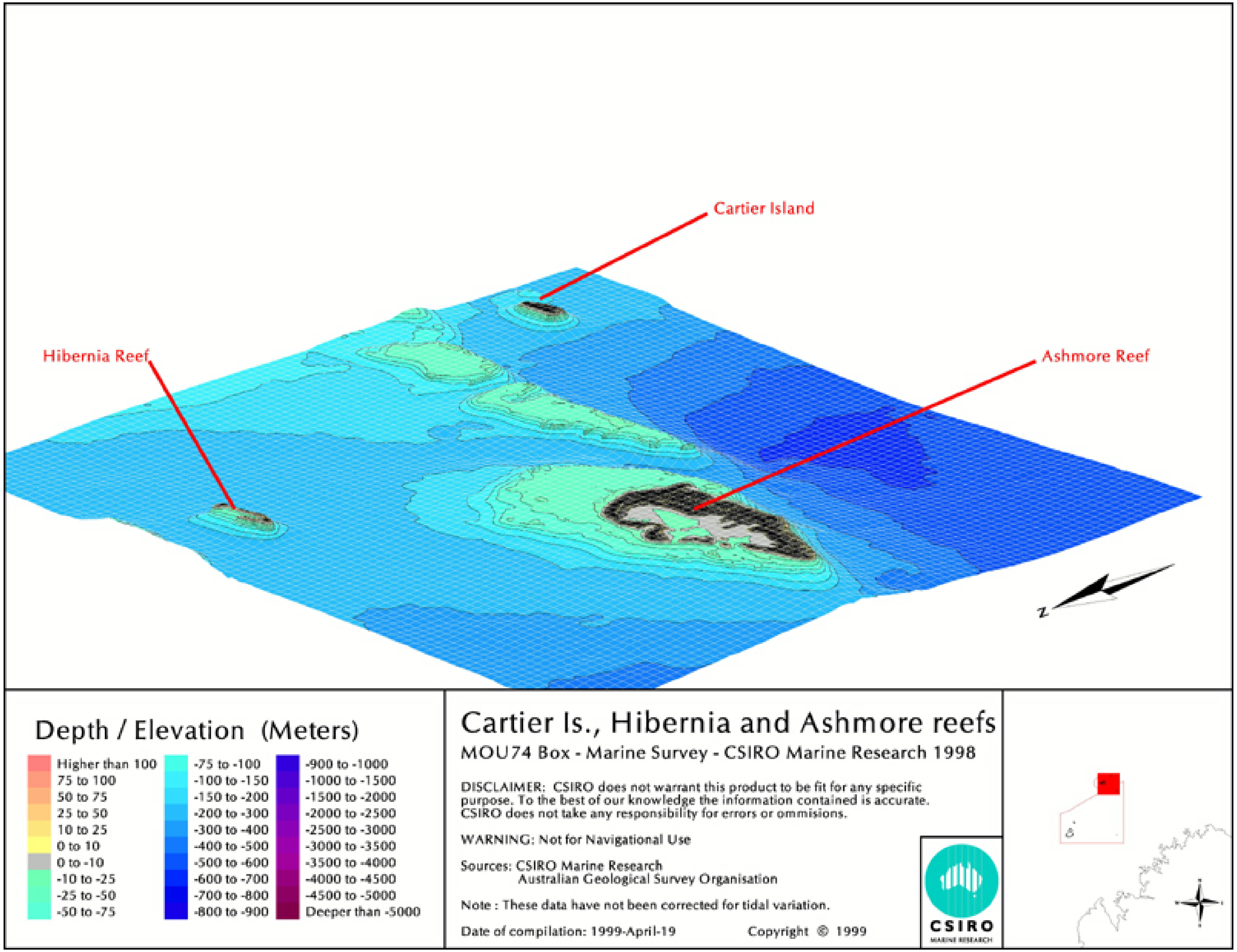
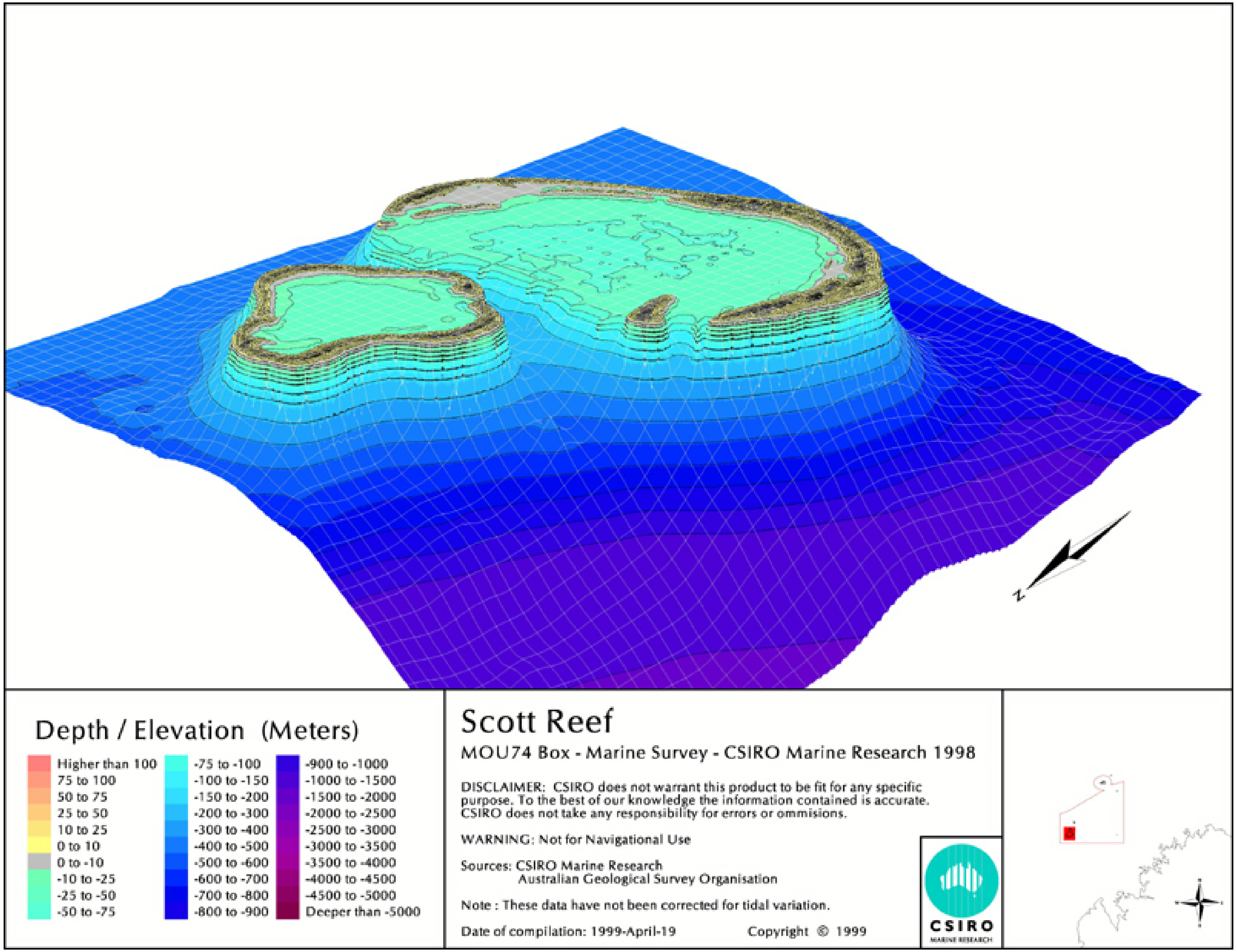


Figure 7. DEM of a southern section of the study area showing the Scott Reefs (aspect; southeast).



Seagrass

Ashmore Reef had the highest average cover of seagrass in the study area (2% cover), and over 80% of all seagrass in the study area (Fig. 10, Appendix D). Seagrass generally occurred on the shallow reef flats (Appendix A).

The dominant species was *Thalassia hemprichii*, a common seagrass on shallow reef flats throughout the Indo-west Pacific. It is a species that tolerates to high water temperature and occasional exposure during low tides. Overall, the species composition and cover were very similar to midshelf reefs on the northern GBR and Torres Strait (Long *et al.*, 1997*a*).

Algae

The highest average cover of algae occurred on Hibernia Reef (38.5% cover)(Fig. 11, Appendix E). In contrast, it was low on Ashmore Reef (14.5% cover), which has a large sandy stratum (Appendix A).

Turf algae, crustose coraline algae, and a stunted form of the green algae *Cladophora* spp. were the most common algae. They are commonly found on dead coral, in high-energy zones and on shallow reef flats respectively. *Halimeda* was also common, especially on the northern reefs.

Soft corals

Hibernia Reef had the highest average cover of soft corals (Fig. 12, Appendix F) with the southern large reefs (Scott and Seringapatam Reefs) having the lowest average cover. Ashmore Reef had 64% of the total soft corals on the shallow reefs in the study area.

On most reefs, *Sarcophyton* spp. were dominant. However, they were less dominant in the southern reefs (Scott and Seringapatam Reefs), which have experienced high mortalities of coral recently. *Sarcophyton* species are highly susceptible to bleaching and mortality (Salih *et al.* 1998; next section).

Coral

There was a wide variation in average cover of live hard corals and the relative cover of the different growth forms on the shallow reefs in the study area (Fig. 13, Appendix G). Hibernia Reef had the highest at 13%. Ashmore and Scott Reef North had the lowest with about 3%. The Ashmore Reef sandy stratum had very low cover of live coral (0.1% cover) (Appendix A). The highest live coral cover was in the Hibernia Reef shallow lagoon, 31%. Apart from these two exceptions, coral cover was fairly consistent for reef strata across the study area.

Ashmore Reef had the highest total area of live coral of any reef in the study area (31% of all live coral; Appendix G) followed closely by Scott Reef South (27%).

Massive corals dominated the live coral cover at Scott Reefs, while branching corals dominated at Hibernia Reef (Fig. 13, Appendix G).

Figure 8. Shallow reefs of the MOU74 Box, and Hibernia Reef showing substrate composition for the reef top. Field data collected in September 1998.

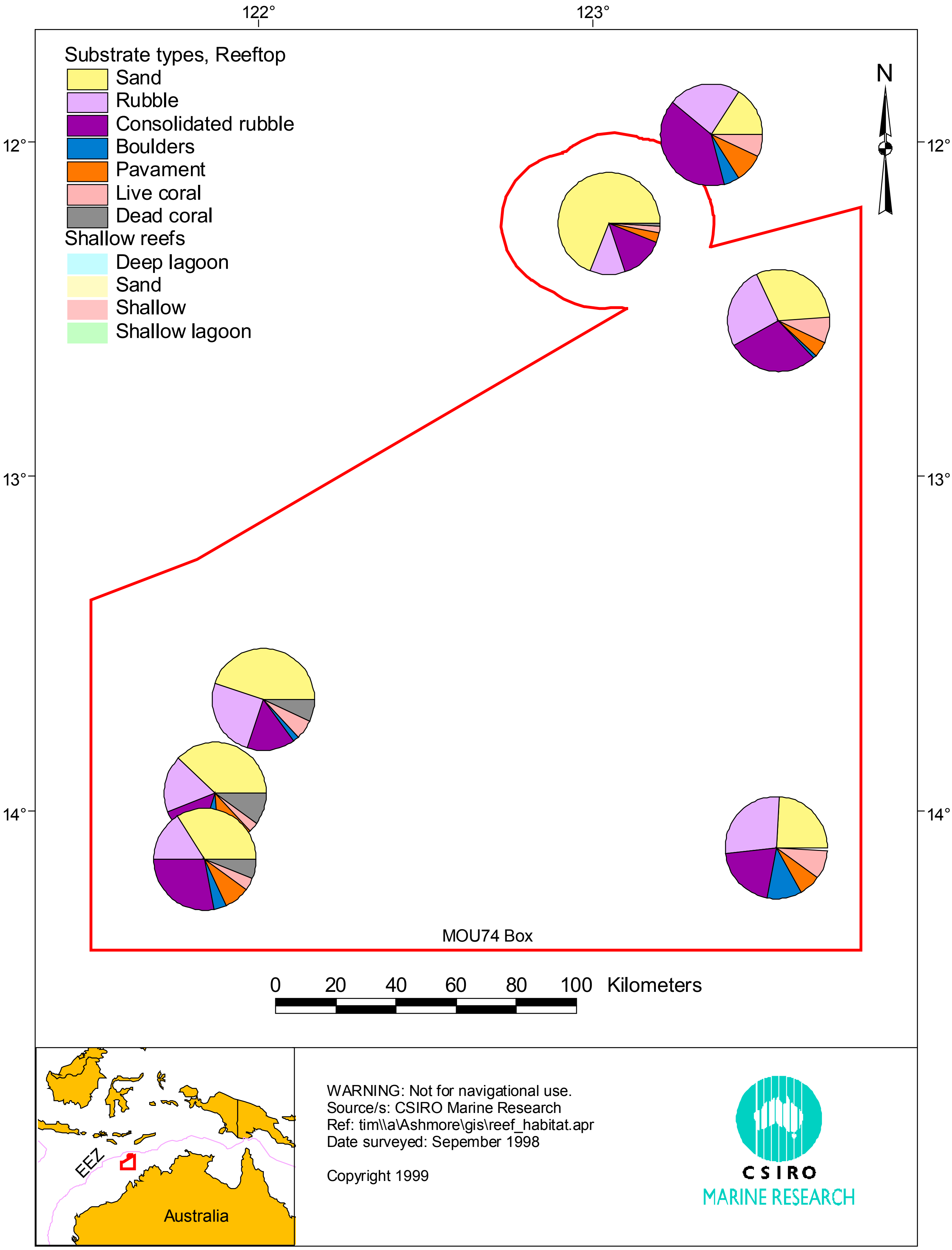


Figure 9. Shallow reefs of the MOU74 Box, and Hibernia Reef showing substrate composition for the reef edge (0-15 m deep). Field data collected in September 1998.

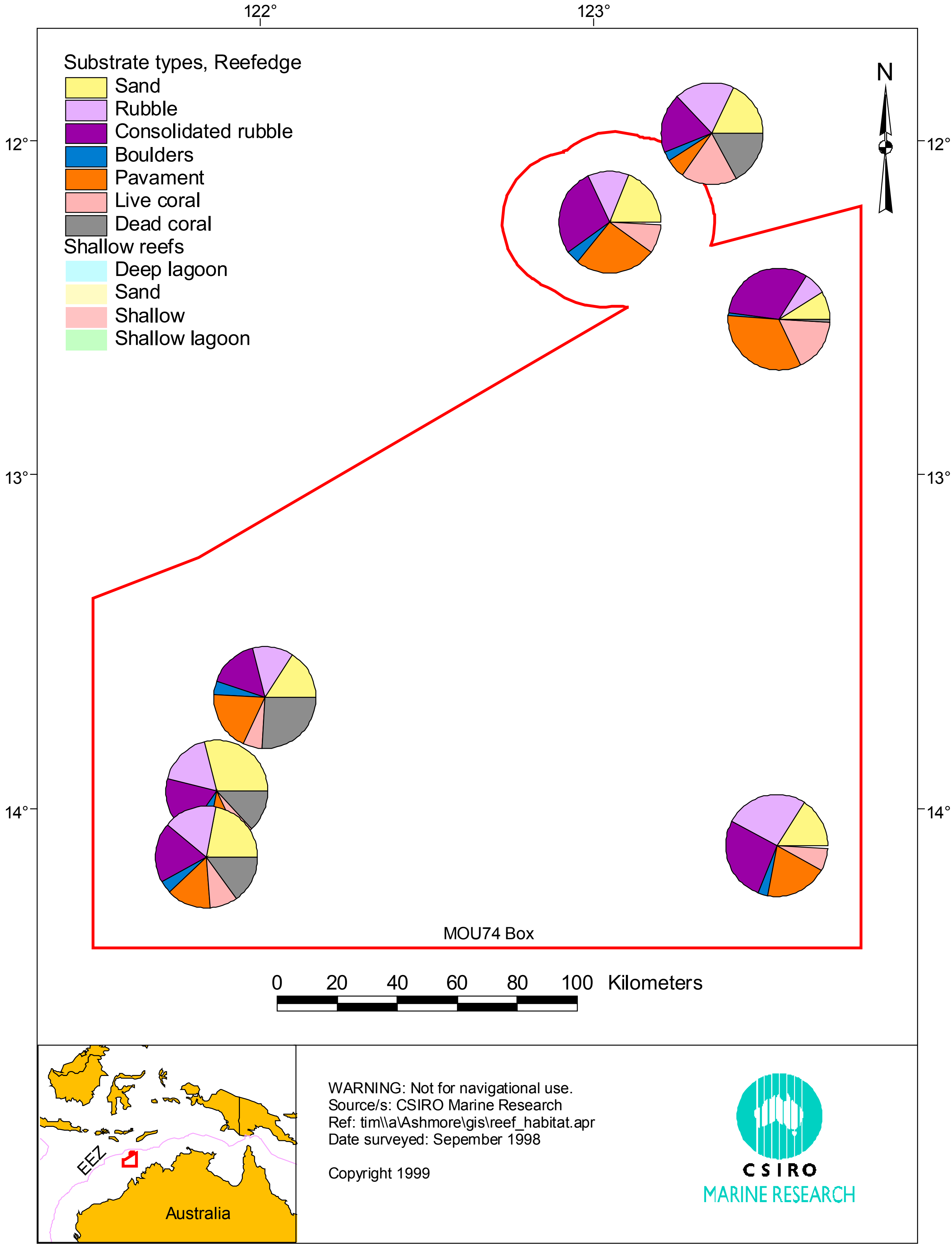


Figure 10. Shallow reefs of the MOU74 Box, and Hibernia Reef showing seagrass species composition. The size of the pie is proportional to the total cover of seagrass (range 0.04% at Seringapatam Reef to 2.07% at Ashmore Reef). Field data collected in September 1998.

