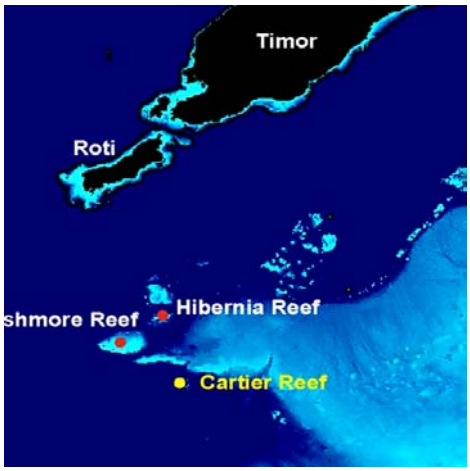

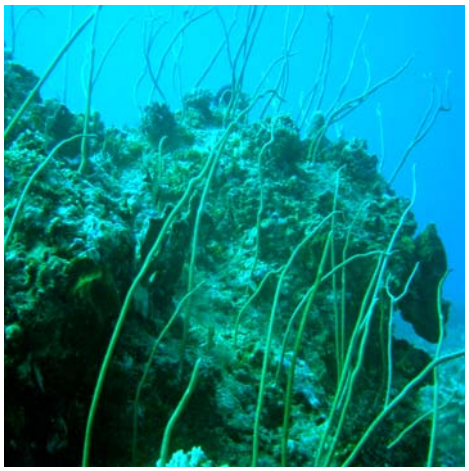

Stocks of trochus and bêche-de-mer at Cartier Reef: 2001 surveys

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Executive Summary

BACKGROUND

Cartier Reef is a small emergent reef system, approximately 12 km^2 in area, on the edge of the continental shelf off the northwest Kimberley coastline of Western Australia. Cartier Reef forms part of Australia's Territory of Ashmore and Cartier Islands and is managed by Australia under the terms of an agreement between the Australian and Indonesian Governments. The reef was proclaimed a reserve in June 2001. Currently, traditional Indonesian fishing for trochus and bêche-de-mer is allowed on Cartier Reef, but is likely to be prohibited when the management plan for Ashmore and Cartier Reserves comes into effect (expected to be mid-2002).

In November 2001, ecologists from the Australian Institute of Marine Science surveyed Cartier Reef. The objectives of this survey were; to determine the distribution and abundance of the trochus, *Trochus niloticus*, and bêche-de-mer, (holothuria); to design and obtain the first data for a long-term monitoring program of these stocks; and to recommend future management strategies. The work was undertaken using the ACV Arnhem Bay.

CURRENT FINDINGS

Trochus are particularly susceptible to unsustainable exploitation because they are so easily collected. The trochus, *Trochus niloticus*, has been severely depleted at Cartier Reef. Extensive surveys recorded 58 trochus, having a mean density on the reef crest and slope of only 3.3 and 2.2 individuals per hectare, respectively. Trochus were extremely rare on the shallow (1-3 m) reef crest, which numerous studies elsewhere indicate they are found in the greatest abundance. The densities of trochus at Cartier Reef are less than at Ashmore Reef, and are far less than on parts of the Great Barrier Reef that are open to fishing. Furthermore, most of the trochus at Cartier Reef are in deep water (>10 m), which provides somke degree of refuge from the traditional fishing methods of reef walking and free diving.

The highly valued bêche-de-mer species, *Holothuria nobilis* (black teat fish) and *H. fuscogilva* (white teat fish) have been severely depleted at Cartier Reef. Only a single white teat fish was recorded (31 m depth), and no *H. nobilis*. In the absence of the high

value bêche-de-mer, Indonesian fishers were observed during the survey targeting all related species. While bêche-de-mer of low or limited value are comparatively abundant at Ashmore Reef, they are in critically low numbers at Cartier Reef. The reef flat at Cartier is fishable in its entirety during a single low tide because of its small size, and consequently most of its bêche-de-mer are easily fished.

MANAGEMENT RECOMMENDATIONS

The trochus and bêche-de-mer fishery at Cartier Reef should be closed. Stocks are critically low, and are likely to become locally extinct in the near future unless a total ban on fishing is implemented. This study provides a foundation for the monitoring of trochus and bêche-de-mer populations, and should repeated every two years using the techniques developed here. Permanent study sites have been established, and a repeated measure analysis of the diversity and abundance of the target species provides a powerful tool to assess stock recovery. If the stocks at Cartier Reef do not recover over time, then methods of stock enhancement, and the translocation of individuals, may be required. The natural recovery of trochus and bêche-de-mer, or the success of a plan to restock Cartier Reef, relies on the enforcement of a total fishing ban.

Basic information about the biology of trochus and bêche-de-mer within the MOU Box is required. Data on size and age of reproduction, growth, and mortality, are critical to models that estimate the sustainable fishing effort, and recovery times, for these exploited stocks. Advice should be sought from marine research agencies, including AIMS, CSIRO and AGSO, to integrate data on biology and ecology, with oceanography and bathymetry. This suite of information enables an assessment of the extent of habitat that may support these target species within the Oceanic Shoals bioregion. It also provides insights into the connectivity to adjacent reefs, that extend beyond the boundaries of the MOU74 Box.

Introduction

BACKGROUND

Cartier Reef is a small (12km^2) emergent reef, on the edge of the continental shelf approximately 350 km2 off the Kimberley coast (Fig. 1). The reef has been know for centuries by Indonesian fishers as Palau Baru. It was first discovered by Europeans in 1800, by Captain Nash, aboard the vessel Cartier. In 1909 it was annexed by Great Britain, and in 1931 placed under the authority of the Commonwealth of Australia. Although the Island and its surrounding area (10 km radius) is gazetted a Defence Practise Area, it has not be used as one for at least a decade. The reef was proclaimed a reserve in June 2001. Currently, traditional Indonesian fishing for trochus and bêche-de-mer is allowed on Cartier Reef, but is likely to be prohibited when the management plan for Ashmore and Cartier Reserves comes into effect (expected to be mid-2002).

Cartier Reef is a typical emergent coral reef, rising from a depth of approximately 200 m. It consists of an emergent sandy islet; a reef flat composed of sand, bare coral pavement, and corals (*Heliopora sp., Porites sp. Acropora palifera*); and a small lagoon, approximately eight metres deep. The reef crest and slope are rich in corals and tropical alga such as *Halimeda spp*. Two wrecks are visible on the reef flat. The Ann Millicent, a 944 ton iron barge on the southern edge of the reef, which was wrecked on 5 January 1888. On the eastern flank of the reef are the remains of a traditional Indonesian fishing vessel, which apparently sank two months before this study was conducted. Additionally, on the sandy islet are the remains of a RAAF Beaufighter, that landed on Cartier during the second War World.

