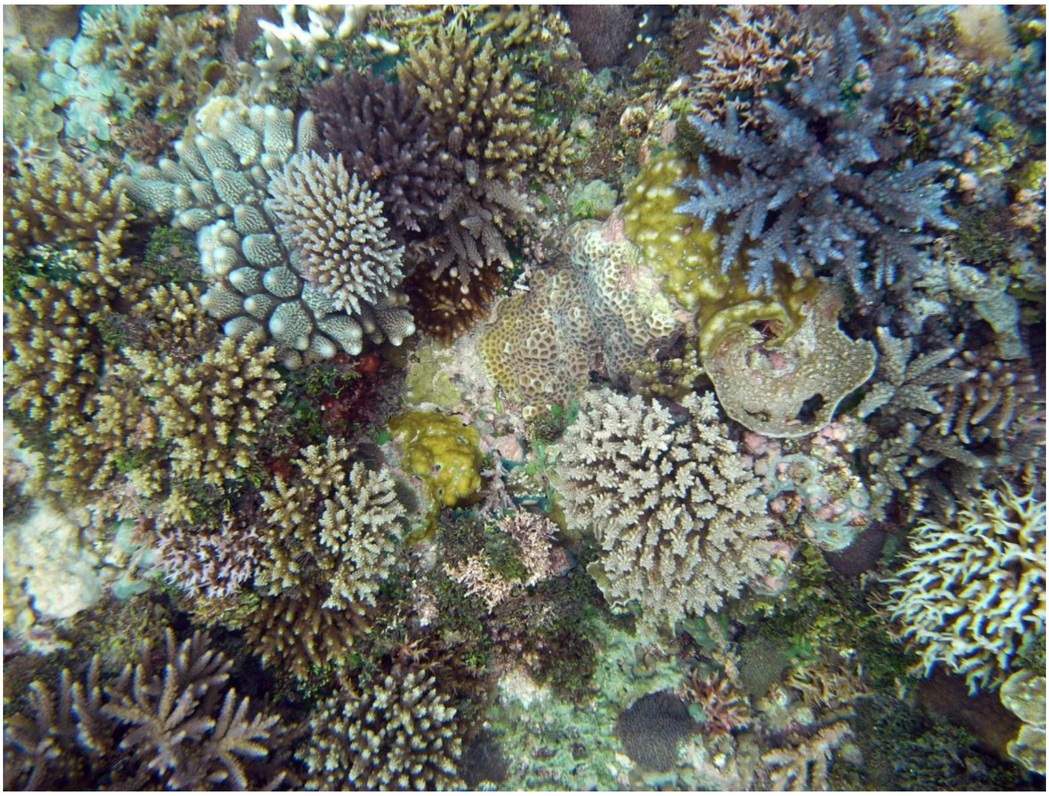
Environmental Study S6.4 Corals

Montara Surveys: Final report on Benthic Surveys at Ashmore, Cartier and Seringapatam Reefs



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Cover Photo : Ashmore Reef – shallow reef crest community on the central northern site A8 in April 2010.

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Executive Summary

In response to the triggering of the shallow coral reefs component of the Montara oil spill scientific monitoring plan, PTTEP Australasia (Ashmore Cartier) Pty Ltd (PTTEPAA) commissioned a survey of shallow benthic habitats by the Australian Institute of Marine Science (AIMS).

Field surveys to assess the status of benthic habitats were conducted during April, 2010. Ashmore and Cartier Reefs were the principal emergent reefs of interest, as they were closest to the Montara Well Head uncontrolled release. To provide a control location, the same sampling was conducted at Seringapatam Reef, a similar emergent reef in the same bioregion but several hundred kilometres to the southwest and well away from modelled spill trajectories.

All three reefs were in the midst of a coral bleaching disturbance when the survey was conducted. There is good supporting evidence that this was caused by region wide thermal stress, although a compounding effect from any pollution stress, though unlikely given the low overall levels of bleaching at sites closest to the spill, cannot absolutely be ruled out. Most corals affected by the bleaching were alive during this survey. As the bleaching event was continuing at the end of the field survey period, the fate of bleached corals, which can recover, die, or become susceptible to disease after bleaching stress, remains unknown. A re-survey of sites over the long-term would be required to quantify overall coral mortality from the bleaching event and investigate the comparative resilience of sites in relation to their distance from the spill.

At the time of this study, both *in situ* and satellite-based data indicate a region-wide thermal stress on the corals associated with warm seawater temperatures, which began to rise abnormally in March 2010. AIMS temperature loggers, that have been monitoring shallow habitats at Ashmore and Cartier Reefs, indicate that temperatures in mid-March exceeded 32°C. This is a threshold frequently observed on other reefs, above which many coral species bleach. Similarly the NOAA satellite data indicate a thermal stress event with potential to trigger coral bleaching was possible around the same time at Scott Reef, adjacent to Seringapatam Reef. Consequently, while it is impossible to rule out additional stress factors that may exacerbate a bleaching response in the corals at Ashmore and Cartier Reefs, the clear correlation with temperature is clearly the most likely cause. The fact that more bleaching was observed at Seringapatam than at the other two reefs also supports the notion of region-wide temperature stress as the principal cause.

The condition of the benthic communities was consistent with previous surveys at Ashmore and Cartier Reefs and no evidence of recent major disturbance was found, suggesting that any effects of oil reaching these reefs was minor, transitory, or sub-lethal and not detectable with the sampling methods used in this survey. Impacts on annual coral reproduction were not able to be determined for the majority of species, as the timing of the survey probably occurred a month after the major annual spawning event. However the very limited data on one species of hard coral observed to spawn during the study indicated normal spawning, gamete quality and embryological development.