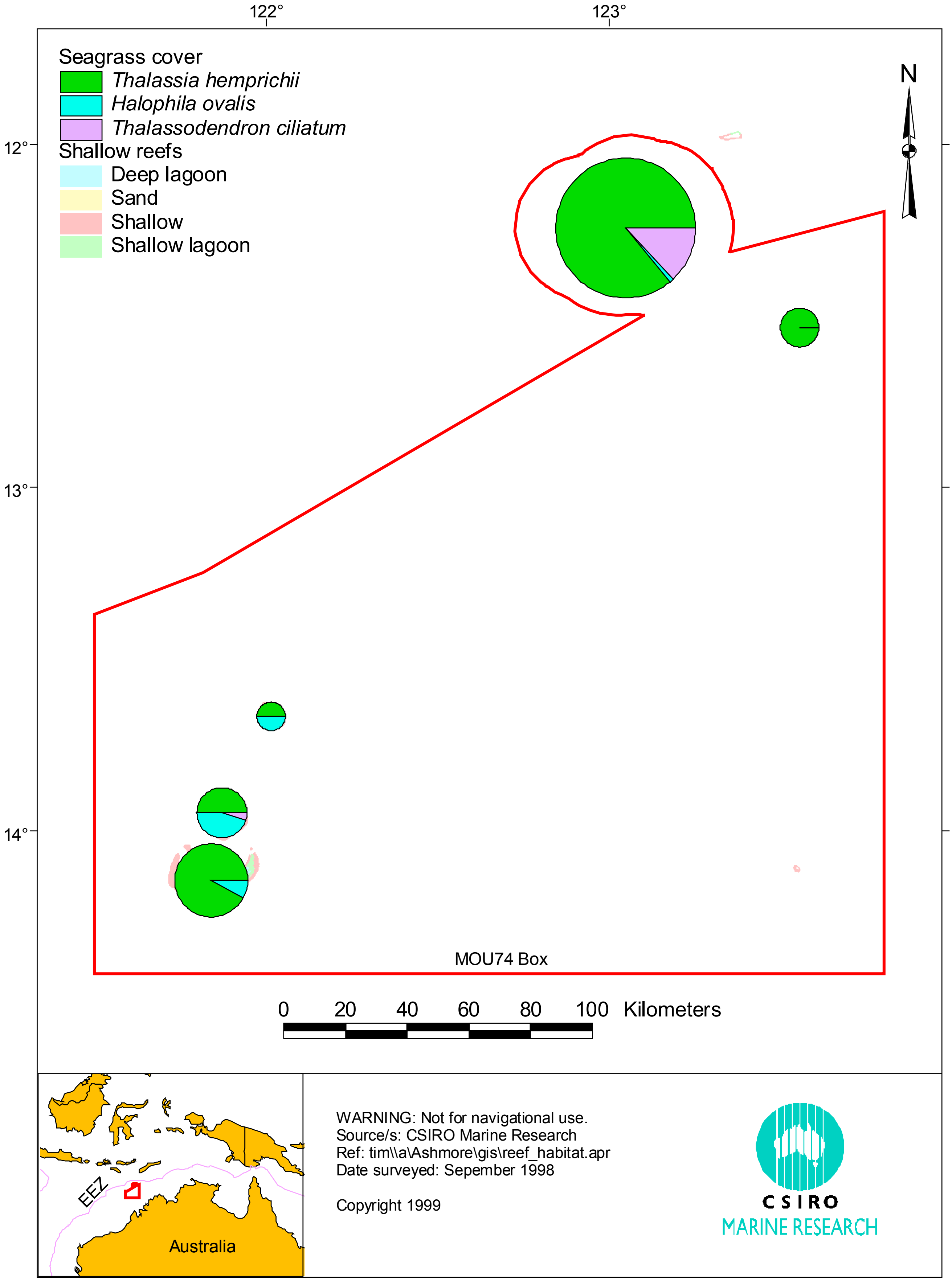


Figure 11. Shallow reefs of the MOU74 Box, and Hibernia Reef showing algae species. The size of the pie is proportional to the total cover of algae coral (range 14.5% at Ashmore Reef to 38.5% at Hibernia Reef). Field data collected in September 1998.

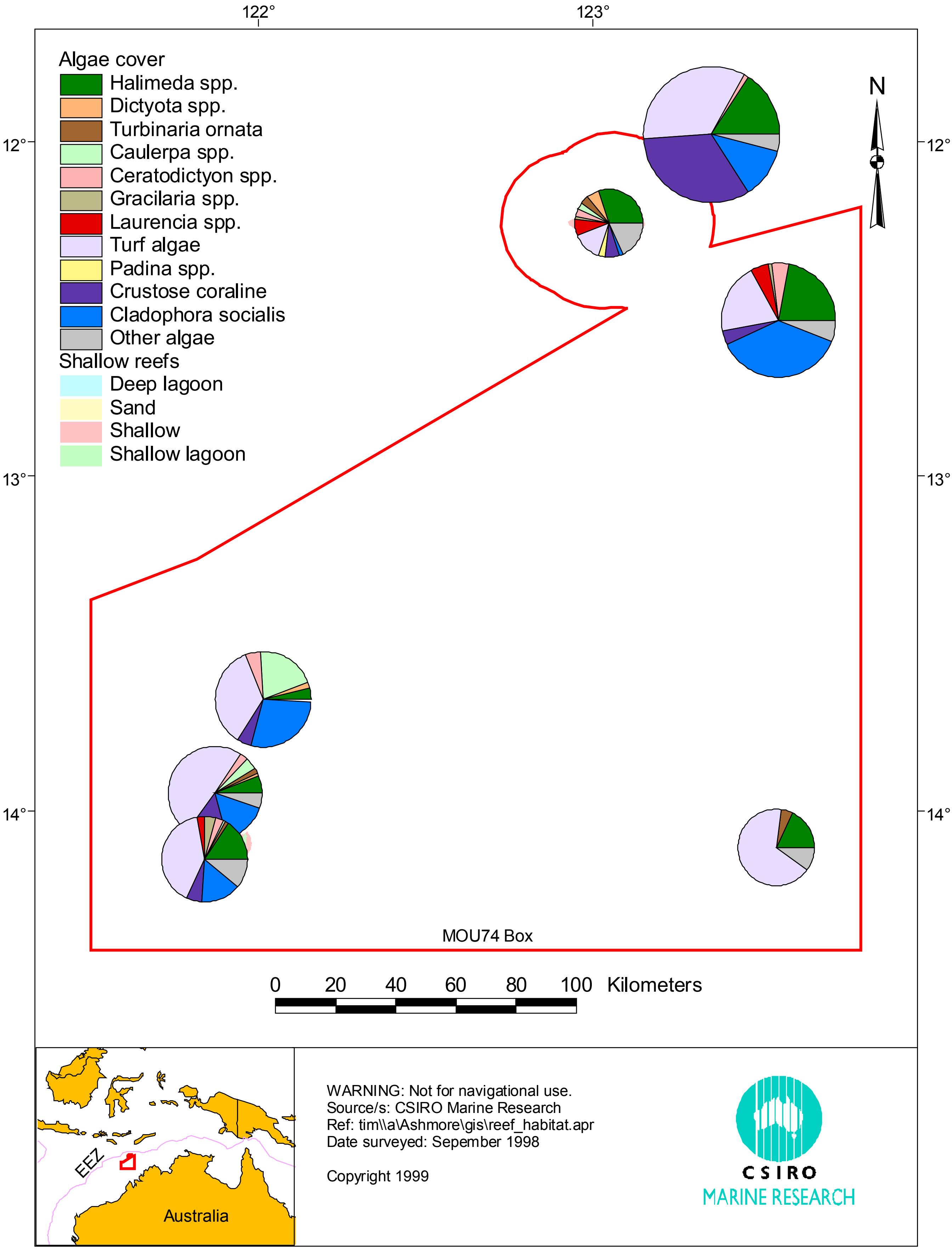


Figure 12. Shallow reefs of the MOU74 Box, and Hibernia Reef showing proportion of soft corals that are Sarcophyton spp. The size of the pie is proportional to the total cover of soft coral (range 0.15% at Browse Island to 3.75% at Hibernia Reef). Field data collected in September 1998.

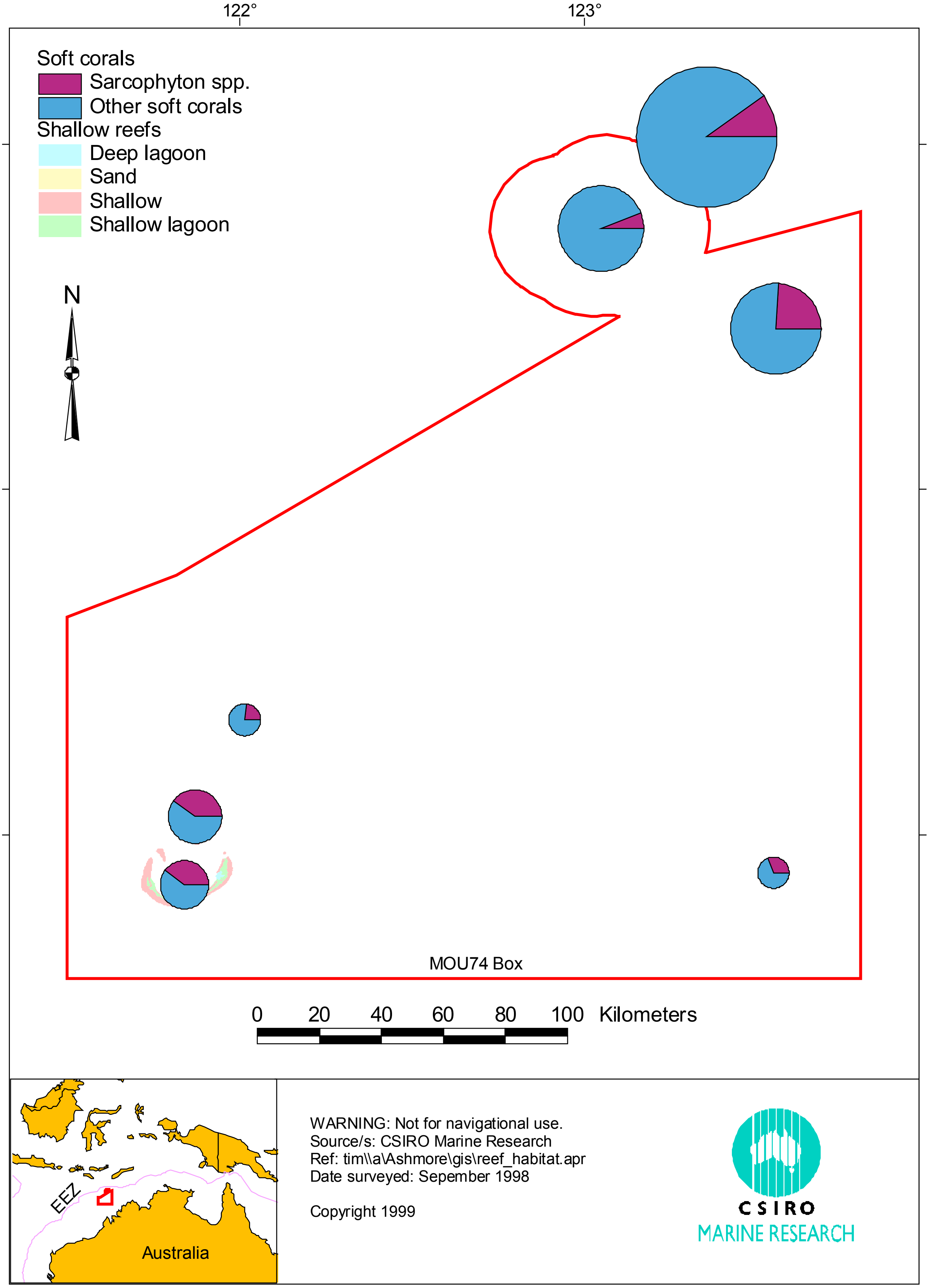
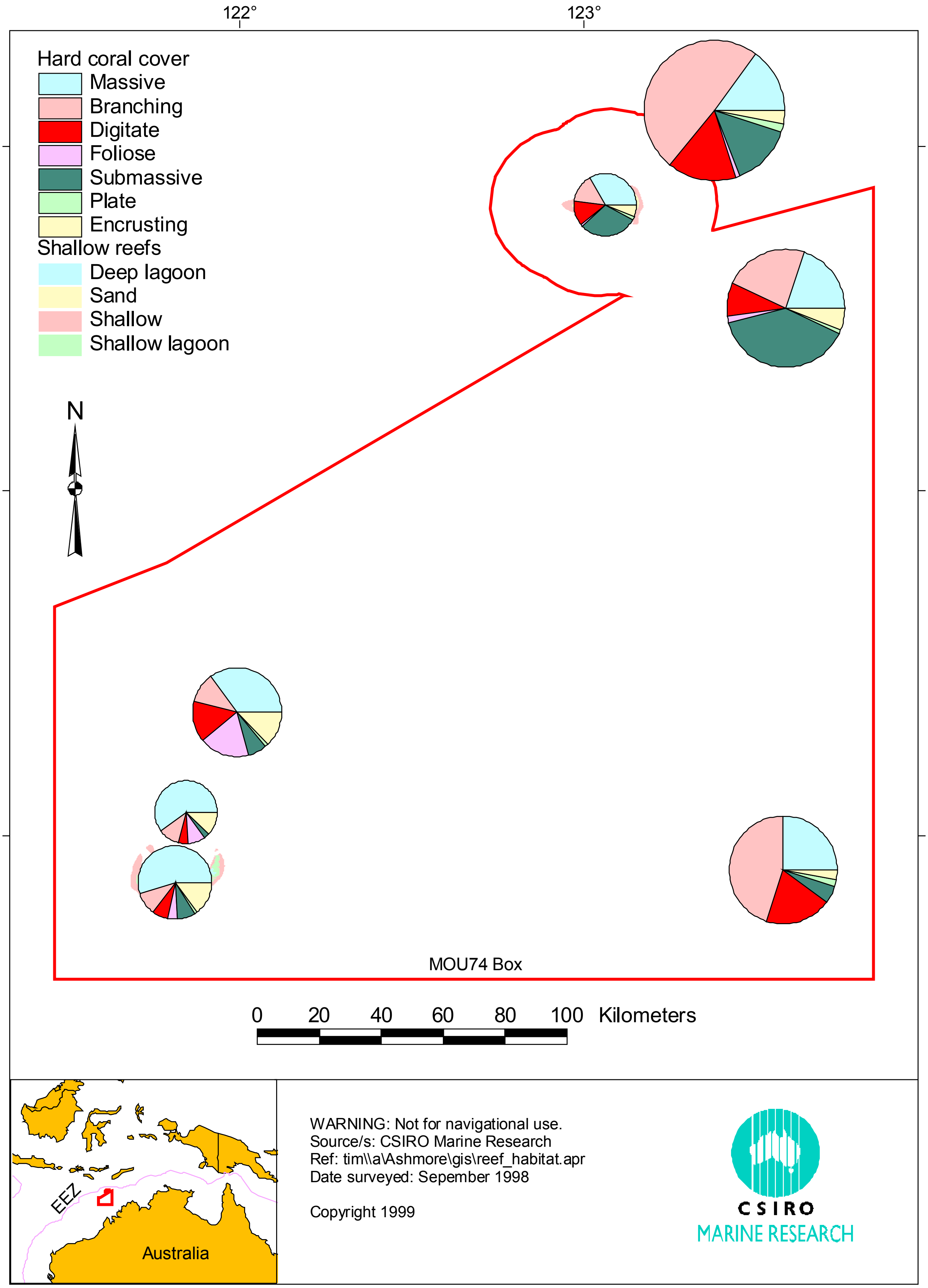


Figure 13. Shallow reefs of the MOU74 Box, and Hibernia Reef showing proportion of live hard coral by growth form. The size of the pie is proportional to the total cover of live coral (range 3.16% at Ashmore Reef to 13.16% at Hibernia Reef). Field data collected in September 1998.