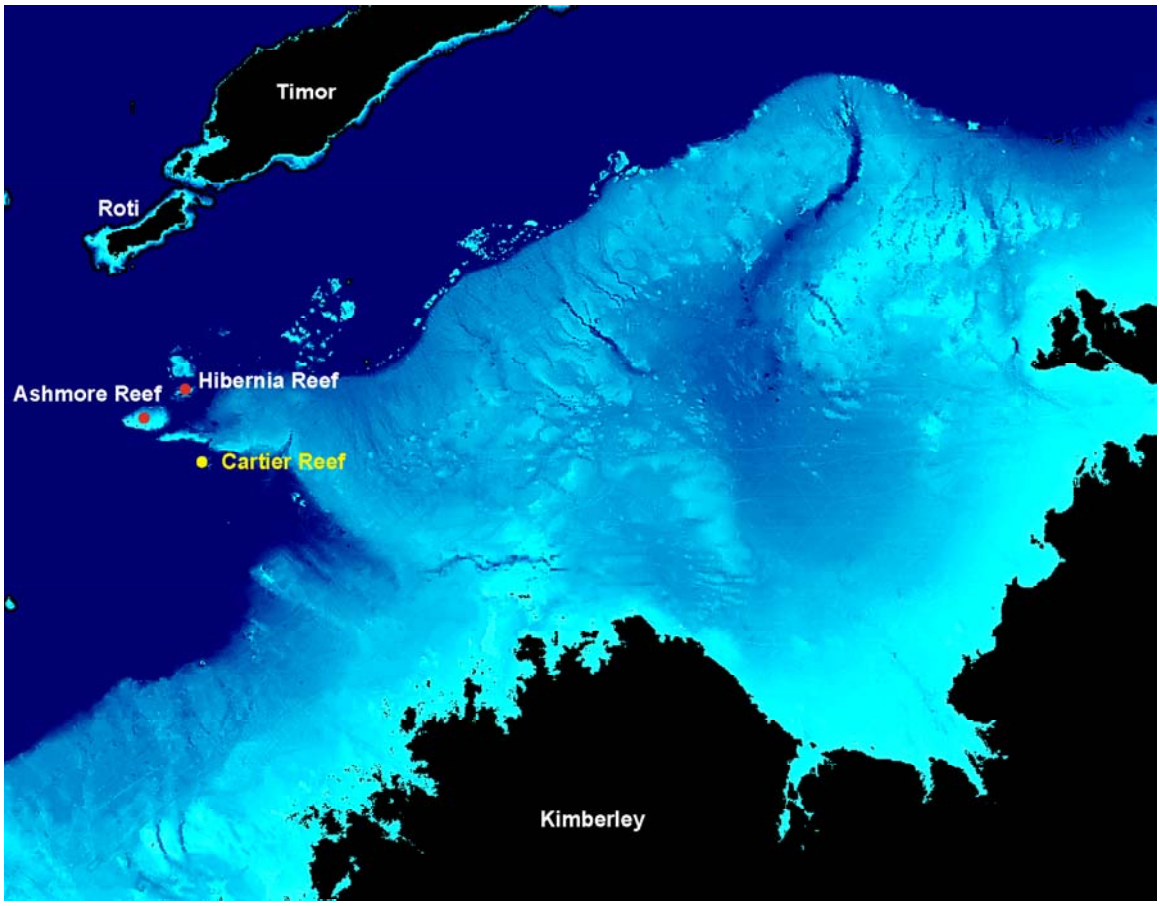


Fig. 1: The far northwest continental shelf showing Cartier Reef (original bathometry figure from AGSO: after Heyward, Pinceratto, & Smith 1997). The majority of submerged reefs in this region are along the edge of the shelf, and may support additional populations of trochus and bêche-de-mer

FISHING OF BÊCHE-DE-MER AND TROCHUS

Bêche-de-mer, also known as holothurians, trepang, or sea cucumbers, have been fished for centuries off the northwest of Australia. Surveys of the Kimberley Coast in the early 1800's encountered numerous Maccasans (from Sulawesi) fishing for bêche-de-mer (Horden 1997). After 1900, their catch likely expanded to trochus shell and shark fin (Anon. 1989). The catch is processed simply and stored at sea and requires no refrigeration.

Bêche-de-mer is traditionally collected by reef walking or by shallow free diving. Certain species are preferred, notably *Holothria nobilis* (black teat fish), *Holothuria fuscogilva* (white teat fish) and *Thelenota ananas* (prickly red fish). However, as populations of these species are reduced, other species are targeted. Once collected,

the animals are cleaned, boiled, and sun-dried (Cannon and Silver 1987) or simply cleaned and salted (pers. obs.). Bêche-de-mer is a valuable catch for these fishers, and sells for up to A$30 per kilogram in Asia (Caddy 1995). Bêche-de-mer is high in protein, but its value may be related to the belief that it is an aphrodisiac.

The large marine snails, from the genus *Trochus* (Figure 4), are collected in similar ways to bêche-de-mer. The meat of this mollusc is usually discarded, because it is of secondary importance to its lustrous shell. The mother of pearl shell is used to produce buttons, jewellery, ceramics, ornaments, cosmetics and metallic paints; and is sold in Asia, Europe and America.

Stocks of trochus and bêche-de-mer on all reefs within the MOU74 Box may be dramatically over-fished. An extensive survey of this region in 1999 found low, to very low, densities of trochus and bêche-de-mer at most locations (Skewes et al. 1999). It was concluded that stocks were severely depleted throughout the whole area of the MOU74 Box. Ashmore Reef had the largest populations of any emergent reef, but even these were depleted in some habitats. An extensive survey of Ashmore Reef in 2000 revealed that stocks of high commercial value bêche-de-mer and trochus were extremely low, and bêche-de-mer of low or moderate value were more abundant (Smith et al. 2001).

In view of these data, an extensive stock assessment of bêche-de-mer and trochus at nearby Cartier Reef was undertaken. The primary aims of that survey were to:

- provide information on the distribution and abundance of bêche-de-mer and trochus at Cartier Reef, between one and 22 m depth;
- provide recommendations for future monitoring studies, and for the management of these target stocks at Cartier Reef.