Benthic survey sites were established at multiple reef edge locations around each of the three reefs. Eight major sites were established at Ashmore Reef, the largest of the three reefs, with six sites at both Cartier and Seringapatam Reefs. Photo transects sampling the benthic communities were established just below the reef crest, along a depth contour 3 m below tidal datum, a shallow habitat zone which can support good coral cover on most reefs. Data from that depth zone at all three reefs were reported previously (Heyward *et al.* 2010) in August 2010. During the field surveys, data on the benthic communities were gathered at additional depths, including fixed transects at 6 m and random geo-referenced transects on the adjacent shallow crest or reef flat. This was done in order to provide a more comprehensive assessment of the status of these reefs and provide greater coverage across a range of shallow depths where water-borne pollutants, near or on the sea surface, might have had an effect. This report presents analysis of the benthic data from all survey depths at Ashmore, Cartier and Seringapatam Reefs.

Analysis of the benthic community structure indicated that most survey sites from all three reefs fell into broadly similar groups. Typical coral reef organisms were encountered at the three reefs. Biota appeared to be normal and most corals appeared healthy, although some coral species were either partially or completely bleached. This bleaching was very recent and ongoing during the April assessment, as only a few corals that were severely bleached showed signs of mortality (algal films developing on extremities). AIMS temperature records from *in situ* recorders previously deployed at Ashmore Reef indicated abnormally high seawater temperatures above 32^{0}C beginning in early to mid-March 2010.

All three reefs surveyed showed evidence of bleaching in a minority of the coral community, although there was a differential effect between coral species and some individual species were strongly affected. The coral bleaching, which appeared to be a region-wide phenomenon associated with abnormally high temperatures, was the major aspect of significant difference in the status of benthic communities on these three reefs. The effect was generally restricted to the 3 m and 6 m reef slope sites where coral cover was higher, being greatest at 3 m, and not a significant component of the low coral cover reef flat habitats. This bias is due to the distribution of sensitive species such as *Pocillopora edouxi, Galaxea fascicularis* and the fire coral *Millepora*. At locations where these types of coral were more abundant, particularly for *P. edouxi* on the upper reef slope, the overall level of bleaching was higher. Most Acroporid corals, which were the dominant group at all sites, showed a low incidence of bleaching. Bleaching levels, measured as a percentage of total live coral, were significantly higher at Seringapatam Reef (≈ 15% of corals at 3 m), which is the farthest from the Montara release, than at Ashmore and Cartier Reefs (both having approximately 3% of corals at 3 m bleached).

The benthic community was dominated by turf algae and hard coral at all reefs. The shallowest areas, on the reef flats adjacent to the dive transects, had consistently low coral cover (3.58 - 7.13% mean cover). This also was generally the case in the shallow reef crest zone, especially Cartier and Seringapatam Reefs (8.88 and 4.10% mean cover respectively), while the reef crest zone was more variable and generally had higher live coral cover at Ashmore Reef (range 0.0 - 60.0 %, mean live cover 21.38%). All three reefs had the highest mean live coral on the 3 m and 6 m transects (range 20.43-36.50%). Coral cover was quite variable depending on location around

each reef for Ashmore and Cartier, but more even between sites at Seringapatam. There were a few locations supporting coral at all three reefs that averaged 40 - 50% live cover across the entire survey site. This is comparable coral cover on healthy, recently undisturbed reefs in many locations, such as the outer slopes of the Great Barrier Reef. At Ashmore and Cartier Reefs, at the finer spatial scales of individual 20 m transects, maximum live coral cover reached 64% and 65% respectively at 3 m, while the highest cover observed on an individual transect at Seringapatam was 58% at 6 m.

A survey of coral reproduction in the first week of April found very few coral species in reproductive condition. No gravid colonies of the dominant Acroporid species were found. Less than 10% of massive colonies in only a few common species, including *Goniastrea edwardsi* and *Favia pallida*, retained mature eggs. However in two common brain coral species, *Goniastrea retiformis* and *Favites abdita*, approximately 30% of the Ashmore populations contained some mature eggs when sampled during the first two days of field work in early April. Both mature and immature eggs were also found in a similar proportion of one species of soft coral *Lobophytum* sp., which has a two year gametogenic cycle with overlapping cohorts of eggs. One hard coral species, *Favites abdita*, was observed to spawn normally on the night of 6 April 2010. Gametes from this species were cross-fertilised aboard ship and observed during early development. Fertilisation rate was very high (89%), indicating good gamete quality, and early embryological development was normal. Cultures were maintained until normal larvae had been seen to develop and these were observed to metamorphose into juvenile corals in the normal fashion. This data is consistent with most corals at Ashmore Reef having spawned prior to this survey, most likely in early March 2010, as significant coral spawning in March 2010 was noted at Ningaloo, Dampier Archipelago and Scott Reef. The coral fertilisation success and subsequent normal development of embryos observed in *Favites abdita* did not indicate any compromised sexual reproduction, but as this pertains to only a single species observation, no generalisations to the broader coral community can be drawn.