Coral mortality

There has been a substantial recent mortality of hard corals on some of the shallow reefs in the study area, with up to 76% mortality of live coral on the larger southern reefs (Fig 14, Appendix G). In contrast, Ashmore Reef, and Browse and Cartier Islands showed low or no coral mortality. Hibernia Reef was intermediate, with the coral mortality restricted to branching forms (mainly *Acropora* spp.) on the inner lagoon edge (Appendix B).

The main coral growth form affected by the mortality was branching coral: over 95 % mortality at Scott North Reef, and over 83% overall on the reefs in the study area were dead (Fig. 15, Appendix G). Massive corals recorded the lowest mortality, but at Scott North Reef it was 34%; about 22% of all the massive coral in the study area were dead. (Fig. 15, 16, Appendix G).

The highest coral mortality was on the lagoon edges (Appendix B). Hibernia Reef lagoon edge had the highest mortality rate of any reef strata. This is an area where the highly susceptible branching coral predominate.

Satellite habitat mapping

Using the results of clustering of satellite data and discriminant function analysis of associated field data, the following habitats were mapped on the reef tops of the shallow reefs in the study area (Fig. 16-19, Appendix H).

Northern Reefs (Ashmore Reef, Hibernia Reef, Cartier Island)

1. Lagoon. Deep reef areas with high percentages of rubble and hard substrate. High cover of living biota including live hard and soft corals and algae.

2. Deep reef flat. Relatively deep reef flat with high cover of rubble and hard substrate. High cover of algae, moderate coral cover and low seagrass.

3. Reef flat. Shallow reef flat with high cover of hard substrate (consolidated rubble) and high cover of seagrass and algae. Moderate coral cover.

4. Sandy intermediate zone. Variable habitat with high cover of sand and low rubble. Low cover of seagrass and algae. Intermediate zone usually found between reef flat and sand areas.

5. Sand. Occasionally has very low cover of seagrass or algae.

6. Lagoon sand/rubble zone. Deep lagoon area with high cover of sand and rubble. High cover of algae and moderate cover of hard and soft corals.

7. Lagoon sand/algae. Deep lagoon area with moderate cover of algae.

8. Blue hole. A large solution depression about 1.2 km long and up to 300 m wide of unknown depth and structure. However, the satellite image analysis indicates a depth of greater than 12 m.

Figure 14. Shallow reefs of the MOU74 Box, and Hibernia Reef showing proportion of hard coral alive and recently dead. The size of the pie is proportional to the total combined cover of live and dead coral (range 3.36% at Ashmore Reef to 15.16% at Hibernia Reef). Field data collected in September 1998.

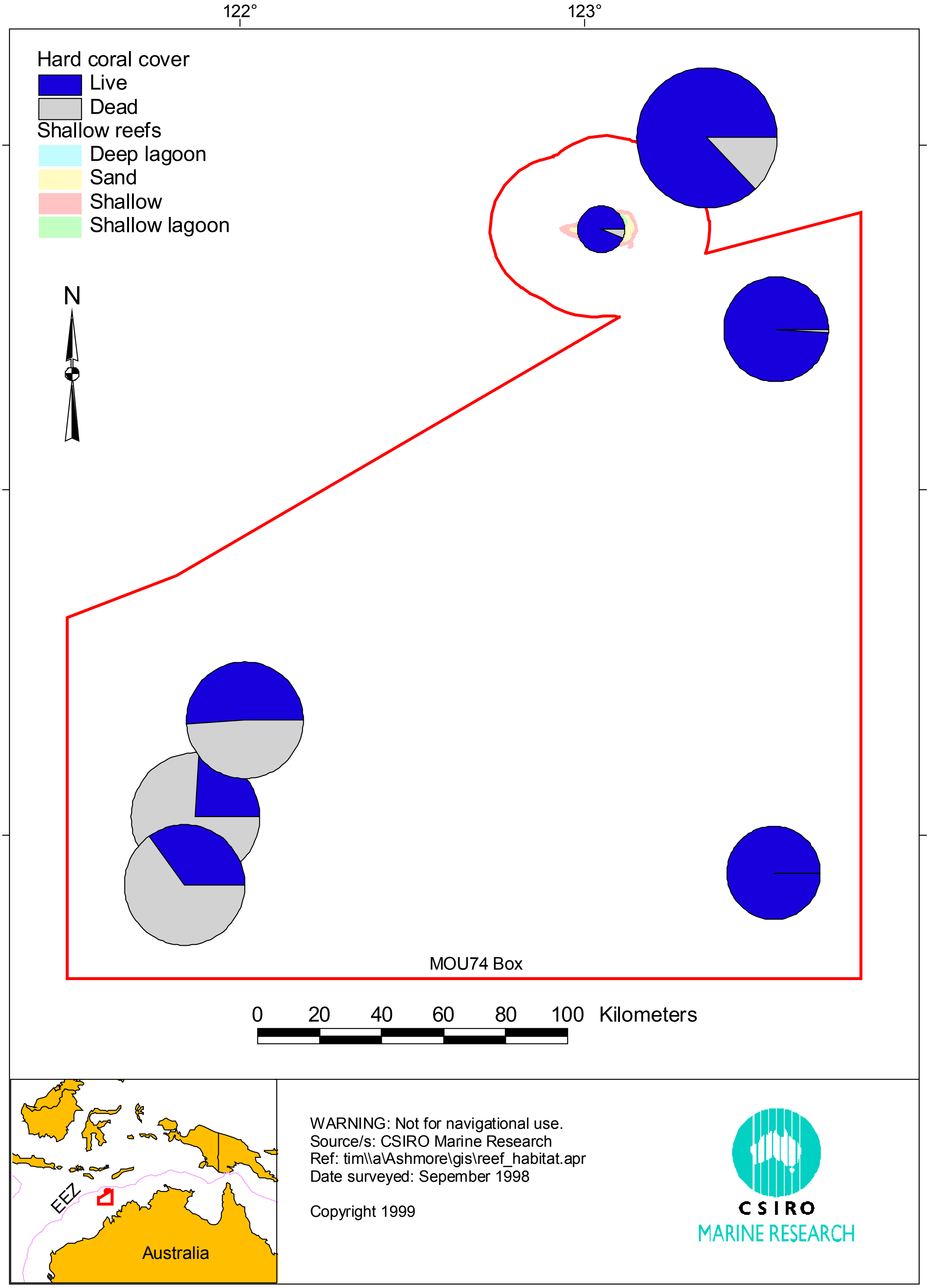
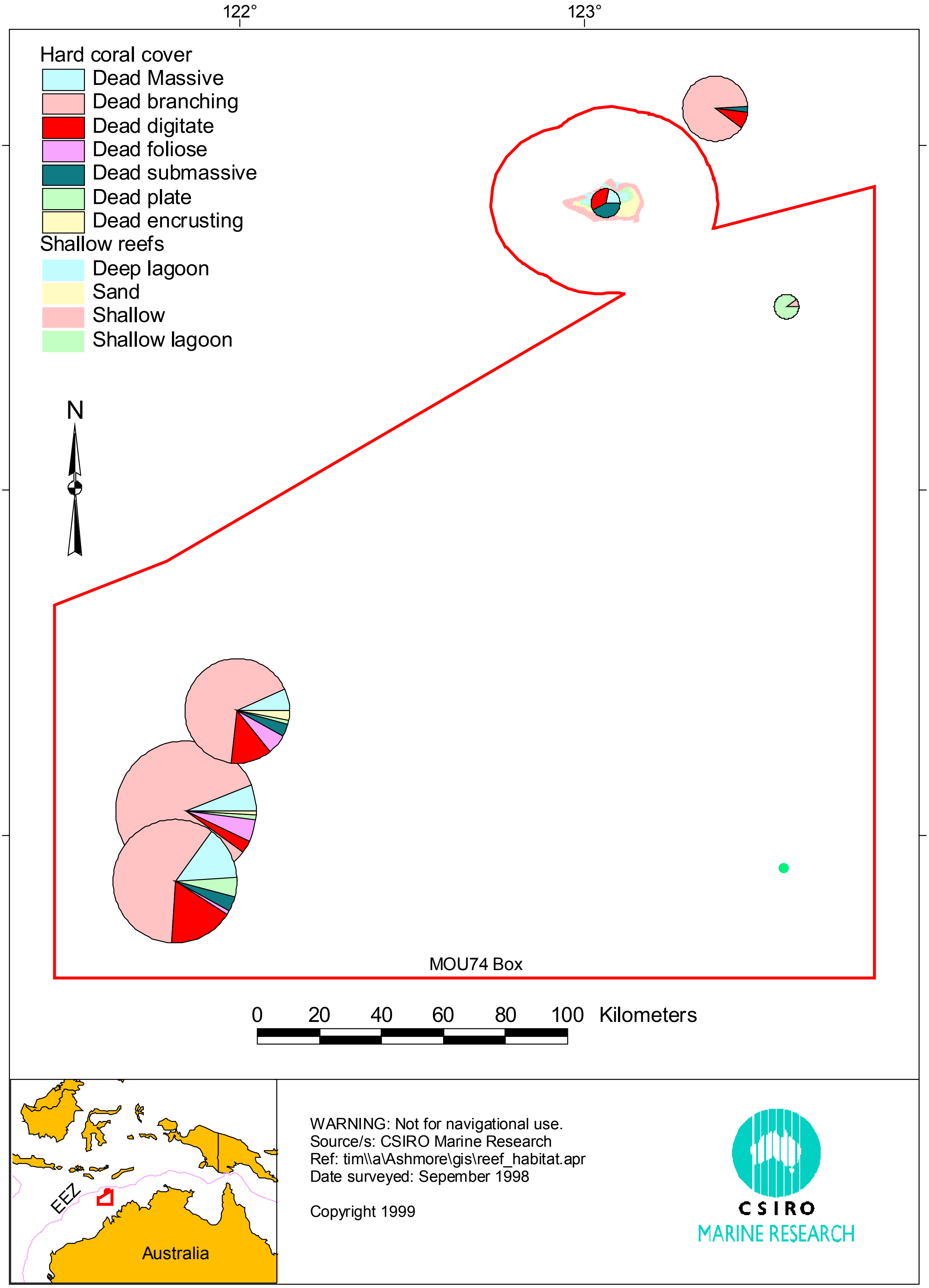


Figure 15. Shallow reefs of the MOU74 Box, and Hibernia Reef showing proportion of recently dead hard coral by growth form. The size of the pie is proportional to the total cover of recently dead coral (range 0.10% at Cartier Island to 10.05% at Scott Nth Reef). Field data collected in September 1998.



Southern Reefs (Scott and Seringapatam Reefs)

1. Deep lagoon. Deep reef areas with moderate cover of rubble and hard substrate. High coral cover, much of which has recently died. Moderate cover of algae and low cover of seagrass. This area has a high topography with coral bombies and dense fish life.

2. Backreef/ shallow lagoon. Poorly discriminated habitat type that includes relatively deep reef flat and shallow lagoon areas. High cover of rubble and hard substrate, moderate algae cover and low coral cover.

3. Deep reef flat. High cover of rubble and hard substrate, moderate cover of coral and algae and low cover of seagrass.

4. Sandy intermediate zone. Relatively high sand cover with moderate cover of hard substrate. Moderate cover of hard corals and low cover of seagrass and algae. This zone is behind reef flat.

5. Reef crest. Shallow area with very low sand cover and high cover of hard substrate, especially pavement. High cover of algae, especially green turf algae and crustose coraline algae, species common in shallow high-energy areas. Moderate cover of live coral and low cover of seagrass.

6. Reef flat. Shallow reef flat with high cover of hard substrate (consolidated rubble) and high cover of seagrass and algae. Moderate coral cover.

Habitats common to both the southern and northern reefs include the reef flat, deep reef flat and sandy intermediate zones. The northern reef habitats were often characterized by having more sand and seagrass, and less dead coral. The reef crest habitat found on the southern reefs was not mapped on Ashmore Reef, which seem not to have the very large southwesterly swells encountered during the study at Scott and Seringapatam Reef.

The original reef edge strata (front, back and lagoon edges) were generally consistent in their biological and substrate components throughout the study area (Appendix B). Descriptions of the three edge types follow (Appendix I).

1. Front reef-edge. (south-facing outer reef edges) High cover of pavement and live coral cover. Low sand cover. Consistent with high-energy environment. Showed the lowest coral mortality of the three reef-edge strata (31%).

2. Back reef-edge. (north-facing outer reef edges) Higher sand and lower pavement cover than reef front edges. Over 50% mortality of coral. Lower energy environment than the front reef.

3. Lagoon reef-edge. (Inner reef edges) High sand cover, low cover of hard substrate such as pavement and consolidated rubble. Low live coral cover and very high coral mortality rate (85%). Relatively Low energy environment.

Figure 16. Ashmore Reef in the MOU74 Box showing reef-top habitats classified from satellite data and interpretation of field data collected on the shallow reefs during the survey in September 1998.

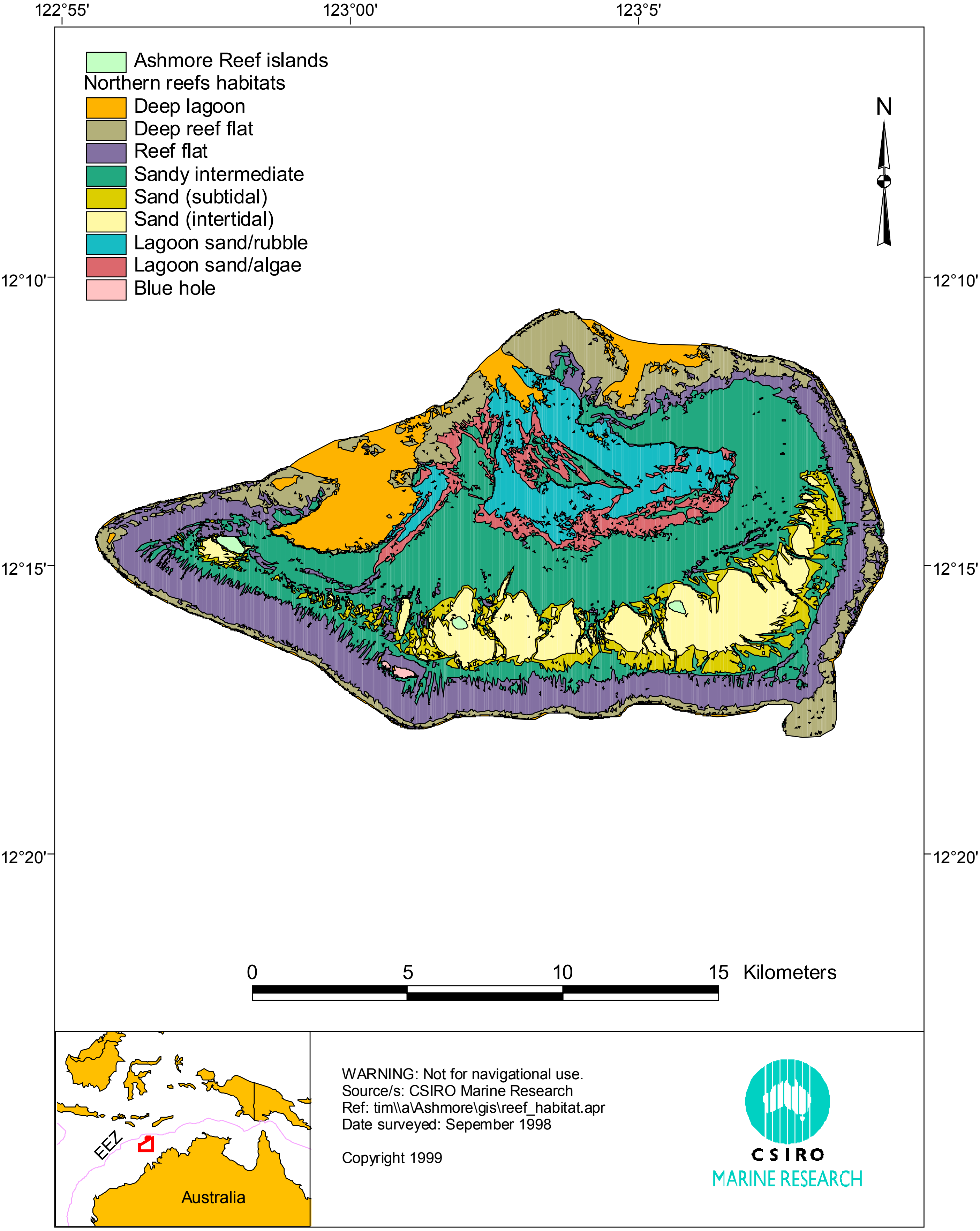


Figure 17. Hibernia Reef and Cartier Island in the MOU74 Box showing reef-top habitats classified from satellite data and interpretation of field data collected on the shallow reefs during the survey in September 1998.