Methods

SURVEY DESIGN

Field surveys relied on the support of the Australian Customs Service, and the use of the ACV Arnhem Bay. This study was designed as both a baseline survey, and as the foundation for a long-term monitoring program of trochus and bêche-de-mer stocks. The sampling design was stratified, and a range of techniques were used to determine the distribution and abundance of stocks, because of the variability in habitat, depth, and oceanographic conditions (eg. currents and tidal conditions) (Fig. 2). Census techniques included; distance swim surveys, manta tows, and timed swims. The location (latitude and longitude) of transects within each habitat were recorded, so that each could be re-visited, enabling an accurate assessment of changes in stock sizes from future surveys. Counts were performed between November 19 and November 23, 2001.

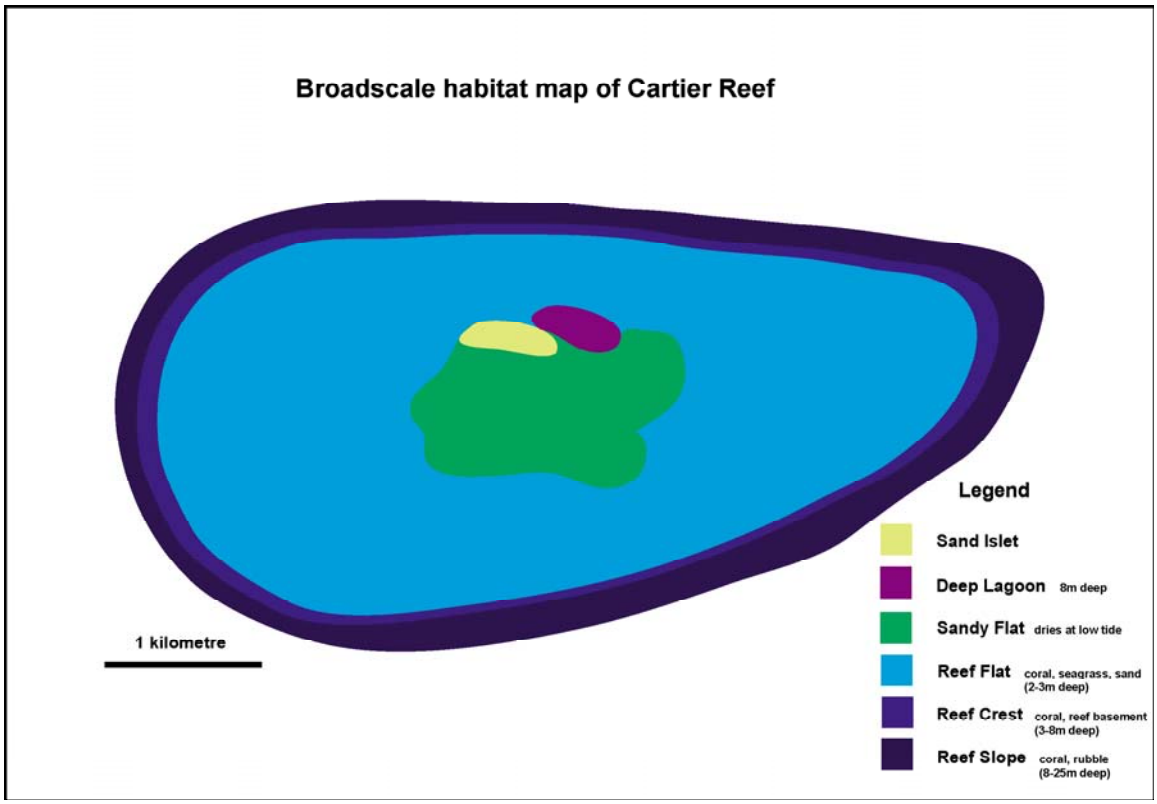


Fig. 2: Habitat map of Cartier Reef

DISTANCE SWIM SURVEYS

Diver observation was used to survey deep, high-current habitats, along the outermost reef flat and upper reef crest (Fig. 3). Snorkel dives, in preference to SCUBA, were used because they facilitated a rapid visual assessment of the benthic habitat. At high tide, each of three observers censused a 500 m by 5 m belt transect. The three observers swam side-by-side, parallel to the outer edge of the reef, with 10 m between them. The outer observer censused the edge of the reef crest and the upper reef slope. The middle and inner observers censused the outer reef flat. At each swim, 7500 m^2 of reef substrata was censused, and a total of 37500 m^2 using this technique. The latitude and longitude of the start and end point of each transect was recorded using a GPS (Appendix 1).

MANTA TOWS

The manta tow technique allows a rapid, large-scale, assessment of benthic organisms on shallow substrata (Fig. 3). A snorkel diver (observer) was towed at a constant speed, by holding a manta board attached with 17 m of rope to a small boat (see Bass and Miller 1996). The observer visually assessed specific variables (depth, habitat type, dominant biota and substrate type), and counted the number of trochus and bêche-de-mer. These were recorded onto waterproof paper attached to the manta board. At each manta tow, a 500 m by 2 m transect (1000 m^2) of the substrata was censused. A total of 26 manta tows were performed, surveying 26000 m^2. The start and end point of each manta tow were recorded using a GPS (Appendix 1).

TIMED SWIMS

An alternative method was required for bêche-de-mer and trochus that inhabit depths greater than those effectively censused by distance swims or manta tow. Consequently, timed swims were performed on SCUBA (Fig. 3). Each swim was 10 minutes long, and undertaken by three observers swimming side-by-side, separated by 5 m. Each observer censused a five metre wide strip of substrata. On average, 300 m was covered in each 10 minute swim. A total of 13 transects were performed using this technique, surveying approximately 58500 m^2 of substrata. The start and end point of each timed swim were recorded using a GPS (Appendix 1).