During the April 2010 field expedition there was no visual sign of oil or waxy oil on the sea surface around the reefs, or during shoreline walks on sandy islets at each reef. A total of 90 paired seabed sediment samples were collected from all dive sites and strand line locations on sandy islets. Hydrocarbon analysis of 50 samples was completed. Although no detectable amounts were recorded for many locations, some hydrocarbons were detected at multiple sites at all three reefs, The preliminary analyses using UV Fluorescence indicated that most positive results were low, in the range of 0 - 0.15 ug/g. There were seven samples with higher levels, in the range of 0.2 - 0.58 ug/g, with some indication of a similar oil composition to the Montara field reference sample. Five of these were found at Ashmore and one at Cartier Reef. One sample at Seringapatam did not have the same UVF pattern. The samples from Ashmore and Cartier Reefs have been subject to further investigated using Gas Chromatography Mass Spectroscopy (GCMS) and results indicate the presence of a low level of degraded crude oil at Ashmore and Cartier Reefs. Based on this chemical evidence of a degraded crude oil (not bunker C or light diesel) above the background concentrations for the Timor Sea and the observations of surface slicks or sheens near the shallow reefs during the spill event, it is reasonable to conclude that Ashmore and, to a lesser degree, Cartier Reefs were contaminated during the Montara uncontrolled release. However, natural attenuation processes have reduced the concentrations and changed

the patterns so that full source matching, as is commonly performed on undegraded oils, is not possible on the sediment samples collected approximately six months after the oil spill was stopped.

Background

The Montara Well Head Platform (MWHP) uncontrolled release (August 21 – November 3, 2009) occurred within the North West Shelf marine biogeographic province defined within the 'Integrated Marine and Coastal Regionalization of Australia (IMCRA): ecosystem-based classification scheme for marine and coastal environments' (IMCRA 2006). Within the province there are many submerged and emergent reefs and cays along the outer edge of the continental shelf extending from the Lydoch and Troubadour shoals in the Arafura Sea (north of Darwin) to the Rowley Shoals north-west of Broome. This 246,404 km^2 area is also referred to as the Oceanic Shoals (OSS) meso-scale region within the IMCRA classification (IMCRA 2006). The limits of this region are nominated as lying between 18° South and 119° East, and 10° 30' South and 131° East.

The lease operator, PTTEP Australasia (Ashmore Cartier) Pty Ltd (PTTEPAA), commissioned this survey in response to the triggering of the shallow coral reefs component of the Montara oil spill scientific monitoring plan, developed by PTTEPAA and DSEWPAC. The primary focus was an assessment of the status of shallow water benthos, particularly corals, in the Ashmore Reef National Nature Reserve and the Cartier Island Marine Reserve, following the spill on the West Atlas drilling platform, approximately 175 km east of Ashmore Reef. Both are emergent fringing reefs at the western end of the Oceanic Shoals bioregion. Seringapatam Reef, another emergent reef in this bioregion, but approximately 180 km south-southwest and hence extremely unlikely to be influenced by any related spill products, was selected as a reference site (see Fig. 1). Additional sampling of sediments, to allow testing for hydrocarbons, was integrated into the diver surveys, as was the collection and assessment of corals for evidence of reproduction prior to a possible spawning window around 7 April 2010 at Ashmore Reef.

Methods

Location

Ashmore Reef (12° 14.382' S, 123° 3.534' E; outer reef dimensions 24.5 x 12.7 km) has within its lagoon small permanent islands, and lies approximately 167 km west-northwest of the MWHP site (chart AUS 314). The reef rises to the surface from surrounding waters of approximately 200 m depth, at the edge of the continental shelf, which drop quickly off the shelf to the west-south west. (see Fig.1). Cartier Reef (12° 31.998' S, 123° 33.432' E ; outer reef dimensions 4.9 x 2.1 km) is similarly located at the shelf edge and lies 108 km west from the MWHP site, while Seringapatam (13° 39.78' S, 122° 0.666' E ; outer reef dimensions 7.0 x 8.4 km) is 296 km south-east from the MWHP and rises from 400 m depths, which drop sharply down the continental slope to the west (see chart AUS 43).

Site selection

The survey of Ashmore, Cartier and Seringapatam required selection of sites to cover a broad and representative range of habitats that might be affected by the spill. Where possible this study co-located survey sites at Ashmore within habitats previously assessed in studies of coral, fish and invertebrate status for DEWHA by JCU (Richards *et al.*. 2009), but also drew on habitat maps from invertebrate stock assessments at Ashmore and Cartier by CSIRO (Skewes *et al.*. 1999). The AIMS team, in undertaking broad-scale spot surveys, confirmed these general habitat maps, which locate most of the significant coral cover around the outer reef flat, crest and slope. During this cruise AIMS established intensive sampling sites within these habitats around the outer reef zones. Once the suite of sites had been established at Ashmore Reef (Fig. 2), ensuring a comprehensive set of sites would account for different levels of exposure to wind and swell, the sites at Cartier and Seringapatam Reefs were located with similar orientations (Figs. 3,4). A minimum of 6 sites at a single depth for each reef was desired. An additional very limited assessment was also conducted at two sites on Scott Reef (Fig. 5), mainly to confirm observations from the three primary reefs, Ashmore, Cartier and Seringapatam, in relation to coral bleaching.