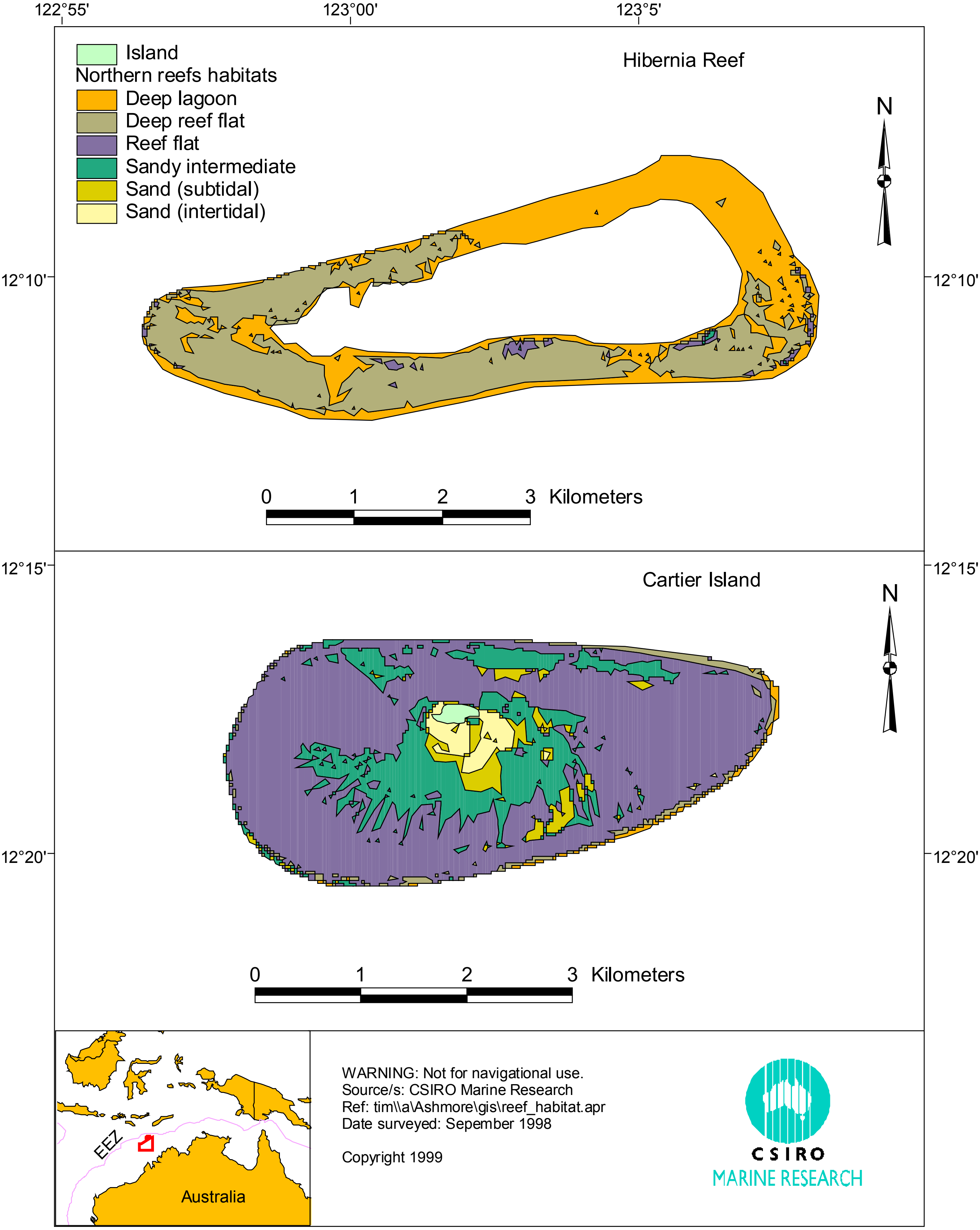


Figure 18. Seringapatam Reef in the southern section of the MOU74 Box showing reef-top habitats classified from satellite data and interpretation of field data collected on the shallow reefs during the survey in September 1998.

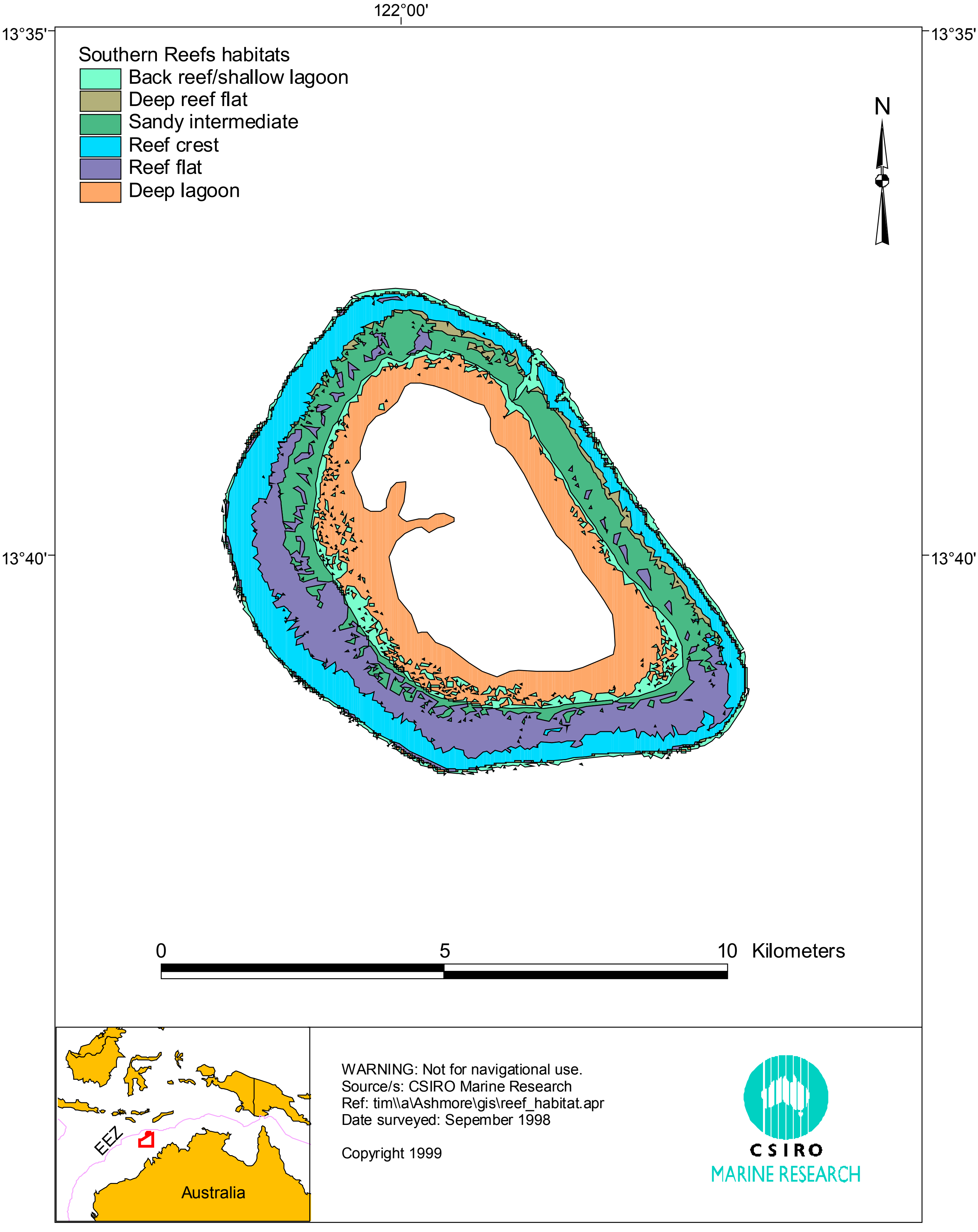
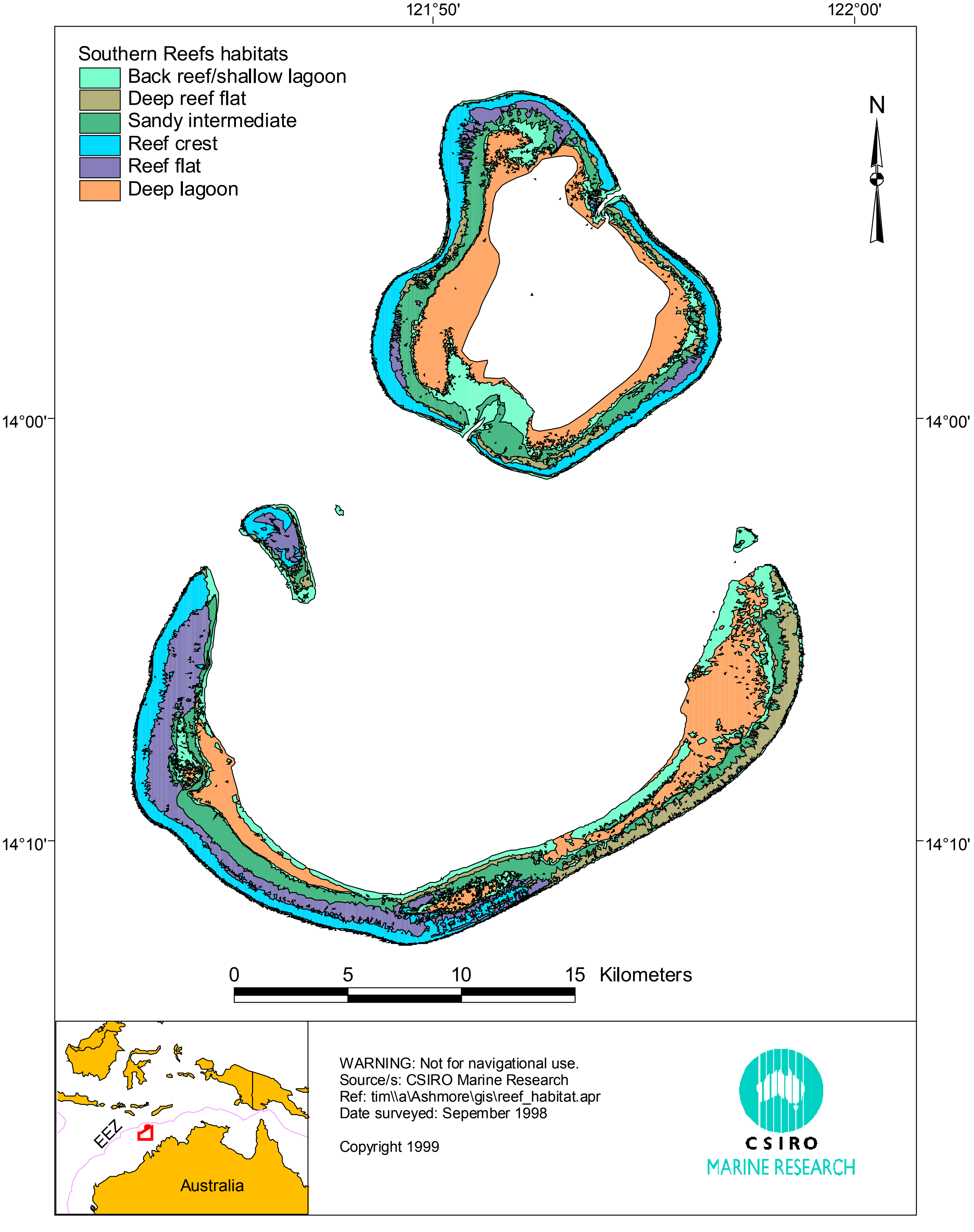


Figure 19. Scott Reefs in the MOU74 Box showing reef-top habitats classified from satellite data and interpretation of field data collected on the shallow reefs during the survey in September 1998.



3.2.2 Shoal areas (15–50 m deep)

The shoals in the northern part of the study area were mostly made up of *Halimeda* sand with areas of reef habitat mainly on the southern margins (Fig 20, 21, 22, Appendix C).

The shoals (or deep lagoons) of the southern large reefs have a higher percentage of hard substrate and coral (Fig. 23, Appendix C). For example, the Scott Reef South shoal (deep lagoon) has about 20% cover of live coral overall (Appendix C).

Scott Reef South acoustic habitat mapping

Data suitable for acoustic discriminant function analysis and habitat mapping were collected for Scott Reef South. The results of the discriminant function analysis was applied to the acoustic signal (Fig. 24). The raw acoustic hardness and roughness data were then contoured (Fig. 25) and the classification from the discriminant function analysis was then applied to the data to produce a map that showed the following habitats (Fig. 26).

1. Sand. High cover of soft sediments and low levels of very sparse epibenthic garden.

2. Coarse sand. Moderate cover of soft sediments and large boulders. Low cover of coral. Moderate cover of *Halimeda* spp.

3. Rubble. High cover of rubble and *Halimeda* spp.. Moderate cover of live coral.

4. Rock. High cover of rock and boulders. Moderate cover of live coral and diverse algae cover.

5. Reef. High cover of rubble and live coral. Coral was mainly foliose growth forms, probably dominated by *Montipora.*

The estimated total area of live coral in the Scott Reef South shoal was 5168.8 ha (+/- 867.3 Ha, 95% C.I.) (Appendix K). This compares with 2289.5 ha of live coral on all the shallow reefs in the MOU74 Box and Hibernia Reef.

Figure 20. Shoal A and Shoal B (< 50 m deep) north of the MOU74 Box showing subtrate type from video data collected on the shoals during the survey in September 1998.

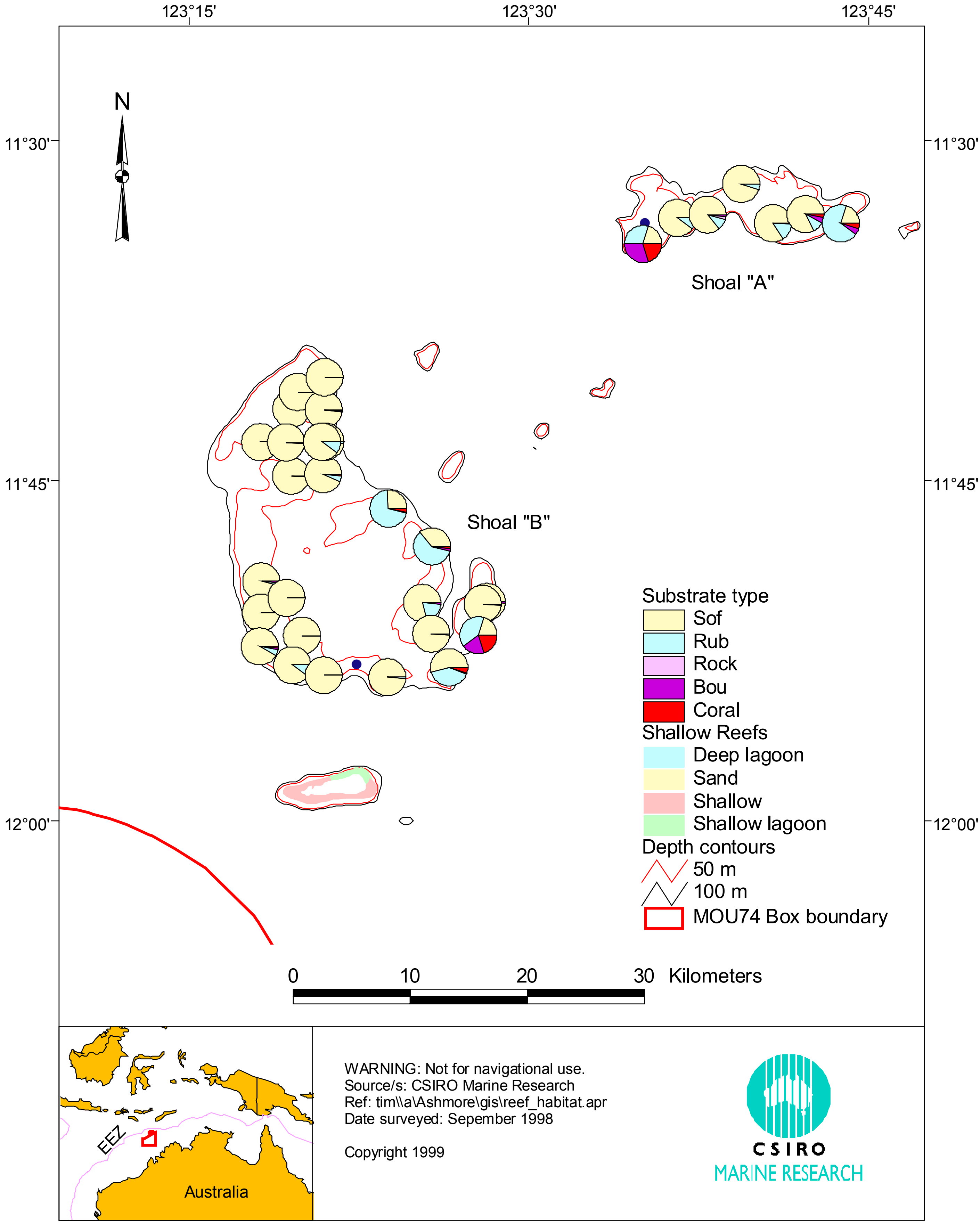


Figure 21. Johnson Bank, Woodbine Bank, Shoal C and Cartier Island shoals (< 50 m) in the MOU74 Box showing subtrate type from video data collected on the shoal area during the survey in September 1998.