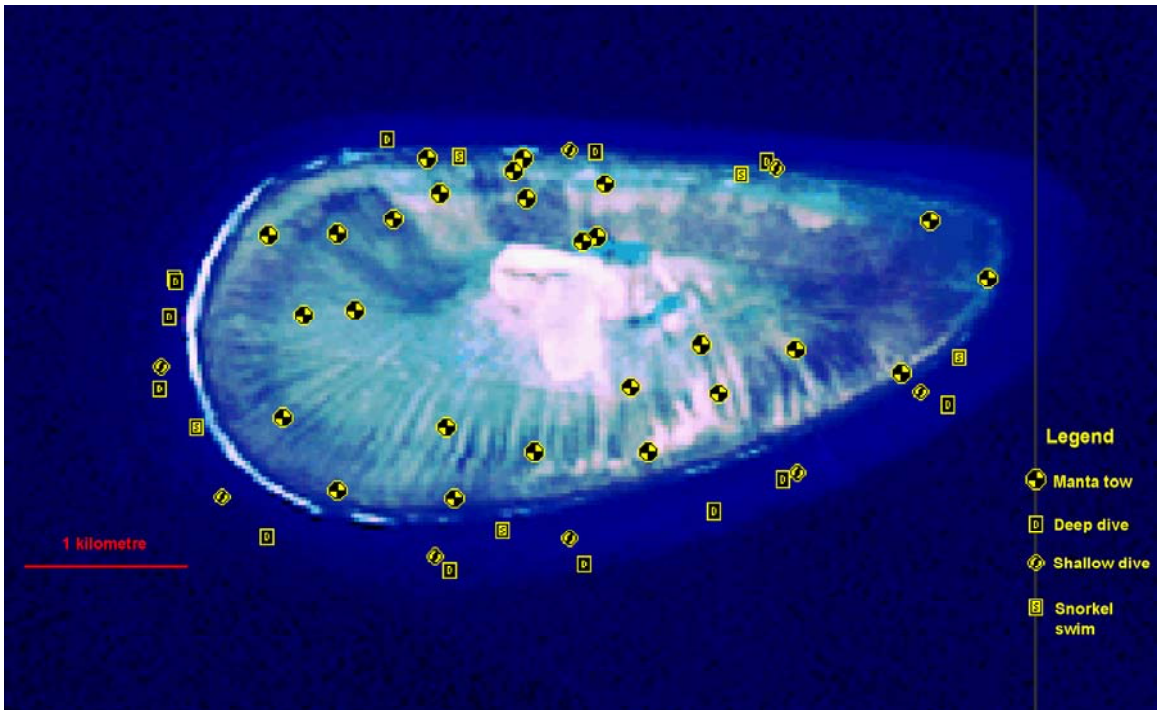


Fig. 3: Map of Cartier Reef showing the location of the different surveys undertaken in November 2001. The map shows the starting point for each census (for full GPS locations, see Appendix 1).

Results

TROCHUS POPULATIONS

Extensive surveys for trochus were undertaken over all habitats shallower than 25m at Cartier Reef. Only 58 individuals of the large commercial species *Trochus niloticus* (Fig. 4*)* were recorded during these surveys. The mean density of trochus on the reef crest (dark blue habitat, Fig. 2) and reef slope (black habitat, Fig. 2) was 2.2 and 3.3 individuals per hectare, respectively (Table 1). Extrapolating from these data indicate that only 951 (± 437%, 95%C.I.) trochus are found at Cartier Reef, of which most are in depths of water greater than 11m (Table 1, Fig. 5).

Fig. 4. A trochus, *Trochus niloticus*, at 18m depth on the southern reef slope of Cartier Reef. The shell is encrusted with crustose and filamentous algae, making visual observations of individuals at these depths, while snorkelling, inaccurate

Previous surveys of Cartier Reef in 1998 estimated that the total number of *T. niloticus* was 222 (± 235%, 95% C.I.; Skewes et al. 1999), which is far less than the estimate of 951 in this study. The apparent difference is probably related to our extensive survey of the deeper reef slope (>15m), which was not surveyed by Skewes (et al. 1999), rather than a recovery of the population.

Table 1. Estimated population size of *T. niloticus*, within each habitat, at Cartier Reef

Habitat Type	Area (ha.)	Total number	Av. Density (per ha.)	95% C.I. (% of mean)*
Sandy Flat (1 – 2m)	107.27	0	0.00	--
Deep Lagoon (6 – 8m)	7.56	0	0.00	--
Reef Flat (2 – 3m)	721.00	0	0.00	--
Reef Crest (2 – 8m)	129.16	172	1.33	327
Reef Slope (9 – 24m)	233.90	779	3.33	262
Total	1198.89	951	0.79	273

* With a 95% confidence, the trochus population size at Cartier is between 344 and 2605 individuals. The low number of trochus encountered at each sampling site and their patchy distribution patterns caused a large difference in upper and lower estimates for total population size.

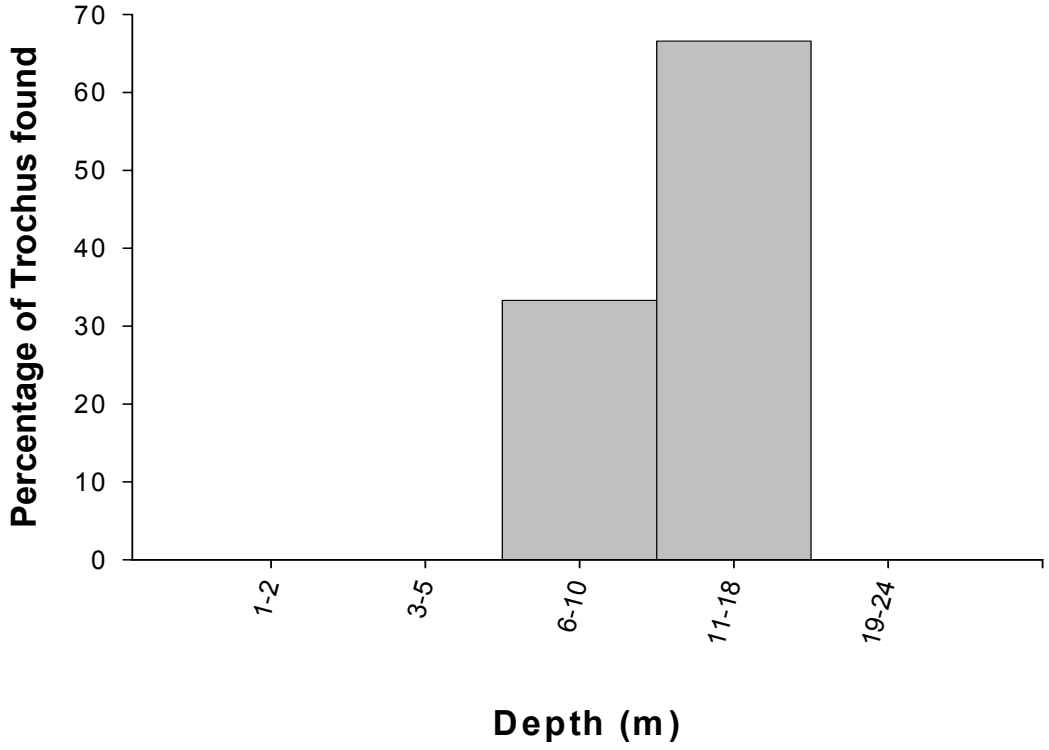


Fig. 5 Depth distribution of *T. niloticus* at Cartier Reef

The average basal width of the trochus at Cartier Reef was 97.8 mm, and most adults were over 100 mm (Fig. 6). The lack of individuals less than 100 mm could be for two reasons. Firstly, juvenile trochus are extremely cryptic, making them very difficult to census. However, the smallest sized trochus were adults above 55 mm, at which size

they would have normally emerged from the reef matrix and would be more visible. Alternatively, and more likely, juveniles are absent because they are found in habitats that are easily fished. Juveniles are found in rubble on the reef flat, and the small adults on the reef crest or the shallow reef slope (Nash 1993). Both of these habitats are easily fished by reef walking or free diving. In contrast, the larger adults are more abundant because they are found in deeper waters that are not easily fished.