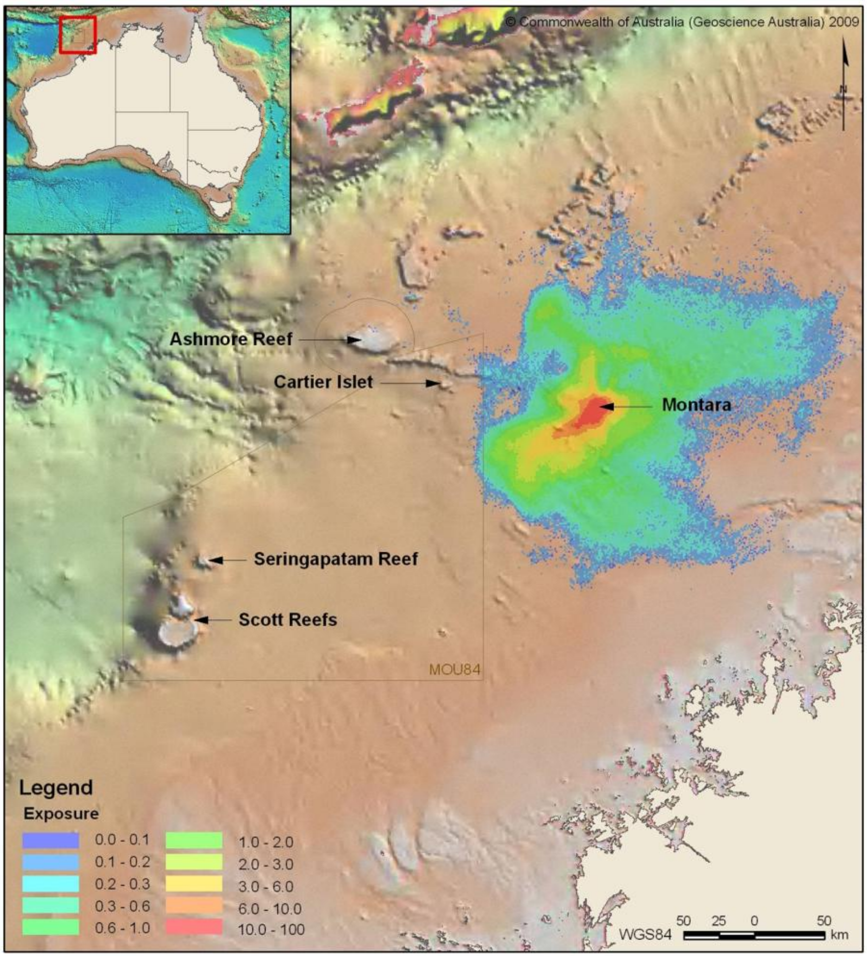


Figure 1. Location of study sites in relation to modeled relative exposure map of the oil spill. Image of the modeled spill provided via PTTEPAA. This is a relative exposure map representing up to 99.9% of occurrences of visible surface oil associated with the Montara incident. It is important to note that the area shown does not represent the extent of any oil slick observed at any time during the spill incident. It is a summation of the area within which isolated patches of oil and wax were observed by aerial or satellite observations and additional oil spill trajectory modeling.

Benthic photo sampling

As this survey was targeting habitats possibly influenced by floating oil sheens and other hydrocarbons, priority was given to shallow habitats near the reef crest. At each survey site, replicate marked transects (6 x 20 m) were established by the dive team at 6 m and 3 m below the estimated low tide datum, calculated from the national tide tables. These transects covered a nominal habitat length of around 200 m along each depth contour. At Ashmore and Cartier Reefs the tidal predictions for Ashmore Reef were used by the dive team each day to adjust the actual dive depth for establishment of the transects (port 62740, Seafarer tides 2010 ver. 1.5.79, Australian Hydrographic Service), while at Seringapatam, the predictions for Scott Reef were used (port 62730).

The AIMS dive team were all ADAS certified and diving was conducted on SCUBA using full face masks, through-water voice communications and spare bailout bottles, from 5.8m inflatable tenders. A medic, chamber operator and recompression chamber were in attendance onboard RV Solander. On each 20 m transect, standard AIMS LTM photo survey methods were employed, with a minimum of 40 photos per transect captured (Jonkers *et al.*. 2008). Waypoints for the start and end of each 6 x 20 m contour group were obtained using GPS located on surface floats.

The snorkel team added survey data at very shallow depths adjacent to the dive transects, using a pair of snorkel divers, each with a camera, and towing a surface GPS. These divers undertook haphazard photo transects while their positions were tracked at five second intervals. After each snorkel photo-swim the images and track files were downloaded for later geo-referencing of all images. The snorkel transects covered the reef crest inshore of the 3 m fixed transects, but on occasion heavy breaking swell limited the amount of data that could be collected in this zone. In some locations it was possible to also obtain additional reef-flat transects. Consequently, each survey site produced data from 3-4 habitat zones, notionally 6 m, 3 m, reef crest and/or reef flat (see Figs. 2 - 4 for examples).

Analysis of benthic images

The approach to image analysis is the same as previously reported from the 3 m depth transects (Heyward *et al.* 2010). For this report, the survey transects established at all depths and all sites were used assessed to provide comparative measures of benthic community at Ashmore, Cartier and Seringapatam Reefs. At each site, for the 3 m and 6 m deep transects, every second photo along each of the six fixed transects was analysed, using the standard AIMS ReefMon point-intercept and database management software (Jonker *et al.*. 2008). Five points per image were classified. This sub-sampling provided 20 images per transect and 120 at each depth, with data for each site generated from 600 points along each depth contour.

For the shallower snorkelling sites, to the extent possible depending on the number of photos collected, an equivalent number were sub-sampled, arranged also into 6 groups of 20 adjacent images using GIS, to mirror the data structure obtained from the diver based sampling. This was achieved for the majority of snorkel sampling stations (See Appendix 2, Table 1, Figs. 1-3), although a number of sites had fewer than 120 images included in the analysis. At Ashmore Reef, 6 of the 8 snorkel sites had adequate replication in terms of the number of useable images, 5 on

the reef crest (A1, A2, A3, A71 and A8) and one on the reef flat (A4). Sites 5 and 6 captured 40 - 60 useable photos and have been excluded from the analyses. For each of the six included shallowest sites on Ashmore there are six transects consisting of 20 photos each (except for transect 6 at site A4 reef crest which only has 8 photos (see Appendix 2).