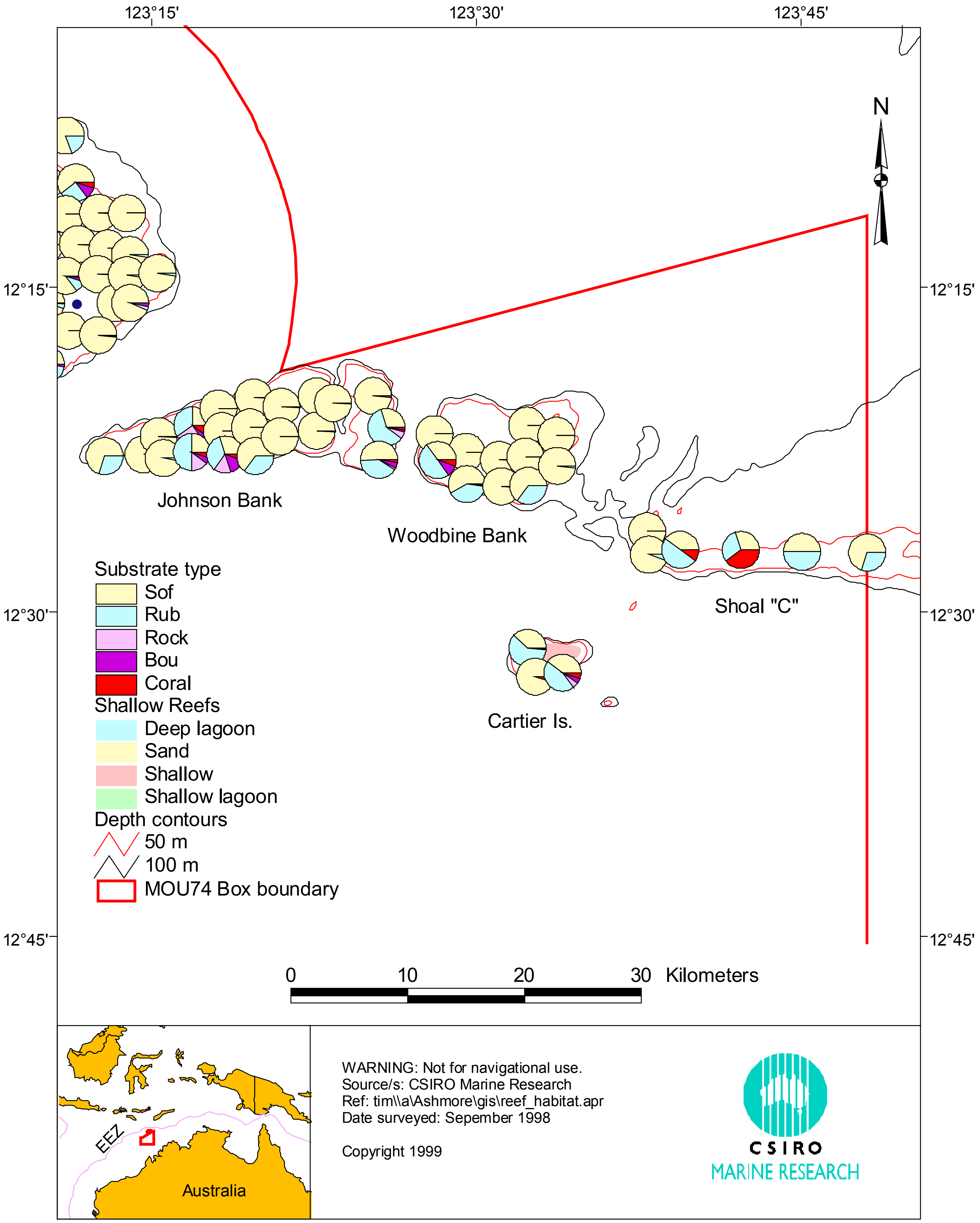


Figure 22. Ashmore Reef shoal (< 50 m) in the MOU74 Box showing subtrate type from video data collected on the shoal area during the survey in September 1998.

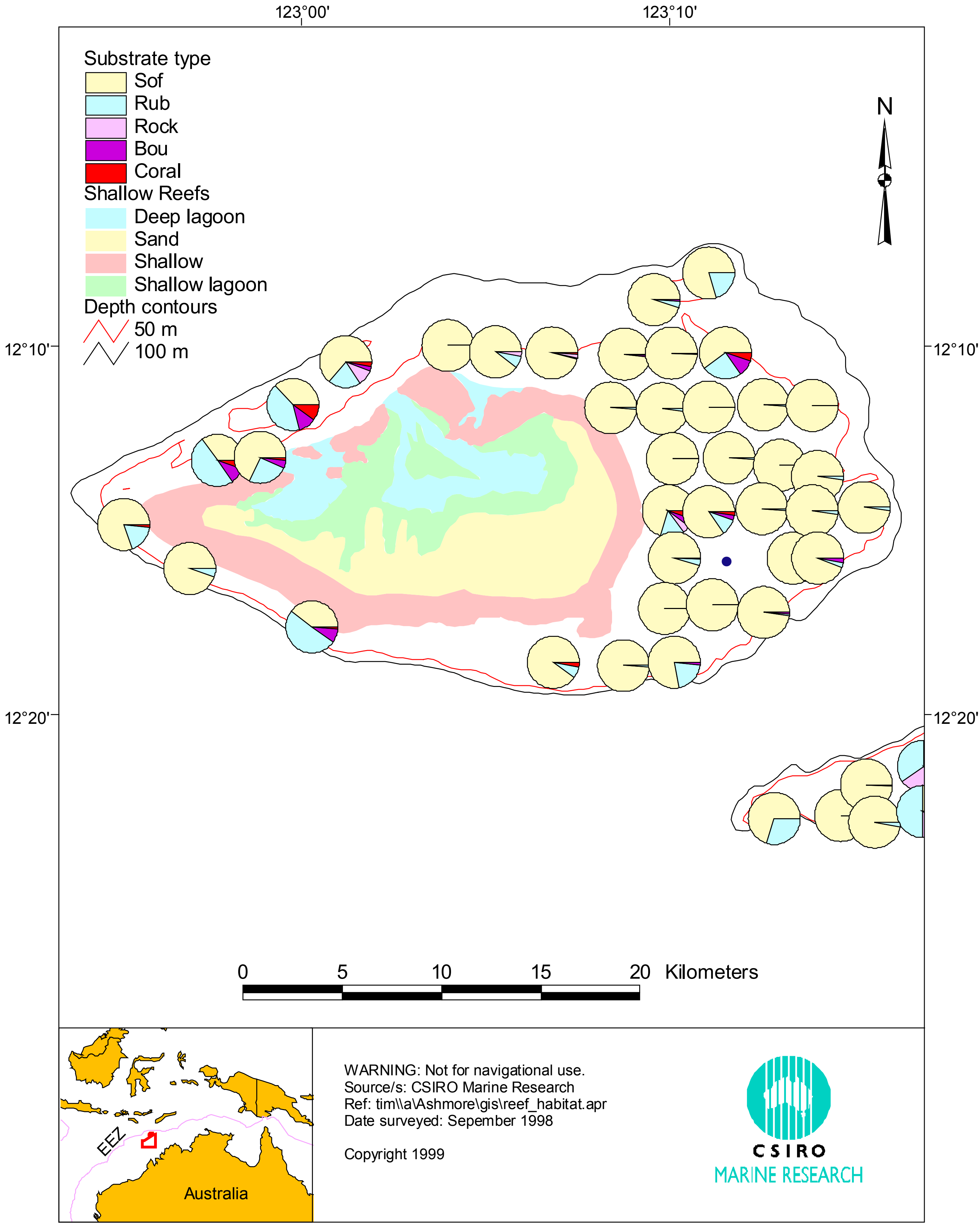


Figure 23. Scott Reef shoals in the MOU74 Box showing subtrate type from video data collected on the shoal area during the survey in September 1998.

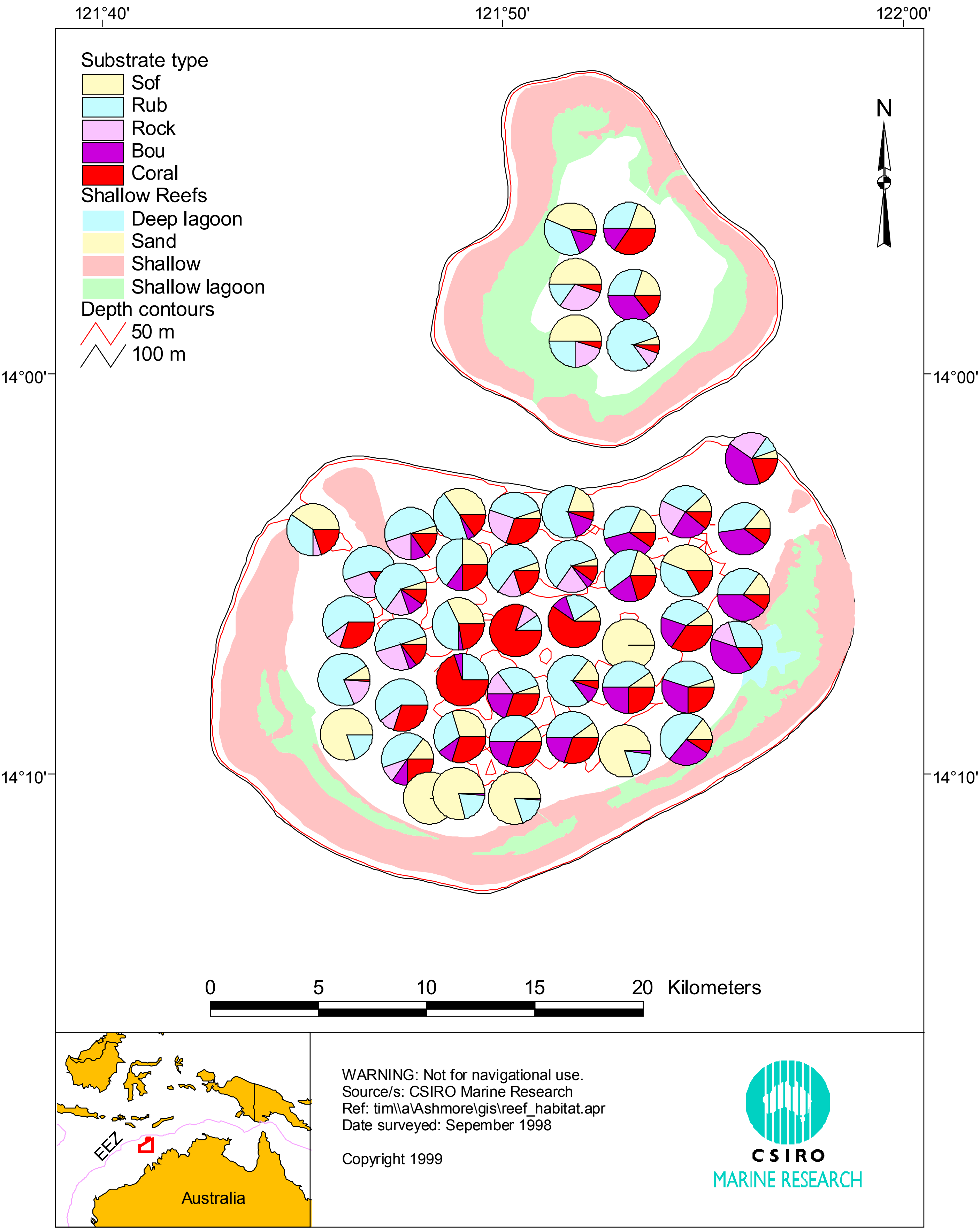
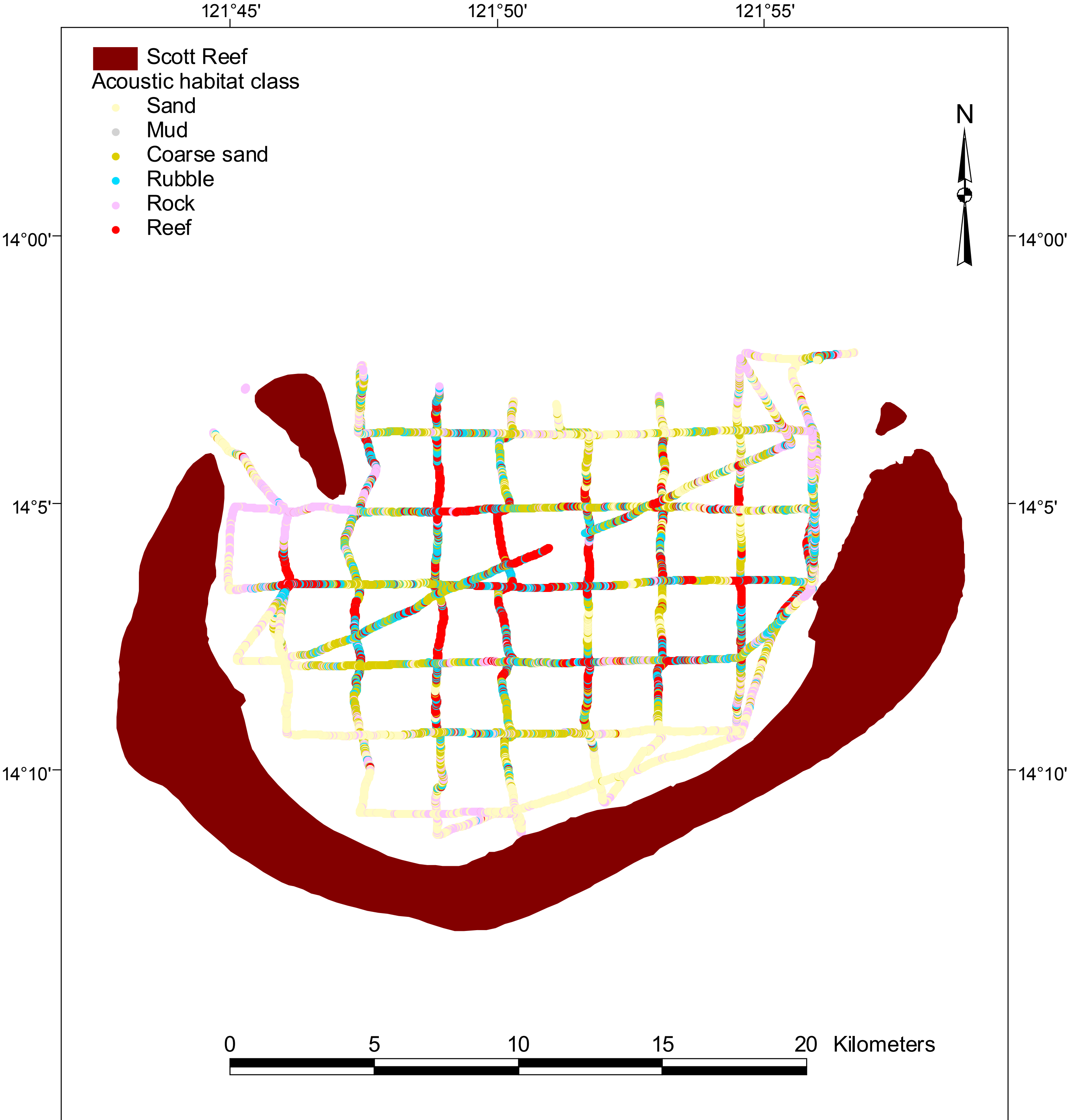
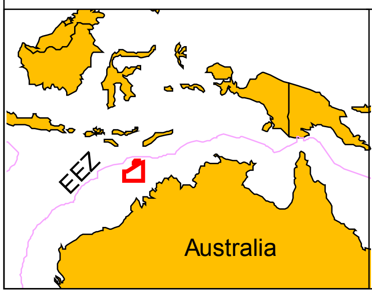


Figure 24. Scott Reef South in the MOU74 Box showing acoustic data track with acoustic signal return classified into habitat types using associated groundtruthing data collected on the shoal area during the survey in September 1998.