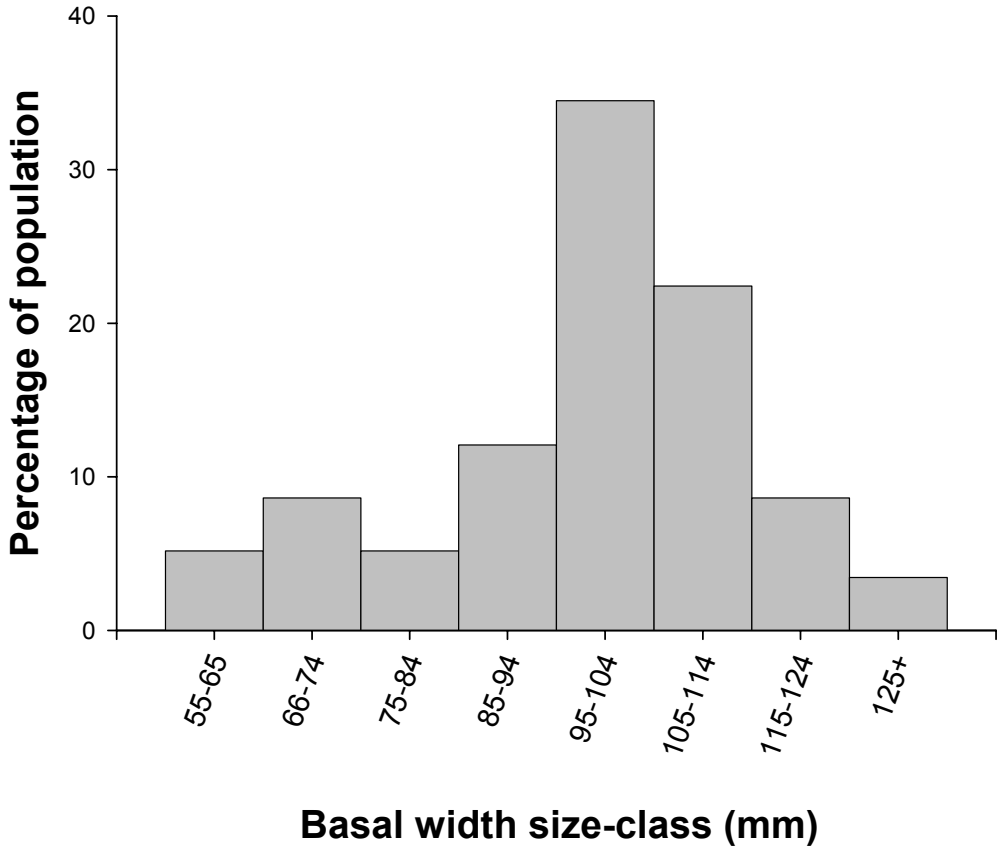


Fig. 6. Size-frequency distribution of *T. niloticus* at Cartier Reef

BÊCHE-DE-MER POPULATIONS

In total, 79 bêche-de-mer, of seven different species, were counted in the survey of Cartier Reef. The majority were on the reef flat in less than three metres of water, and were species of limited commercial value. However, all of these species were observed being collected by Indonesian fishers during this survey. *Holothuria atra* was the most abundant (64%) of the bêche-de-mer species (Fig. 7). Extrapolating from these data, the population size of *H. atra* at Cartier Reef is 6401 (Table 2). In contrast,

only a six individuals from all of the highly valued commercial species *(H. nobilis, H. fuscogilva, T. ananas*) was observed. Medium or high value commercial species were only observed on SCUBA in deep water (>15m).

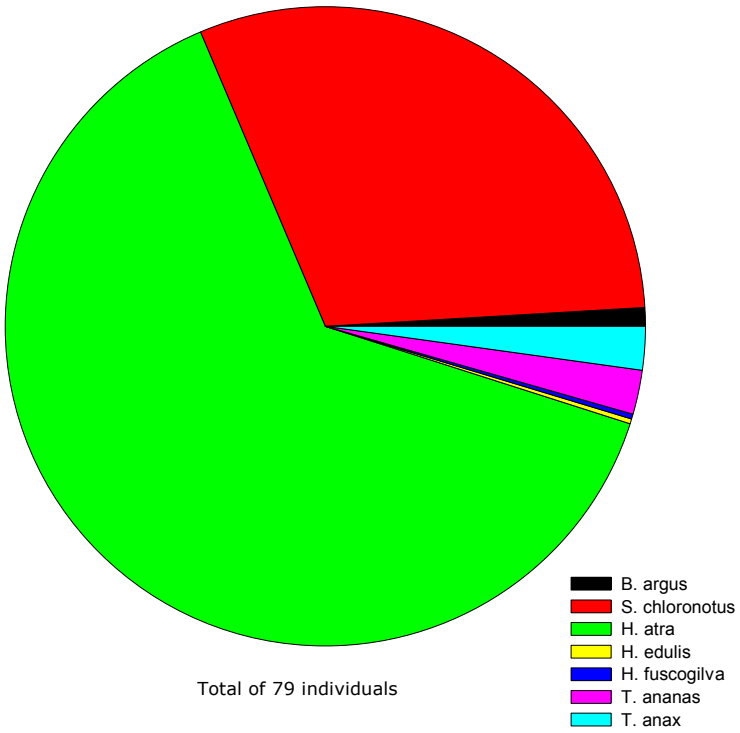


Fig. 7. Proportion of each species of bêche-de-mer at Cartier Reef

Table 2. Estimated population size of each species of bêche-de-mer, within each habitat, at Cartier Reef.