The same sub-sampling approach was applied to the snorkel diver images collected in the shallowest locations at Cartier and Seringapatam. Data included in the analyses represented 5 of the 6 sites at Cartier (see Appendix 2), including 5 sites on the reef crest (C1, C2, C3, C4 and C6) and 3 on the reef flat (C2, C3 and C4). Six sites are represented at Seringapatam, 2 on the reef crest (SR2 and SR3) and 6 on the reef flat (SR1, SR2, SR3, SR4, SR5 and SR6) (Appendix 2). Photo replication across these very shallow areas is a little lower than at Ashmore, with between 60 (chosen as the minimum) to 120 photos available for each site.

The relationships between benthic groups, coral groups and the effects of bleaching were modeled between reefs and depths using Generalized Linear Models (McCullagh and Nelder 1989; Fairway 2006) (Tables 1, 3, 4).The dependant variables in each model where a) cover of major benthic group b) cover of major coral group c) proportion of benthic cover bleached (including both partial and totally bleached coral colonies). The dependant variables were analyzed using a hierarchical nested design with three factors in this order a) reef b) depth and c) coral or benthic group. Models fit was checked using the studentized residuals and Cooks D distance (Dunteman *et al.* 2006; Faraway 2006). Model means and calculated +/- 95% confidence limits for each three models are shown in Figures 18, 25 and 31.

Sediment collection and analysis

A total of 90 duplicate sediment samples were collected as shown in Figure 6. In a majority of sites, sediments were collected from more than one depth by the dive and snorkel teams or by a shore party accessing sand cays (see Figs. 6 and 8). A metadata summary of all sampling site locations is provided in Appendix 1.

Fifty sediment samples were selected on the basis of one from each pair and all of the single samples. Frozen sediments in sealed glass jars were defrosted and analysed in the organic geochemistry laboratory at AIMS, Townsville. All glassware and Teflon and stainless steel implements were thoroughly cleaned for trace analysis and rinsed in GCMS grade solvents. Seawater overlaying sediment was pipetted into a glass tube with Teflon lined screw cap. Two ml of extraction solvent was added to this water and used to extract any hydrocarbons that may have been dissolved off the sediments during freezing.

Sandy sediments in the jars were thoroughly stirred with a stainless steel spatula and sub-sampled for wet to dry weight determinations. The remainder (20 to 30 g wet) was weighed into a 250 ml beaker and had approximately 2 to 3 times the wet weight of pre-combusted powdered sodium sulfate added to bind water. This mixture was thoroughly stirred to make sure the salt was evenly blended with the sediment. The sediment mixture was then scrapped into a 90 ml Teflon bottle. The solvent from the water extraction was also added to the Teflon bottle. 35 ml of 10%

methanol in dichloromethane (DCM) was then added to start the extraction. Surrogate standards (OTP or orthoterphenyl and C22:1) were added to track recovery. Bottles were sealed tightly and shaken vigorously to disperse the solvent with the sediment. Bottles were then placed in a plastic tray with water in the bottom and the probe of a sonicator lowered into the water. Bottles were sonicated for an average of 40 minutes. First extracts were allowed to soak overnight in a refrigerator. Extracts were then filtered through a 10 ml glass syringe plugged with pre-cleaned cotton and packed with about 3 cm of powdered sodium sulfate in a vacuum filter box into a 250 ml round bottom glass flask. Each sample had its own syringe filter. Second and third extractions were done by adding 35 ml of DCM and repeating the sonication and filtration. The three extracts were combined and reduced in volume to about 2 ml using a chilled rotary evaporator.

Reduced extracts were transferred to Teflon lined screw cap tubes and carefully reduced to near dry using pure nitrogen gas. They were then taken up in 0.2 ml solvent and cleaned on a mini column of 1 g Al_2O_3 to remove some of the interfering plant pigments. Hydrocarbons were eluted off the alumina with 2 ml hexane followed by 2 ml DCM. Extracts were then brought up to 2 ml with DCM for UVF analysis. Complete procedural blanks were obtained by extraction 30 g of precombusted sodium sulfate.

The Hitachi UV fluorometer was calibrated against a standard of "Montara oil" sourced from Trevor Bastow at CSIRO. A sample of NAPL (non-aqueous phase liquid) from an oil/water sample recovered by fishermen from one of the Montara oil slicks was given to WA Fisheries. This was sent to Trevor Bastow at CSIRO for confirmation and then on to the AIMS lab as a reference sample. The oil was made up to concentrations of 0.2 mg/ml for UVF analysis and 2.0 mg/ml for the GCMS. A six point calibration curve was constructed from the oil standard. Samples were analysed by putting increasing amounts of samples (10 to 50 µl additions) to 1 m of hexane in the quartz cell. This method ensures the measurements do not suffer inner filter effects. Each extract was examined at wavelengths of 280 nm excitation / 327 nm emission and 310 nm ex / 360 nm em. Each extract was also synchronously scanned with excitation and emission monochrometers set 25 nm apart. Spectra were obtained from 280 to 500 nm emission. The Montara oil is light-weight crude and its UVF maximum was in the lower wavelength range. The amounts of oil listed in the table are based on the lower wavelength measurements. Amounts are expressed as mg oil per g dry weight.

Samples were judged positive when they had at least 3 times the blank values. Seven samples that had detectable oil by UVF and a UVF spectrum that somewhat matched the Montara oil were selected for GCMS analysis. The selected samples were carefully reduced to 100 µl and transferred to a GCMS vial with a 150 µl glass liner. Internal standards were added and the samples were then analysed for their aromatic hydrocarbons using an acquisition program designed for SIM acquisition of 293 aromatic hydrocarbons and standards. Total hydrocarbons and alkanes were measured by a second SCAN/SIM program.

Reference oil from CSIRO which was collected by WA Fisheries during the oil spill was analysed along with the sediment samples to assist in interpretation of the sediment extracts.