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CSIRO MARINE RESEARCH

Figure 25. Scott Reef South shoal in the MOU74 Box showing roughness and hardness using idices of the acoustic signal collected on the shoal area during the survey in September 1998.

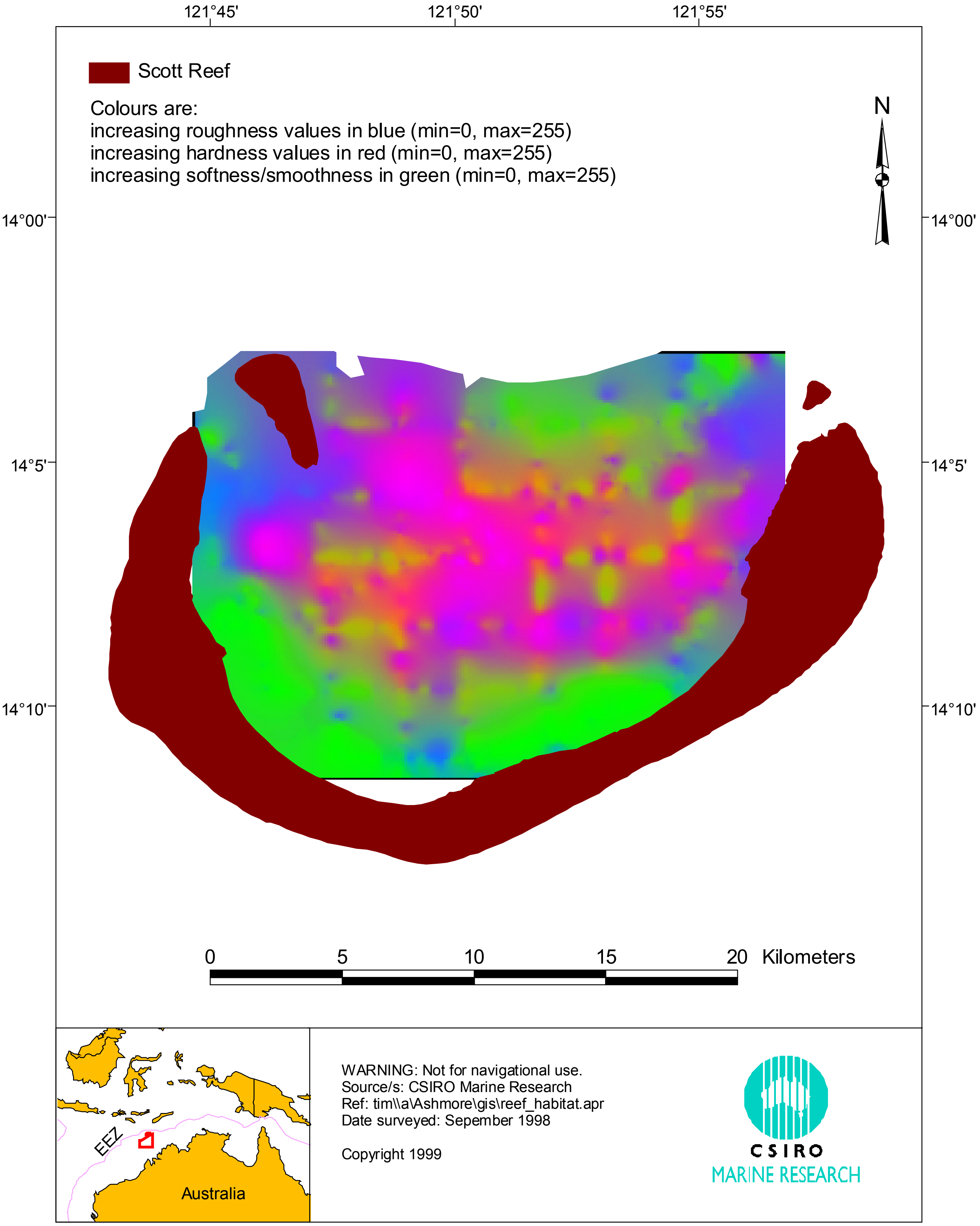
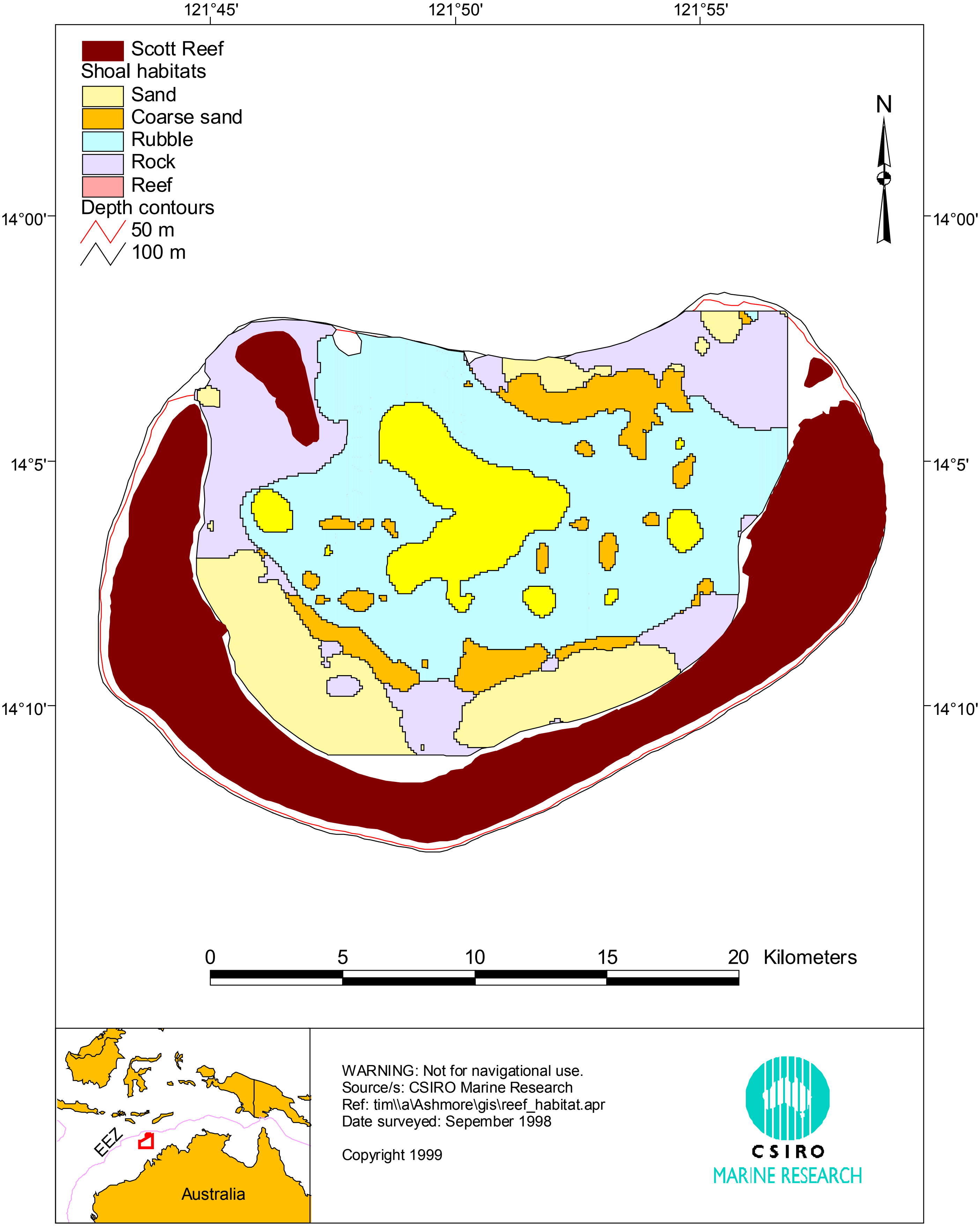


Figure 26. Scott Reef South shoal (<50 m deep) in the MOU74 Box showing habitats classified from acoustic data and interpretation of field data collected on the shoal area during the survey in September 1998.



4. DISCUSSION

The reefs in the study area show a wide variation in size and structure. The four largest reefs, — Scott North Reef, Scott South Reef, Seringapatam Reef and Ashmore Reef — make up over 95% of the shallow reef area in the study area. Ashmore Reef differed markedly from the Scott and Seringapatam Reefs. Generally, it had more sandy habitats, and lacked the extensive shallow reef crest habitat of the southern reefs. It also lacked the deep lagoon and associated lagoon reef edge found on Scott and Seringapatam Reefs. However, several habitats were common to these larger reefs, including the reef flat, and front-reef and back-reef edges. Generally, Ashmore Reef was very similar to midshelf reefs of the northern GBR and Torres Strait, whereas the southern reefs were similar to outer barrier reefs (Long *et al.*, 1997a), and probably reflect the balance between shelf and oceanic influence, such as nutrient input from surrounding waters.

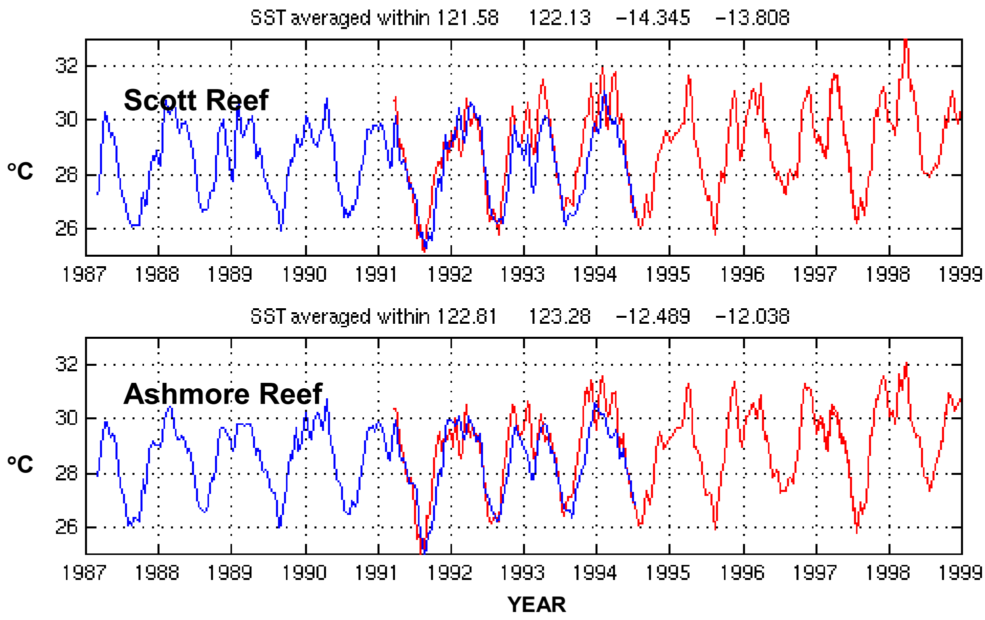
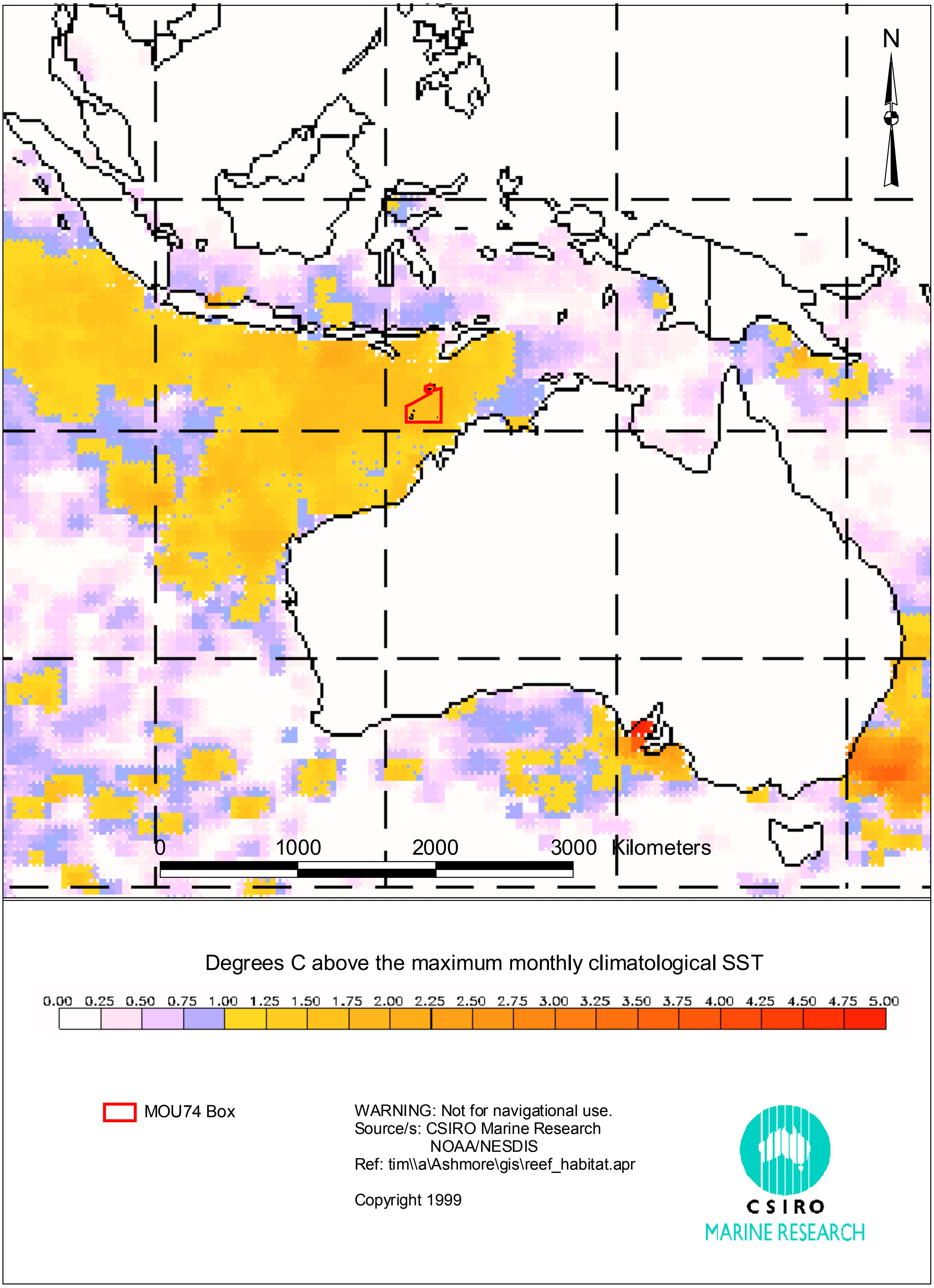


Figure 28. Plot of satellite derived sea surface temperature for two 2500 km^2 areas of water surrounding Scott Reef and Ashmore Reef in the MOU74 Box.

The shoals in the northern part of the study area are mostly made up of *Halimeda* sand with small areas of reef habitat mainly on the southern margins. In contrast, the large shoal (or deep lagoon) associated with Scott Reef South had a high cover of hard substrate and live coral.

The coral mortality seen on the shallow reefs occurred within the last 12 months (Andrew Heywood, AIMS, pers comm.) and coincided with widespread coral bleaching and mortality in the Indo-Pacific region caused by higher than normal sea-surface temperatures. Such temperatures occurred in the study area during April and May of 1998 (Fig. 27) (SST information provided by NOAA). The cause of the differences in mortality rates between reefs is probably related to differences in maximum daily temperatures in the waters surrounding the two reefs during March 1998 (CSIRO, unpublished data) (Fig. 28). The southern reefs including the Scott Reefs and Seringapatam Reef, were in a sea surface temperature hotspot that was hotter and lasted longer than the northern reefs.

Figure 27. Sea surface temperateure (SST) anomaly (hotspot) data for March 24, 1998, (SST data courtey of NOAA/NESDIS). Colour represent degrees C above average longrun maximum monthly climatological SST.



SST anomalies can cause coral bleaching in a number of ways, causing cumulative heat stress (Winter *et al.*, 1998). Corals do have the ability to recover from bleaching events, however this depends on the duration of the SST anomaly, its severity and whether other environmental conditions return to normal (Winter *et al.*, 1998; Hoegh-Guldberg, 1999).