SPECIES NAME	*Lagoon*	*Reef Flat*	*Reef Crest*	*Reef Slope*	*Total*
Bohabscia argus	0	0	0	93	93
Stichopus chloronotus	0	3035	0	25	3060
Holothuria atra	0	6072	143	186	6401
Holothuria edulis	0	0	0	25	25
Holothuria fuscogilva	0	0	0	25	25
Thelenota ananas	0	0	0	223	223
Thelenota anax	0	0	0	223	223
GRAND TOTAL					10050

COMPARISON OF TROCHUS AND BÊCHE-DE-MER POPULATIONS AT ASHMORE AND CARTIER REEFS

There are major differences between the densities of trochus found at Cartier Reef, compared to Ashmore Reef. While trochus stock densities are very low at Ashmore Reef, compared to reefs on the GBR and Pacific region, they are significantly greater than densities found at Cartier Reef (6.4 vs 1.3 individuals per hectare, Table 3). While it is likely that both populations have been dramatically over-fished, the smaller size of Cartier Reef has probably caused it to suffer a greater fishing pressure (per unit area), from traditional fishers, than Ashmore Reef. For example, both Ashmore and Cartier Reef have southern edges that are exposed to large oceanic swells, which makes fishing difficult on this edge. During short periods of good weather (ie no swell), only small areas of Ashmore Reef's southern edge could be fished, while all of the southern edge of Cartier Reef could be fished.

Table 3. Comparison of trochus densities between locations

Location	Density no. per hectare	Reference
Micronesia	Fished 45-255 Unfished 55-379	Heslinga *et al.* 1984
GBR	500+	Long *et al.* 1993, Castell 1997
Ashmore Reef	0.5	Russell and Vail (1988)
Ashmore Reef	7.5 reef crest	Skewes *et al*. (1999)
Ashmore Reef	6.4 reef crest	Smith *et al.* (2001)
Cartier Reef	0.2 reef crest	Skewes *et al*. (1999)
Cartier Reef	1.33 reef crest (2-8m) 3.33 reef slope (9-24m)	This study

The bêche-de-mer populations at Ashmore and Cartier Reefs are very different, both in terms of species richness and abundance. Smith et al. (2001) found 19 species of bêche-de-mer at Ashmore Reef and estimated that the total number of individuals (of all species) at Ashmore to be over six million. In contrast, only seven species of bêche-de-mer were found at Cartier during this study, and the estimate of total numbers of

individuals was 10050. Obviously, the larger size of Ashmore Reef is able to support a greater number of bêche-de-mer species and individuals.

The most common species found at Ashmore Reef, *Holothuria leucospilota* is completely absent at Cartier Reef (Table 4). It is unlikely that fishing has caused the local extinction of this species, since this species is of no commercial value. It is most likely a result of habitat differences or some historical feature (eg. cyclone disturbance, larval supply). *Holothuria atra*, is common at both Ashmore and Cartier Reefs. However, it has a population density is 10-15 times higher at Ashmore compared to Cartier Reef across all habitats. High value bêche-de-mer (*H. nobilis, H. fuscogilva, T. ananas*) were rare or absent at Cartier Reef, compared to Ashmore Reef. For example, the highly valued white teatfish, *H. fuscogilva*, was common in Ashmore lagoon (11.7 per hectare), while only one individual was found at Cartier Reef (at 31m on the reef slope).

Table 4. Mean density of each species of bêche-de-mer (within each habitat) at Cartier Reef compared to Ashmore Reef (this study is compared to Smith *et al.* 2001).

Reef	Species	*H. leucospilota*	*B. argus*	*S. chloronotus*	*H. atra*	*H. edulis*	*H. fuscogilva*	*T. ananas*	*T. anax*
Cartier	Lagoon	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Cartier	Reef Flat	0.0	0.0	4.2	8.4	0.0	0.0	0.0	0.0
Cartier	Reef Crest	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0
Cartier	Reef Slope	0.0	0.4	0.1	0.8	0.1	0.1	1.0	1.0
Ashmore	Lagoon	2.5	0.6	28.3	20.6	10.6	11.7	2.5	2.5
Ashmore	Reef Flat	1289.0	0.0	18.3	96.7	0.0	0.0	0.0	0.0
Ashmore	Reef Crest	4.1	0.0	17.1	38.8	0.6	0.0	0.0	0.0
Ashmore	Reef Slope	0.0	2.8	14.4	5.6	32.8	0.0	5.6	7.8

FISHERS ENCOUNTERED AT CARTIER REEF

Two traditional Indonesian Type II fishing vessels were encountered during the survey of Cartier Reef; the first was a shark-fin fishing vessel, and the second a trochus and bêche-de-mer vessel. Both vessels were from Papela, Roti. The crew aboard the vessel fishing for shark-fin rested at Cartier Reef for two days, before returning to the submerged shoals around Cartier Reef to continue fishing. The second vessel remained at Cartier Reef for the duration of this survey, and its crew consisted of five

Indonesians aged between 15 and 25. They used two different fishing methods depending on the tide. At high tide, four snorkellors swam along the reef crest collecting trochus and bêche-de-mer, and their catch was passed to the fifth crew-member who was paddling a sampan (simple canoe). At low tide, during both the day and night, all crew members fished by reef walking. Simple kerosene lamps were used for lighting.

Once collected, the trochus were bagged, unprocessed, below the deck, and the bêche-de-mer were gutted and sea salt rubbed in their skin. The inside of the bêche-de-mer were partially filled with salt. During the day, the bêche-de-mer were placed on the deck to dry in the sun, resulting in a semi-dried product. The catch after 5 d consisted of 150 individuals, or approximately 15 kg, of bêche-de-mer. These included *H. atra* (65), *B. argus* (35), *H. ananas* (25), *H. edulis* (15) and *H. fuscopunctata* (7). All species of bêche-de-mer were collected, and no high value species were amongst the catch. In addition to the bêche-de-mer, a total of five trochus had been found, with an average basal width of 95 mm. The fishers apparently sell trochus for 10000rp (A$2.00) per kg, and bêche-de-mer for 4000rp (A$0.80) per kg, in Papela. Consequently, the five days of fishing had earned them 80000rp (A$16), or 3200rp (A$0.60) per fisher, per day.