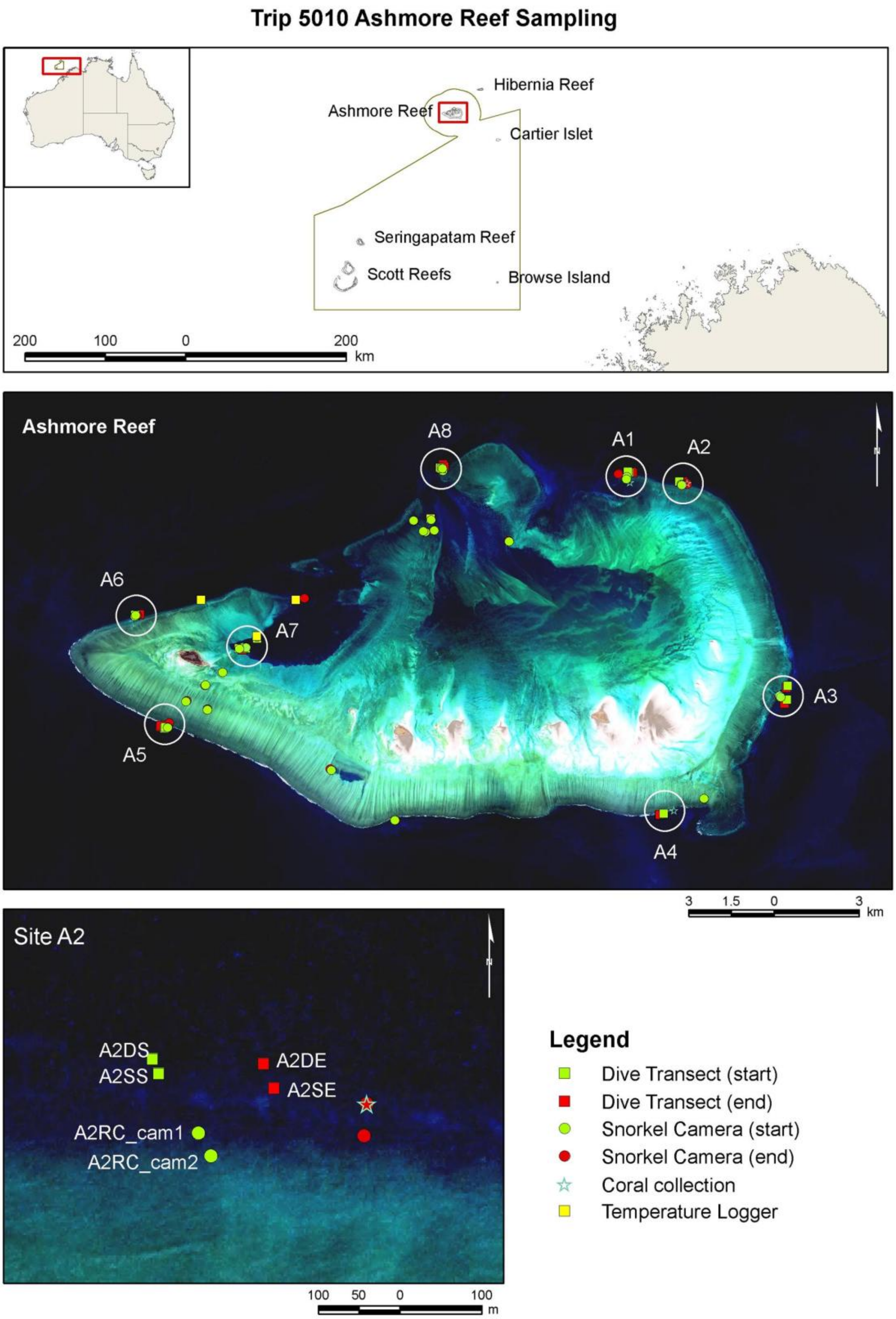


Figure 2. Location of survey sites at Ashmore Reef. Small image is a detailed example of the start and end of survey transects at site A2 in relation to the reef edge. 3 m dive transects were referred to as Shallow and included an S (e.g. A2SS is site A2, start of the 3 m transect), while 6 m dive transects were referred to as Deep and included a D in the transect start and end waypoints (e.g. A2DE is the end of the 6 m transect).