The effect of the coral mortality on the ecology of the reef is not known. However, we would expect a decline in coral-eating organisms (such as Chaetodont fishes), and an increase in turf algae growing on dead coral. Once the coral becomes broken, there would also be a loss of habitat for small animals that use it for shelter. There is unlikely to be a direct 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.

The coral mortality observed on the shallow reefs was not seen in the shoals, including the extensive coral cover in the Scott South Reef shoal (deep lagoon). It may be that the depth of the shoal habitats (~50 m deep) affords some protection to corals from bleaching and subsequent mortality. Light has been implicated as having an important role in bleaching mechanism (Salih *et al.*, 1998).

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APPENDIX A

Average depth and percent cover of major substrate types and biota for reef top strata of the shallow reefs in the study area.

Reef	Strata	Sites	Area (ha)	Depth (m)	Sand	Rubble	Cons-rubble	Boulders	Bommies	Pave-ment	Live coral	Dead coral	Coral mortality	Soft corals	Algae	Seagrass	Sponges
Ashmore	Deep lagoon	9	3183.8	6.6	56.4	18.4	13.3	0.6	3.3	0.0	8.3	0.0	0.0	5.0	15.3	0.1	3.6
Ashmore	Sand	43	6123.3	1.5	94.3	2.6	2.9	0.2	0.0	0.0	0.1	0.0	0.0	0.0	6.0	0.1	0.7
Ashmore	Shallow	98	8252.8	1.8	54.3	14.6	22.3	0.5	0.2	4.9	3.8	0.5	2.4	1.1	17.6	5.5	2.2
Ashmore	Shallow lagoon	45	4108.9	1.7	81.9	10.0	7.0	0.0	0.0	0.7	0.8	0.0	0.0	0.4	16.3	0.1	1.1
Browse	Shallow	20	353.5	2.0	22.9	25.8	19.0	10.3	0.0	6.8	8.9	0.0	0.0	0.0	19.2	0.0	0.1
Cartier	Shallow	20	938.7	1.2	31.5	25.8	29.1	0.6	0.0	4.5	8.1	0.0	0.0	0.8	33.3	0.1	0.5
Hibernia	Shallow	24	675.9	2.8	17.3	23.0	38.3	4.8	1.0	9.4	5.3	0.0	0.0	2.6	45.4	0.0	0.7
Hibernia	Shallow lagoon	2	190.3	2.1	0.0	22.5	46.5	0.0	0.0	0.0	31.0	0.0	0.0	3.0	50.0	0.0	1.8
Scott Nth	Shallow	61	5673.4	3.1	36.2	17.3	16.4	4.6	1.9	16.9	2.7	3.0	19.1	0.3	27.0	0.2	0.3
Scott Nth	Shallow lagoon	37	4030.8	8.8	34.4	16.8	6.6	8.0	6.4	0.5	3.6	19.4	66.6	0.2	15.7	0.2	1.6
Scott Sth	Deep lagoon	2	419.0	24.3	25.0	22.5	20.0	15.0	7.5	0.0	5.0	7.5	58.3	1.0	5.0	0.0	0.3
Scott Sth	Shallow	104	9116.8	2.6	28.7	17.6	33.4	3.1	0.7	10.0	3.3	4.6	27.3	0.2	24.3	0.8	0.6
Scott Sth	Shallow lagoon	30	2962.7	11.9	52.8	8.6	5.7	6.3	7.5	0.2	4.1	13.5	69.4	0.4	8.9	0.1	1.4
Seringapatam	Deep lagoon	5	1330.0	20.9	41.0	31.0	12.0	4.0	4.0	0.0	5.6	1.0	10.0	0.1	13.0	0.0	0.6
Seringapatam	Shallow	22	2561.9	1.1	51.5	17.8	22.9	1.3	0.0	0.5	4.7	1.2	14.4	0.0	20.4	0.0	0.3
Seringapatam	Shallow lagoon	12	1225.6	13.6	30.0	33.8	1.3	3.3	8.3	0.0	8.9	12.8	53.9	0.1	38.3	0.0	2.1

APPENDIX B

Average width and percent cover of major substrate types and biota for reef edge strata (0-15 m) of the shallow reefs in the study area.

Reef	Strata	Sites	Area (ha)	Width (m)	Sand	Rubble	Cons-rub	Boulders	Bomm-ies	Pave-ment	Live coral	Coral mortality	Percent d_coral	Soft corals	Algae	Sea-grass	Sponges
Ashmore	Back edge	7	160.2	140.1	13.4	5.9	53.7	3.8	2.7	10.7	9.9	0.0	0.0	3.2	39.3	0.0	6.1
Ashmore	Front edge	27	688.7	156.9	9.7	8.1	26.0	4.0	2.3	38.7	11.3	0.0	0.0	6.5	28.7	0.0	2.7
Ashmore	Lagoon edge	11	179.3	100.0	43.0	27.2	13.6	3.5	4.5	1.9	3.2	0.0	0.0	2.3	29.4	0.5	0.9
Browse	Front edge	6	101.7	149.2	14.3	23.4	23.7	2.6	3.6	18.1	6.4	0.0	0.0	0.6	9.3	0.0	0.8
Cartier	Back edge	3	35.5	80.7	17.6	4.4	19.2	2.0	0.0	50.7	6.1	0.0	0.0	14.2	3.5	0.0	1.4
Cartier	Front edge	4	111.3	142.5	3.1	9.8	41.6	0.9	0.0	19.1	24.4	1.0	1.7	4.4	8.0	0.0	1.2
Hibernia	Back edge	6	109.2	100.3	28.3	13.3	20.7	1.6	0.4	7.0	14.4	15.3	29.5	3.8	15.1	0.0	7.7
Hibernia	Front edge	6	161.2	159.3	12.3	26.7	17.5	4.9	9.3	7.3	24.3	0.0	0.0	9.2	13.0	0.0	3.8
Hibernia	Lagoon edge	2	11.0	100.0	4.0	9.1	18.1	3.4	2.5	0.0	10.1	56.8	85.0	9.5	24.5	0.0	10.8
Scott Nth	Back edge	9	132.0	88.9	6.9	19.0	28.3	13.0	4.8	14.6	5.4	9.5	58.2	2.9	45.4	0.0	1.2
Scott Nth	Front edge	19	332.6	97.8	7.9	13.6	26.8	9.8	9.6	19.5	7.0	6.1	33.3	6.2	28.7	0.0	2.2
Scott Nth	Lagoon edge	24	444.4	100.0	51.6	16.2	6.5	1.6	4.6	0.5	2.8	19.0	79.1	1.1	12.3	1.0	1.8
Scott Sth	Back edge	25	648.1	148.4	19.0	22.5	20.8	6.0	5.5	3.0	7.7	16.6	65.2	1.4	9.2	0.1	1.1
Scott Sth	Front edge	31	679.6	125.8	3.2	9.5	26.4	5.0	4.1	32.8	15.3	7.5	36.7	2.5	32.7	0.0	1.7
Scott Sth	Lagoon edge	24	574.2	100.0	49.3	19.4	5.6	1.5	2.2	0.2	2.4	19.9	84.2	0.2	11.4	0.5	0.5
Seringapatam	Back edge	6	93.2	98.5	6.5	10.8	32.8	3.9	1.4	21.8	6.7	14.4	64.3	2.2	18.2	0.0	1.0
Seringapatam	Front edge	10	119.5	68.3	3.1	8.4	17.9	5.7	3.9	37.3	3.0	20.1	45.9	1.9	46.8	0.0	4.1
Seringapatam	Lagoon edge	11	189.2	100.0	31.4	17.1	4.3	1.3	2.0	0.0	6.9	36.6	81.0	0.3	17.7	0.5	1.2

APPENDIX C

Average depth and percent cover of major substrate types and biota for shoals and shoal strata in the study area.

Shoal	Sites	Area (ha)	Depth (m)	Sand	Rubble	Rock	Boulders	Live coral	Algae	Seagrass	Halimeda
Ashmore Rf	39	30382.7	36.4	85.4	8.7	0.5	1.6	1.0	5.9	0.0	3.3
Browse Is	4	541.9	21.3	45.0	33.8	10.0	0.0	11.3	2.5	0.0	0.0
Cartier Is	3	867.4	37.3	57.7	35.0	1.7	2.0	3.7	15.0	0.0	9.0
Johnson Bk	17	12196.9	30.9	88.6	10.1	0.5	0.6	0.2	2.5	0.0	1.9
Johnson reef habitat	9	1526.5	21.5	22.8	23.8	41.8	7.8	4.4	18.9	3.7	14.4
Scott Nth Rf	5	3309.8	18.2	31.0	35.0	12.0	9.0	6.6	6.2	0.0	0.8
Scott Sth Rf	42	28895.5	47.0	23.4	38.9	7.2	12.7	20.0	4.4	0.0	4.3
Shoal A	8	7585.2	42.4	59.6	18.8	0.3	5.4	3.6	23.1	0.0	20.6
Shoal B	27	22516.6	42.3	83.9	10.0	0.0	1.1	1.3	15.6	0.0	12.8
Shoal C	6	5458.4	40.3	64.2	27.5	0.0	0.0	8.3	9.2	0.0	4.3
Woodbine Bk	12	8348.4	29.9	91.8	7.9	0.0	0.2	0.1	4.3	0.0	3.8
Woodbine reef habitat	4	1005.2	20.5	13.8	25.0	50.0	5.8	5.8	37.5	0.0	34.9

APPENDIX D

Stratified mean abundance and variance estimates for the calculation of cover of seagrass estimates by reef and for the total study area. Column headings correspond to formula in Appendix L.

REEF	ZONE	Sites n_h	Area (ha)	Reef W_h	Total W_h	S_grass Y_h	S_grass 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	0.06	0.03	0.01	0.00	0.00	0.00
Ashmore	Front edge	27	688.68	0.030	0.012	0.00	0.00	0.00	0.00	0.00	0.00
Ashmore	Lagoon edge	11	179.30	0.008	0.003	0.48	0.53	0.00	0.00	0.00	0.00
Ashmore	Sand	43	6123.30	0.270	0.110	0.14	0.30	0.04	0.00	0.02	0.00
Ashmore	Shallow	98	8252.84	0.364	0.148	5.51	91.15	2.00	0.12	0.81	0.02
Ashmore	Shallow lagoon	45	4108.87	0.181	0.073	0.12	0.12	0.02	0.00	0.01	0.00
Browse	Front edge	6	101.73	0.223	0.002	0.00	0.00	0.00	0.00	0.00	0.00
Browse	Shallow	20	353.45	0.789	0.006	0.00	0.00	0.00	0.00	0.00	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	0.13	0.07	0.11	0.00	0.00	0.00
Hibernia	Back edge	6	109.23	0.095	0.002	0.00	0.00	0.00	0.00	0.00	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	0.02	0.01	0.00	0.00	0.00	0.00
Scott Nth	Lagoon edge	24	444.40	0.042	0.008	0.98	0.50	0.04	0.00	0.01	0.00
Scott Nth	Shallow	61	5673.40	0.535	0.101	0.19	0.20	0.10	0.00	0.02	0.00
Scott Nth	Shallow lagoon	37	4030.76	0.380	0.072	0.20	0.71	0.08	0.00	0.01	0.00
Scott Sth	Back edge	25	648.10	0.045	0.012	0.07	0.05	0.00	0.00	0.00	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	0.00	0.00	0.00	0.00	0.00	0.00
Scott Sth	Lagoon edge	24	574.20	0.040	0.010	0.51	0.46	0.02	0.00	0.01	0.00
Scott Sth	Shallow	104	9116.75	0.633	0.163	0.77	2.60	0.49	0.01	0.13	0.00
Scott Sth	Shallow lagoon	30	2962.67	0.206	0.053	0.12	0.08	0.02	0.00	0.01	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	0.45	0.42	0.02	0.00	0.00	0.00
Seringapatam	Shallow	22	2561.94	0.464	0.046	0.05	0.02	0.02	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 seagrass cover.

Reef	*n*	Area (ha)	yst (%)	$v(Y_{st})$	Total area (ha)	95% CI (%)
Ashmore	240	22697.09	2.07	0.12	470.73	33.40
Browse	26	455.18	0.00	0.00	0.00	
Cartier	27	1085.47	0.11	0.00	1.17	96.47
Hibernia	40	1147.73	0.00	0.00	0.00	
Scott Nth	150	10613.11	0.22	0.00	23.30	55.24
Scott Sth	216	14400.34	0.54	0.01	77.43	36.94
Seringapatam	66	5519.43	0.04	0.00	2.02	87.46
Total area	765	55918.37	1.03	0.0212	574.65	27.80

APPENDIX D (CONT.)

Stratified mean cover and estimated total area of seagrass by species for the shallow reefs in the MOU 74 Box.

Type	Reef	Cover (%)	s.e.	Area (ha)	95% CI
Total seagrass	Ashmore	2.07	0.35	470.73	33.40
	Browse	0.00	0.00	0.00	#DIV/0!
	Cartier	0.11	0.05	1.17	96.47
	Hibernia	0.00	0.00	0.00	#DIV/0!
	Scott Nth	0.22	0.06	23.30	55.24
	Scott Sth	0.54	0.10	77.43	36.94
	Seringapatam	0.04	0.02	2.02	87.46
	Total area	1.03	0.15	574.65	27.80
Thalassia hemprichii	Ashmore	1.78	0.24	403.93	26.04
	Browse	0.00	0.00	0.00	#DIV/0!
	Cartier	0.11	0.05	1.17	96.47
	Hibernia	0.00	0.00	0.00	#DIV/0!
	Scott Nth	0.11	0.03	11.40	59.42
	Scott Sth	0.49	0.10	70.66	40.18
	Seringapatam	0.02	0.01	1.16	137.78
	Total area	0.87	0.10	488.34	22.28
Halophila ovalis	Ashmore	0.03	0.02	5.70	125.66
	Browse	0.00	0.00	0.00	#DIV/0!
	Cartier	0.00	0.00	0.00	#DIV/0!
	Hibernia	0.00	0.00	0.00	#DIV/0!
	Scott Nth	0.10	0.05	10.81	92.41
	Scott Sth	0.04	0.01	6.24	54.69
	Seringapatam	0.02	0.01	0.86	86.62
	Total area	0.04	0.01	23.61	53.84
Thalassodendron ciliatum	Ashmore	0.27	0.26	61.05	193.59
	Browse	0.00	0.00	0.00	#DIV/0!
	Cartier	0.00	0.00	0.00	#DIV/0!
	Hibernia	0.00	0.00	0.00	#DIV/0!
	Scott Nth	0.01	0.01	0.80	148.57
	Scott Sth	0.00	0.00	0.00	#DIV/0!
	Seringapatam	0.00	0.00	0.00	#DIV/0!
	Total area	0.11	0.11	61.85	190.43

APPENDIX E

Stratified mean cover and estimated total area of algae by genus for the shallow reefs in the MOU 74 Box.