Figure 8: Bêche-de-mer of the reef flat of Cartier Reef

Manta Tow

Manta tow snorkellor surveying holothuria population

Sand Islet

Sand cay showing numerous turtle nests

Reef Flat

Reef flat at Cartier Reef showing Indonesian fishers at low tide

Indonesian fishers at Cartier Reef at the time of the survey

Stichopus chloronotus

Greenfish

Found in shallow waters of the reef crest and flat
Low value

H. atra

Lollyfish

Commonly found in shallow water on the reef flat
Low commercial value

Figure 9: Bêche-de-mer of the deep lagoon of Cartier Reef

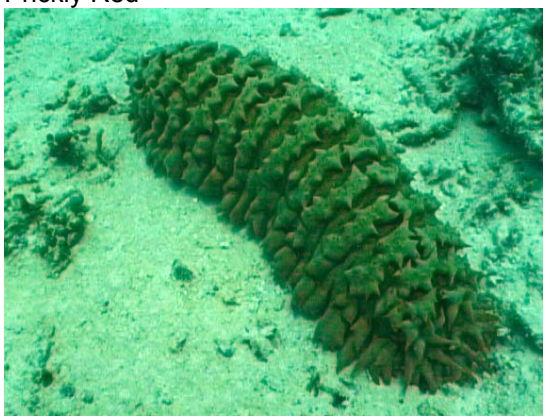
Deepwater diver

Diver surveys deep water habitat at 19 m

Holothuria fuscogilva
White Teatfish

Commonly found water deeper than 15m
Usually covered in sediment and alga
Highly commercial species

H. ananas
Prickly Red



Orange to red in colour
Commonly found in water deeper than 10m
Moderate commercial species

H. anax
Amberfish

Commonly found in water deeper than 8m
Low commercial value

H. fuscopunctata
Elephant Trunkfish

Found in water deeper than 8m

Bohadschia argus
Leopardfish

Found over all depths from 2 to 20m

Discussion

TROCHUS POPULATIONS

The trochus, *Trochus niloticus* has been severely depleted throughout the reefs of the MOU74 Box (Skewes et al. 1999). Trochus are particularly vulnerable to unsustainable exploitation because they are so easily collected. Stock-densities of trochus on the Great Barrier Reef commonly exceed 500 per hectare (Long et al. 1993, Castell 1997). In comparison, the Cartier Reef stocks have less than 1.3 and 3.3 individuals per hectare, on the reef crest and reef slope, respectively.

Trochus niloticus have a broad depth distribution in the tropics, but are usually found in less than seven metres of water (Nash 1993). They are in greatest abundance in shallow habitats that are regularly exposed at low tide (Nash 1985, 1988). However, at Cartier Reef, two-thirds of the trochus were in water below 11m, and some were in depths of 18m (Fig. 5). It is likely that Indonesian fishers have substantially depleted the shallow water populations, using their traditional fishing methods of reef-walking and free diving. The deeper slope habitats at Cartier Reef, in which much of the remaining stocks of trochus are found, provide a refuge from these traditional methods of fishing.

BÊCHE-DE-MER POPULATIONS

Cartier Reef has probably not sustained large populations of bêche-de-mer for over a decade. A limited survey in 1992, by the Northern Territory authorities, found very low numbers of bêche-de-mer at five sampling stations (Russell and Hanley 1993). Skewes et al. (1999) found low numbers at Cartier Reef in 1998, compared to the adjacent, Ashmore Reef. There was also little diversity of bêche-de-mer species at Cartier Reef, with only six species, compared to 19 at Ashmore Reef. This low abundance and diversity is probably related to Cartier Reef's small size, its limited amount of suitable habitat, and because most reef habitats can be easily fished over single tidal cycle. Comparatively, Ashmore Reef has many areas at the edge of its large reef flat that are difficult to reach during a single low tide (see Smith et al. 2001). During our survey of Cartier Reef, only a single individual (*H. fuscogilva*) of the highly valued bêche-de-mer species was found. Medium valued species (eg. *T. ananas*)

were also rare, with most being found in water deeper than 15m. As with the remaining trochus, these individuals have probably escaped capture because they are difficult to fish in deep water.

MANAGEMENT AND RECOVERY OF DEPLETED STOCKS

The continued fishing of these minimal stocks of bêche-de-mer and trochus at Cartier Reef is of serious concern. Currently, all species, of all sizes, throughout all accessible habitats, are collected. These offer very little financial return to the fishers, even by local standards. The Indonesians fishing at Cartier Reef, during this survey, had collected approximately A$0.60 worth of catch, per person, per day. Clearly, the long-term recovery of trochus and bêche-de-mer populations relies on the closure of Cartier Reef to traditional fishing. Unless Cartier Reef is closed to fishing, at least some species will become locally extinct.

If Cartier Reef is closed to fishing, then the recovery times for its trochus and bêche-de-mer populations are difficult to estimate with our current level of knowledge. There have been few studies on the biology and ecology of these target species, and certainly not in such a unique habitat as Cartier Reef. Some large adults remain, although their distribution is unusually deep, and their gametes may be highly diluted during spawning events, preventing successful fertilisation and subsequent recruitment. It is important to investigate patterns of reproduction in these species, particularly their timing, and the behaviour of individuals during spawning episodes. These parameters have important consequences for the production of larvae, their dispersal, and the degree of connectivity between stocks. Genetic studies of stocks on different reefs, within the MOU74 box, are a powerful and effective means of addressing some of these questions. Understanding patterns of gene flow between reefs provides insights into the mechanisms and timing of stock recovery. Given the low abundance of trochus and bêche-de-mer at Cartier, Scott and Seringaptam Reefs (Skewes et al. 1999), the comparatively large populations at Ashmore (Smith et al. 2001) are likely to be an important refuge for the emergent reefs within the MOU74 Box.

THE MONITORING PROGRAM

In addition to providing baseline data on the distribution and abundance of trochus and bêche-de-mer, this study provides the foundation for a simple yet effective monitoring program of stock dynamics at Cartier Reef. A range of census methods were used to survey the diversity of habitats at Cartier Reef. Censuses were stratified according to the size of habitat, and the stock distribution, so as to invest the appropriate amount of sampling effort into each habitat. From these data, a realistic estimate of stocks sizes at Cartier Reef were extrapolated. We suggest this is an effective means of monitoring trochus and bêche-de-mer at Cartier Reef, and should be repeated every two years. Repeated measures analysis of the monitoring data will provide a powerful tool to assess stock dynamics, and recovery, through time. The use of the ACV Arnhem Bay, or equivalent vessel, provides a low cost support for future monitoring studies.

Conclusions

The populations of trochus and bêche-de-mer at Cariter reef are severely depleted. Their sizes are dramatically smaller than those at nearby Ashmore Reef, where there is some refuge from fishing pressure (Smith et al. 2001, Skewes et al. 1999). A ban on fishing at Cartier Reef is required if its stocks are to have a chance of recovery. A monitoring program of the sites set-up for this study should be established, using the stratified sampling design we have described. Stock dynamics at Cartier Reef can only be assessed accurately by revisiting these sites and repeating the surveys periodically using some methods. Stock recovery can be assessed in this way, and a reactive management plan implemented in the light of new data. If populations show no sign of recovery, then a stock enhancement plan provide one option for the future.