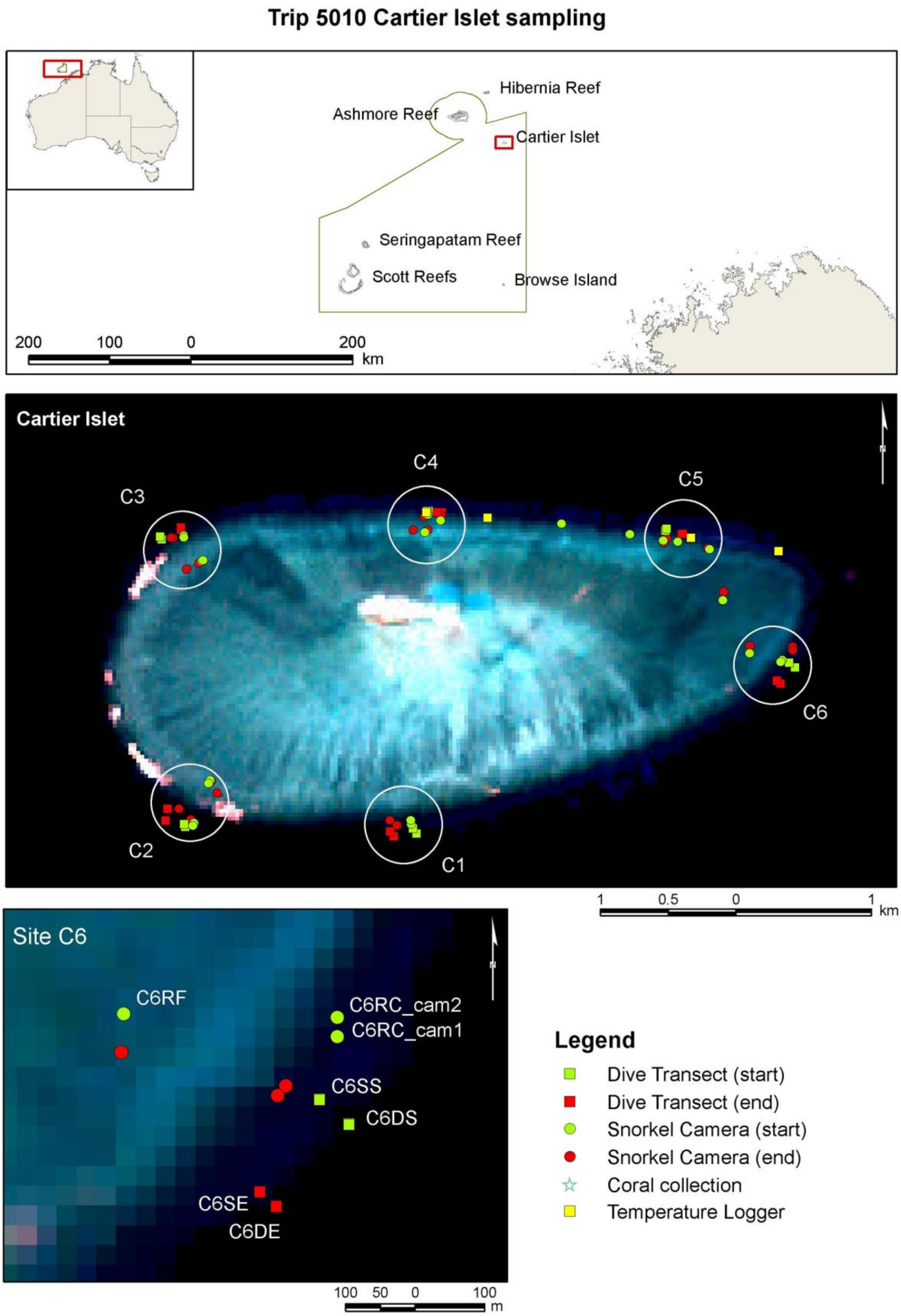


Figure 3. Location of survey sites at Cartier Islet. Small image is a detailed example of the start and end of survey transects at site C6 in relation to the reef edge. Transect C6RF is a fourth survey area on the adjacent reef flat. 3 m dive transects were referred to as Shallow and included an S (e.g. C6SS is site C2, start of the 3 m transect), while 6 m dive transects were referred to as Deep and included a D in the transect start and end waypoints (e.g. C6DE is the end of the 6 m transect).