Type	Reef	Cover (%)	s.e.	Area (ha)	95% CI
Algae	Ashmore	14.51	1.22	3292.63	16.63
	Browse	16.95	2.23	77.16	27.06
	Cartier	29.69	3.59	322.29	24.78
	Hibernia	38.53	7.03	442.21	36.88
	Scott Nth	22.38	1.84	2374.79	16.27
	Scott Sth	19.76	1.29	2844.88	12.89
	Seringapatam	23.05	2.89	1272.01	25.03
	Total area	19.00	0.77	10625.97	7.92
Halimeda spp.	Ashmore	4.33	0.46	983.12	21.13
	Browse	3.07	0.57	13.96	38.18
	Cartier	6.40	0.92	69.43	29.53
	Hibernia	6.03	1.26	69.19	42.32
	Scott Nth	1.26	0.24	133.34	37.79
	Scott Sth	3.15	0.29	452.93	17.90
	Seringapatam	1.02	0.28	56.08	55.35
	Total area	3.18	0.21	1778.04	13.07
Dictyota spp.	Ashmore	0.92	0.31	209.71	65.04
	Browse	0.00	0.00	0.00	#DIV/0!
	Cartier	0.00	0.00	0.00	#DIV/0!
	Hibernia	0.00	0.00	0.00	#DIV/0!
	Scott Nth	0.20	0.17	21.03	164.85
	Scott Sth	0.00	0.00	0.00	#DIV/0!
	Seringapatam	0.43	0.34	23.83	158.73
	Total area	0.46	0.13	254.57	56.99
Turbinaria ornata	Ashmore	0.55	0.12	124.96	42.93
	Browse	0.78	0.27	3.53	70.34
	Cartier	0.00	0.00	0.00	#DIV/0!
	Hibernia	0.00	0.00	0.00	#DIV/0!
	Scott Nth	0.46	0.15	48.33	66.53
	Scott Sth	0.11	0.04	16.20	78.41
	Seringapatam	0.07	0.06	3.67	190.52
	Total area	0.35	0.06	196.69	32.52
Caulerpa spp.	Ashmore	0.48	0.24	108.30	99.41
	Browse	0.00	0.00	0.00	#DIV/0!
	Cartier	0.00	0.00	0.00	#DIV/0!
	Hibernia	0.07	0.07	0.84	202.11
	Scott Nth	0.87	0.33	91.87	75.81
	Scott Sth	0.15	0.10	22.15	126.37
	Seringapatam	4.63	1.46	255.59	62.78
	Total area	0.86	0.19	478.76	42.79
Ceratodictyon spp.	Ashmore	0.63	0.12	142.12	39.12
	Browse	0.00	0.00	0.00	#DIV/0!
	Cartier	1.54	0.64	16.71	84.87
	Hibernia	0.45	0.29	5.21	127.23
	Scott Nth	0.57	0.17	60.78	59.75
	Scott Sth	0.63	0.13	91.43	41.17
	Seringapatam	1.12	0.35	62.07	62.70
	Total area	0.68	0.08	378.32	22.84

Type	Reef	Cover (%)	s.e.	Area (ha)	95% CI
Gracilaria spp.	Ashmore	0.10	0.05	22.11	93.70
	Browse	0.00	0.00	0.00	#DIV/0!
	Cartier	0.32	0.25	3.52	158.44
	Hibernia	0.00	0.00	0.00	#DIV/0!
	Scott Nth	0.07	0.06	6.91	188.51
	Scott Sth	0.83	0.14	118.85	33.29
	Seringapatam	0.00	0.00	0.00	#DIV/0!
	Total area	0.27	0.04	151.38	30.81
Laurencia spp.	Ashmore	1.16	0.36	263.73	61.05
	Browse	0.00	0.00	0.00	#DIV/0!
	Cartier	1.60	1.17	17.37	150.59
	Hibernia	0.00	0.00	0.00	#DIV/0!
	Scott Nth	0.02	0.02	2.23	167.38
	Scott Sth	0.68	0.29	97.30	83.19
	Seringapatam	0.00	0.00	0.00	#DIV/0!
	Total area	0.68	0.17	380.63	47.64
Turf algae	Ashmore	2.08	0.25	472.09	24.14
	Browse	11.29	1.63	51.41	29.69
	Cartier	5.97	2.90	64.77	99.63
	Hibernia	13.03	4.11	149.52	63.70
	Scott Nth	10.89	1.09	1155.47	19.82
	Scott Sth	7.88	0.87	1134.17	21.85
	Seringapatam	8.12	1.28	448.04	31.57
	Total area	6.22	0.36	3475.46	11.42
Padina spp.	Ashmore	0.48	0.09	109.23	36.42
	Browse	0.00	0.00	0.00	#DIV/0!
	Cartier	0.09	0.09	0.94	205.18
	Hibernia	0.00	0.00	0.00	#DIV/0!
	Scott Nth	0.10	0.05	10.38	105.74
	Scott Sth	0.01	0.01	1.47	118.32
	Seringapatam	0.00	0.00	0.00	#DIV/0!
	Total area	0.22	0.04	122.02	33.76
Crustose coraline algae	Ashmore	0.95	0.12	216.22	24.16
	Browse	0.00	0.00	0.00	#DIV/0!
	Cartier	1.16	0.72	12.56	127.37
	Hibernia	12.53	2.44	143.83	39.40
	Scott Nth	3.06	0.81	324.38	52.08
	Scott Sth	1.14	0.20	163.49	34.37
	Seringapatam	1.10	0.28	60.69	50.00
	Total area	1.65	0.18	921.18	21.21
Cladophora socialis	Ashmore	0.35	0.15	80.43	82.24
	Browse	0.00	0.00	0.00	
	Cartier	11.03	2.77	119.68	51.47
	Hibernia	4.53	1.25	51.96	55.76
	Scott Nth	3.64	0.86	386.67	46.55
	Scott Sth	2.96	0.63	426.00	42.20
	Seringapatam	6.56	2.30	361.93	70.15
	Total area	2.55	0.33	1426.67	25.75

APPENDIX F

Stratified mean cover and estimated total area of all soft corals and *Sarcophyton* spp. for the shallow reefs in the MOU 74 Box.

Type	Reef	Cover	s.e.	Area (ha)	95% CI
Total soft corals	Ashmore	1.42	0.40	323.37	55.00
(Alcyonacea)	Browse	0.14	0.07	0.65	99.46
	Cartier	1.59	0.49	17.22	62.92
	Hibernia	3.75	0.61	43.04	33.03
	Scott Nth	0.53	0.11	56.18	40.53
	Scott Sth	0.42	0.05	60.06	23.17
	Seringapatam	0.15	0.04	8.02	48.96
	Total area	0.91	0.16	508.54	35.41
Sarcophyton spp.	Ashmore	0.08	0.03	18.82	66.63
	Browse	0.04	0.04	0.17	205.55
	Cartier	0.38	0.16	4.15	85.09
	Hibernia	0.38	0.17	4.37	88.76
	Scott Nth	0.21	0.04	22.49	33.87
	Scott Sth	0.16	0.03	22.59	31.78
	Seringapatam	0.03	0.01	1.70	76.61
	Total area	0.13	0.02	74.28	23.00

APPENDIX G

Stratified mean cover and estimated total area of live and dead coral by growth form for the shallow reefs in the MOU 74 Box.

		live			dead			
Coral type	Reef	Cover (%)	s.e.	Area (ha)	Cover (%)	s.e.	Area (ha)	% Dead
Total	Ashmore	3.16	0.61	717.64	0.20	0.09	44.63	5.86
	Browse	8.31	3.06	37.83	0.00	0.00	0.00	0.00
	Cartier	9.71	2.01	105.39	0.10	0.10	1.12	1.06
	Hibernia	13.16	4.90	151.06	2.00	0.77	22.97	13.20
	Scott Nth	3.21	0.28	340.75	10.05	1.27	1066.74	75.79
	Scott Sth	4.24	0.31	610.38	7.83	0.69	1127.12	64.87
	Seringapatam	5.91	0.55	326.46	5.57	0.76	307.69	48.52
	Total area	4.09	0.29	2289.52	4.60	0.31	2570.27	52.89
Massive	Ashmore	1.02	0.19	231.98	0.04	0.02	9.26	3.84
	Browse	2.14	0.38	9.72	0.00	0.00	0.00	0.00
	Cartier	1.98	0.30	21.44	0.00	0.00	0.00	0.00
	Hibernia	1.93	0.23	22.12	0.01	0.01	0.11	0.50
	Scott Nth	1.91	0.22	202.58	0.61	0.20	65.26	24.37
	Scott Sth	2.21	0.23	318.51	1.13	0.22	162.87	33.83
	Seringapatam	2.06	0.34	113.42	0.37	0.06	20.49	15.30
	Total area	1.64	0.11	919.78	0.46	0.07	257.99	21.91
Branching	Ashmore	0.46	0.18	105.21	0.00	0.00	0.84	0.79
	Browse	3.81	2.77	17.35	0.00	0.00	0.00	0.00
	Cartier	2.28	1.20	24.74	0.01	0.01	0.11	0.45
	Hibernia	6.53	4.95	74.95	1.77	0.76	20.33	21.34
	Scott Nth	0.36	0.08	37.92	8.43	1.25	894.78	95.93
	Scott Sth	0.40	0.07	57.01	4.52	0.49	651.37	91.95
	Seringapatam	0.65	0.14	35.99	3.64	0.70	200.94	84.81
	Total area	0.63	0.13	353.17	3.16	0.28	1768.37	83.35
Digitate	Ashmore	0.42	0.11	95.42	0.07	0.04	16.00	14.36
	Browse	1.70	0.48	7.73	0.00	0.00	0.00	0.00
	Cartier	0.87	0.52	9.47	0.00	0.00	0.00	0.00
	Hibernia	2.12	0.56	24.35	0.16	0.15	1.83	6.98
	Scott Nth	0.16	0.03	16.58	0.26	0.07	28.03	62.84
	Scott Sth	0.30	0.05	43.61	1.28	0.21	184.65	80.90
	Seringapatam	0.89	0.26	49.24	0.70	0.15	38.62	43.96
	Total area	0.44	0.06	246.39	0.48	0.06	269.13	52.20
Foliose	Ashmore	0.03	0.02	6.29	0.00	0.00	0.00	0.00
	Browse	0.00	0.00	0.00	0.00	0.00	0.00	
	Cartier	0.17	0.17	1.88	0.00	0.00	0.00	0.00
	Hibernia	0.10	0.05	1.12	0.00	0.00	0.00	0.00
	Scott Nth	0.29	0.07	30.99	0.46	0.11	49.01	61.26
	Scott Sth	0.16	0.07	23.06	0.07	0.03	10.77	31.83
	Seringapatam	1.04	0.31	57.57	0.33	0.16	18.31	24.13
	Total area	0.22	0.04	120.90	0.14	0.03	78.09	39.24
Submassive	Ashmore	0.93	0.29	210.75	0.08	0.04	18.53	8.08
	Browse	0.46	0.19	2.10	0.00	0.00	0.00	0.00
	Cartier	3.80	0.65	41.22	0.00	0.00	0.00	0.00
	Hibernia	1.90	0.25	21.75	0.06	0.04	0.70	3.12
	Scott Nth	0.10	0.03	10.89	0.03	0.01	3.54	24.56
	Scott Sth	0.33	0.07	47.66	0.30	0.09	43.19	47.54
	Seringapatam	0.42	0.17	23.22	0.23	0.11	12.96	35.82
	Total area	0.64	0.12	357.58	0.14	0.03	78.92	18.08

Coral type	Reef	live			dead			
		Cover (%)	s.e.	Area (ha)	Cover (%)	s.e.	Area (ha)	% Dead
Plate	Ashmore	0.06	0.02	14.51	0.00	0.00	0.00	0.00
	Browse	0.16	0.05	0.75	0.00	0.00	0.00	0.00
	Cartier	0.13	0.06	1.46	0.09	0.09	1.01	40.93
	Hibernia	0.32	0.06	3.68	0.00	0.00	0.00	0.00
	Scott Nth	0.00	0.00	0.40	0.05	0.01	4.82	92.36
	Scott Sth	0.03	0.01	4.68	0.35	0.11	50.79	91.56
	Seringapatam	0.08	0.05	4.44	0.08	0.05	4.68	51.29
	Total area	0.05	0.01	29.92	0.11	0.03	61.30	67.20
Encrusting	Ashmore	0.20	0.09	46.09	0.00	0.00	0.00	0.00
	Browse	0.23	0.16	1.07	0.00	0.00	0.00	0.00
	Cartier	0.48	0.18	5.24	0.00	0.00	0.00	0.00
	Hibernia	0.41	0.07	4.75	0.00	0.00	0.00	0.00
	Scott Nth	0.39	0.05	41.32	0.16	0.05	16.81	28.91
	Scott Sth	0.61	0.09	87.60	0.05	0.02	7.73	8.11
	Seringapatam	0.80	0.16	44.31	0.14	0.04	7.96	15.24
	Total area	0.41	0.05	230.38	0.06	0.01	32.50	12.36

APPENDIX H

Reef habitats classified from satellite data and interpretation of field data. Tables represent two satellite scenes.

a) Southern reefs (including Scott Reefs).

Habitat	Sites	Depth (m)	Sand	Rubble	Con. rub.	Boulder	Pavement	Coral live	Coral dead	Soft coral	Seagrass	Green algae	Brown algae	Red algae
Deep lagoon	81	12.19	30.96	18.26	11.11	6.93	5.22	5.02	13.36	0.27	0.11	5.86	0.15	0.00
Back reef /shallow lagoon	36	4.89	48.17	17.39	8.89	4.42	4.31	2.00	12.25	0.38	0.07	2.24	0.51	2.10
Deep reef flat	31	2.50	22.13	13.87	39.45	3.97	10.81	4.00	7.13	0.08	0.27	4.92	0.54	3.61
Sandy intermediate	44	2.21	63.34	16.45	10.50	3.55	0.68	1.69	4.07	0.06	0.09	3.90	1.05	3.89
Reef crest	37	1.67	10.54	20.92	31.57	2.73	28.65	3.80	0.84	0.41	0.47	19.84	0.18	1.20
Reef flat	43	1.60	39.26	16.93	33.35	2.44	2.33	4.49	0.72	0.16	1.45	11.74	0.19	3.24

b) Northern reefs (including Ashmore Reef).

Habitat	Sites	Depth (m)	Sand	Rubble	Con. rub.	Boulder	Pavement	Coral live	Coral dead	Soft coral	Seagrass	Green algae	Brown algae	Red algae
Lagoon	25	4.07	27.24	22.14	29.36	2.72	5.60	10.24	0.48	4.88	3.01	5.90	1.91	0.87
Deep reef flat	35	2.14	24.29	27.60	35.60	2.14	5.77	4.69	0.03	1.98	0.76	12.51	5.64	4.73
Reef flat	65	1.44	49.65	16.26	25.35	0.28	4.29	4.16	0.46	0.58	5.31	10.16	1.76	3.17
Sandy intermediate	72	1.43	90.79	4.50	3.89	0.26	0.00	0.90	0.14	0.02	1.20	3.24	1.32	0.75
Sand	20	1.50	100.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.68	0.03	0.01	0.00
Deep sand/rubble	11	3.45	61.18	21.73	13.00	0.00	2.73	2.93	0.00	1.45	0.66	11.91	1.14	2.50
Deep sand/algae	8	2.03	78.75	9.75	11.25	0.00	0.00	0.38	0.00	0.13	0.00	7.85	2.08	3.89

APPENDIX I

Reef edge habitats based in reef-edge orientation and relation to reef.

Edge strata	Sites	Length (m)	Width (m)	Area (ha)	Sand	Rubble	Cons-rub	Boulders	Bommies	Pave-ment	Live coral	Dead coral	Soft corals	Algae	Seagrass	Sponges
Front reef	103	172547.05	127.19	2194.60	6.92	11.60	25.47	5.39	4.73	29.44	11.89	5.37	4.53	28.81	0.00	2.31
Back reef	56	95272.90	123.67	1178.24	15.94	16.67	27.31	5.93	3.77	10.82	8.13	12.14	2.92	20.07	0.03	2.43
Lagoon edge	72	34171.66	409.14	1398.10	45.12	18.91	7.24	1.84	3.32	0.51	3.55	20.14	1.10	15.80	0.64	1.39

APPENDIX J

Scott Reef South shoal (deep lagoon) habitats derived from discriminant function analysis of the results of video analysis and acoustic data collection.

Habitat	Area (Ha)	Sites	Depth (m)	Soft seds	Rubble	Rock	Boulders	Live coral	No garden	V. sparse garden	Sparse garden	Dense garden	Reef	Alage	*Halimeda* spp
Sand	4932.411	6	44.50	71.33	26.00	3.50	0.67	0.17	89.50	10.00	0.17	0.33	0.00	2.67	2.67
Coarse sand	2556.018	6	50.83	29.17	36.67	5.00	20.83	15.00	21.67	7.50	15.00	19.17	36.67	5.00	5.00
Rubble	12227.37	14	47.86	15.36	45.14	9.29	11.64	20.36	10.00	9.64	31.07	10.00	25.00	7.50	7.36
Rock	6364.261	6	39.50	15.00	39.17	11.67	20.00	16.67	27.50	9.17	19.17	10.00	34.17	2.33	1.50
Reef	3156.022	9	50.33	8.33	40.00	3.89	8.89	38.89	1.11	13.33	18.33	6.67	60.56	1.78	1.78

APPENDIX K

Strata mean abundance and variance estimates for the calculation of cover of live coral estimates for the Scott Reef South shoal (deep lagoon) area. Column headings correspond to formula listed in Appendix L.

	Sites			Coral	Coral	Total	Total
Habitat	n_h	Area (ha)	Wh	Y_h	S^2_h	Y_{st}	$v(Y_{st})$
Sand	6	4932.411	0.169	0.17	0.17	0.03	0.00
Coarse sand	6	2556.018	0.087	15.00	160.00	1.31	0.20
Rubble	14	12227.37	0.418	20.36	67.17	8.51	0.84
Rock	6	6364.261	0.218	16.67	36.67	3.63	0.29
Reef	9	3156.022	0.108	38.89	636.11	4.20	0.82

	Sites		yst			Total Area	95% CI
Habitat	n	Area (ha)	(%)	$v(Y_{st})$	s.e.	(ha)	%
Total area	41	29236.08	17.68	2.1571	1.47	5168.82	16.78

APPENDIX L

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