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APPENDIX 1

GPS positions for the sampling sites at Cartier Reef.
Legend: DP; Deep Swim, MAN; Manta Tow, TR; Trochus, SW; Snorkel Swim

Survey NO.	Start / Finish	LAT. (south)	LONG. (east)
MAN001	S	12° 31. 463'	123° 33. 255'
MAN001	F	12° 31. 463'	123° 33. 539'
MAN002	S	12° 31. 546'	123° 33. 533'
MAN002	F	12° 31. 512'	123° 33. 261'
MAN003	S	12° 31. 599'	123° 33. 262'
MAN003	F	12° 31. 609'	123° 33. 536'
MAN004	S	12° 31. 725'	123° 33. 508'
MAN004	F	12° 31. 702'	123° 33. 234'
MAN005	S	12° 31. 746'	123° 33. 457'
MAN005	F	12° 31. 918'	123° 33. 669'
MAN006	S	12° 31. 864'	123° 34. 857'
MAN006	F	12° 31. 651'	123° 34. 690'
MAN007	S	12° 31. 673'	123° 34. 653'
MAN007	F	12° 31. 851'	123° 34. 859'
MAN008	S	12° 32. 184'	123° 34. 557'
MAN008	F	12° 32. 174'	123° 34. 283'
MAN009	S	12° 32. 108'	123° 34. 190'
MAN009	F	12° 32. 141'	123° 33. 917'
MAN010	S	12° 32. 088'	123° 33. 865'
MAN010	F	12° 32. 087'	123° 33. 590'
MAN011	S	12° 31. 461'	123° 32. 922'
MAN011	F	12° 31. 452'	123° 33. 197'
MAN012	S	12° 31. 507'	123° 33. 217'
MAN012	F	12° 31. 504'	123° 32. 942'
MAN013	S	12° 31. 582'	123° 32. 966'
MAN013	F	12° 31. 578'	123° 33. 241'
MAN014	S	12° 31. 724'	123° 32. 375'
MAN014	F	12° 31. 992'	123° 32. 412'
MAN015	S	12° 31. 995'	123° 32. 498'
MAN015	F	12° 31. 725'	123° 32. 533'
MAN016	S	12° 31. 720'	123° 32. 611'
MAN016	F	12° 31. 988'	123° 32. 589'
MAN017	S	12° 31. 980'	123° 32. 673'
MAN017	F	12° 31. 712'	123° 32. 690'
MAN018	S	12° 31. 670'	123° 32. 808'
MAN018	F	12° 31. 937'	123° 32. 781'
MAN019	S	12° 32. 611'	123° 33. 019'
MAN019	F	12° 32. 527'	123° 33. 281'
MAN020	S	12° 32. 453'	123° 33. 295'
MAN020	F	12° 32. 458'	123° 33. 019'
MAN021	S	12° 32. 373'	123° 32. 989'
MAN021	F	12° 32. 260'	123° 33. 254'

MAN022	S	12° 32. 586'	123° 32. 615'
MAN022	F	12° 32. 428'	123° 32. 390'
MAN023	S	12° 32. 341'	123° 32. 425'
MAN023	F	12° 32. 409'	123° 32. 691'
MAN024	S	12° 32. 454'	123° 33. 686'
MAN024	F	12° 32. 362'	123° 33. 945'
MAN025	S	12° 32. 256'	123° 33. 928'
MAN025	F	12° 32. 311'	123° 33. 658'
MAN026	S	12° 32. 235'	123° 33. 624'
MAN026	F	12° 32. 131'	123° 33. 878'
DP001	S	12° 31. 440'	123° 33. 500'
DP001	F	12° 31. 429'	123° 33. 876'
DP002	S	12° 31. 470'	123° 34. 092'
DP002	F	12° 31. 444'	123° 34. 332'
DP003	S/F	12° 32. 295'	123° 34. 719'
DP004	S	12° 32. 547'	123° 34. 152'
DP004	F	12° 32. 464'	123° 34. 346'
DP005	S/F	12° 32. 653'	123° 33. 914'
DP006	S	12° 32. 834'	123° 33. 464'
DP006	F	12° 32. 852'	123° 33. 310'
DP007	S	12° 32. 856'	123° 33. 000'
DP007	F	12° 32. 896'	123° 33. 167'
DP008	S	12° 32. 744'	123° 32. 373'
DP008	F	12° 32. 694'	123° 32. 226'
DP009	S	12° 32. 247'	123° 31. 998'
DP009	F	12° 32. 142'	123° 32. 031'
DP010	S	12° 31. 869'	123° 32. 050'
DP010	F	12° 32. 123'	123° 31. 973'
DP011	S	12° 32. 000'	123° 32. 034'
DP011	F	12° 31. 652'	123° 32. 176'
DP012	S	12° 31. 880'	123° 32. 055'
DP012	F	12° 31. 648'	123° 32. 170'
DP013	S	12° 31. 396'	123° 32. 782'
DP013	F	12° 31. 431'	123° 32. 876'
TR001	S	12° 32. 808'	123° 32. 951'
TR001	F	12° 32. 826'	123° 33. 085'
TR002	S/F	12° 32. 749'	123° 33. 417'
TR003	S	12° 32. 252'	123° 34. 625'
TR003	F	12° 32. 346'	123° 34. 668'
TR004	S	12° 32. 525'	123° 34. 201'
TR004	F	12° 32. 482'	123° 34. 250'
TR005	S	12° 32. 610'	123° 32. 216'
TR005	F	12° 32. 498'	123° 32. 126'
TR006	S	12° 32. 170'	123° 32. 004'
TR006	F	12° 32. 079'	123° 31. 997'
TR007	S	12° 31. 436'	123° 33. 415'
TR007	F	12° 31. 434'	123° 33. 568'
TR008	S	12° 31. 495'	123° 34. 126'
TR008	F	12° 31. 507'	123° 34. 310'

SW001	S	12° 32. 130'	123° 34. 758'
SW001	F	12° 32. 290'	123° 34. 526'
SW002	S	12° 32. 720'	123° 33. 183'
SW002	F	12° 32. 740'	123° 32. 909'
SW003	S	12° 32. 374'	123° 32. 128'
SW003	F	12° 32. 563'	123° 32. 294'
SW004	S	12° 31. 459'	123° 33. 031'
SW004	F	12° 31. 462'	123° 32. 749'
SW005	S	12° 31. 513'	123° 34. 004'
SW005	F	12° 31. 481'	123° 33. 715'