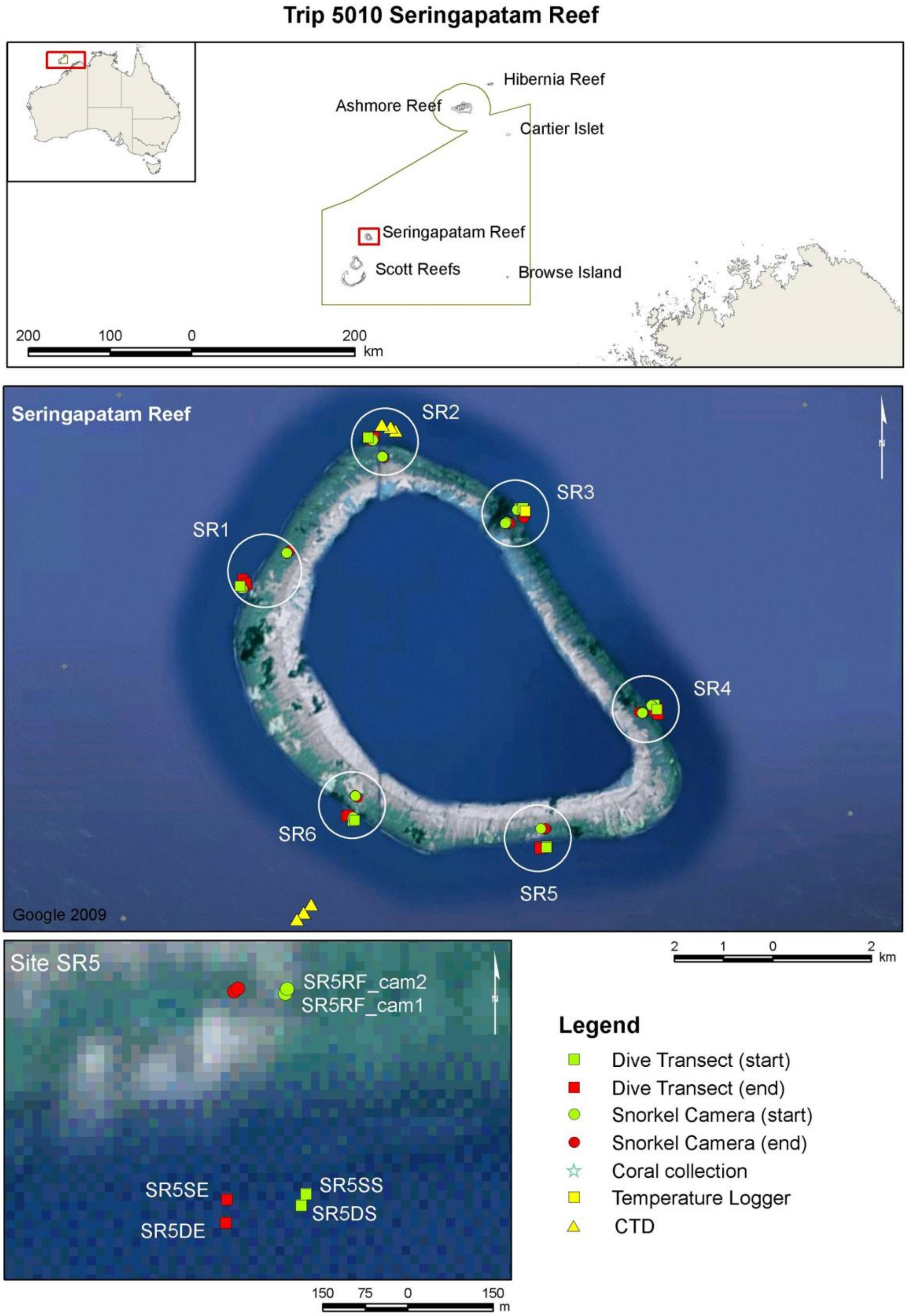


Figure 4. Location of survey sites at Seringapatam Reef. Small image is a detailed example of the start and end of survey transects at site SR5 in relation to the reef edge. CTD profiles were obtained north and south of the reef. 3 m dive transects were referred to as Shallow and included an S (e.g. SR5SS is site SR5, start of the 3 m transect), while 6 m dive transects were referred to as Deep and included a D in the transect start and end waypoints (e.g. SR5DE is the end of the 6 m transect).

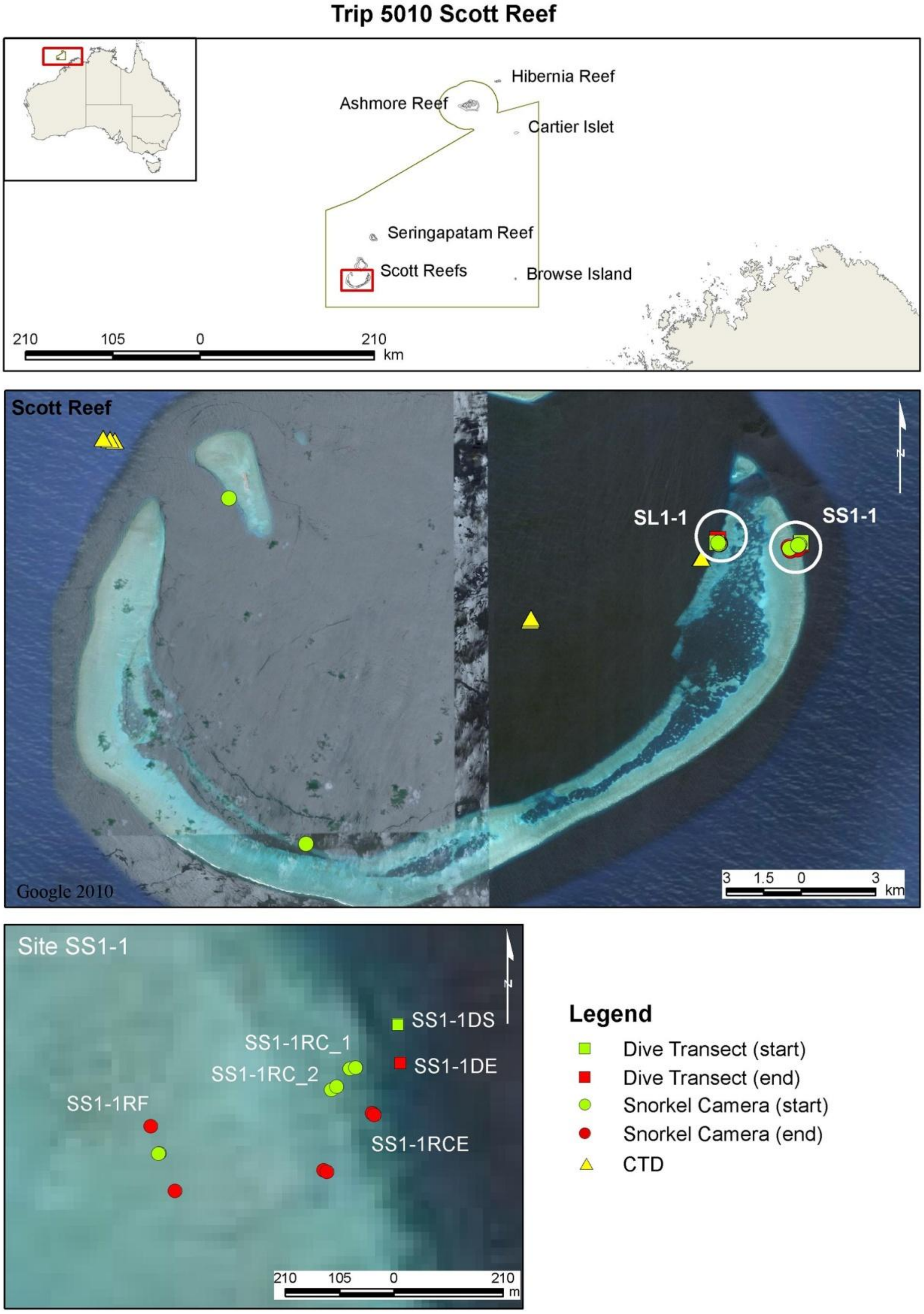


Figure 5. Location of survey sites at East Hook, South Scott Reef. Small image is a detailed example of the start and end of survey transects at site SS1 in relation to the reef edge. CTD profiles were obtained within the lagoon and offshore northwest of the reef.

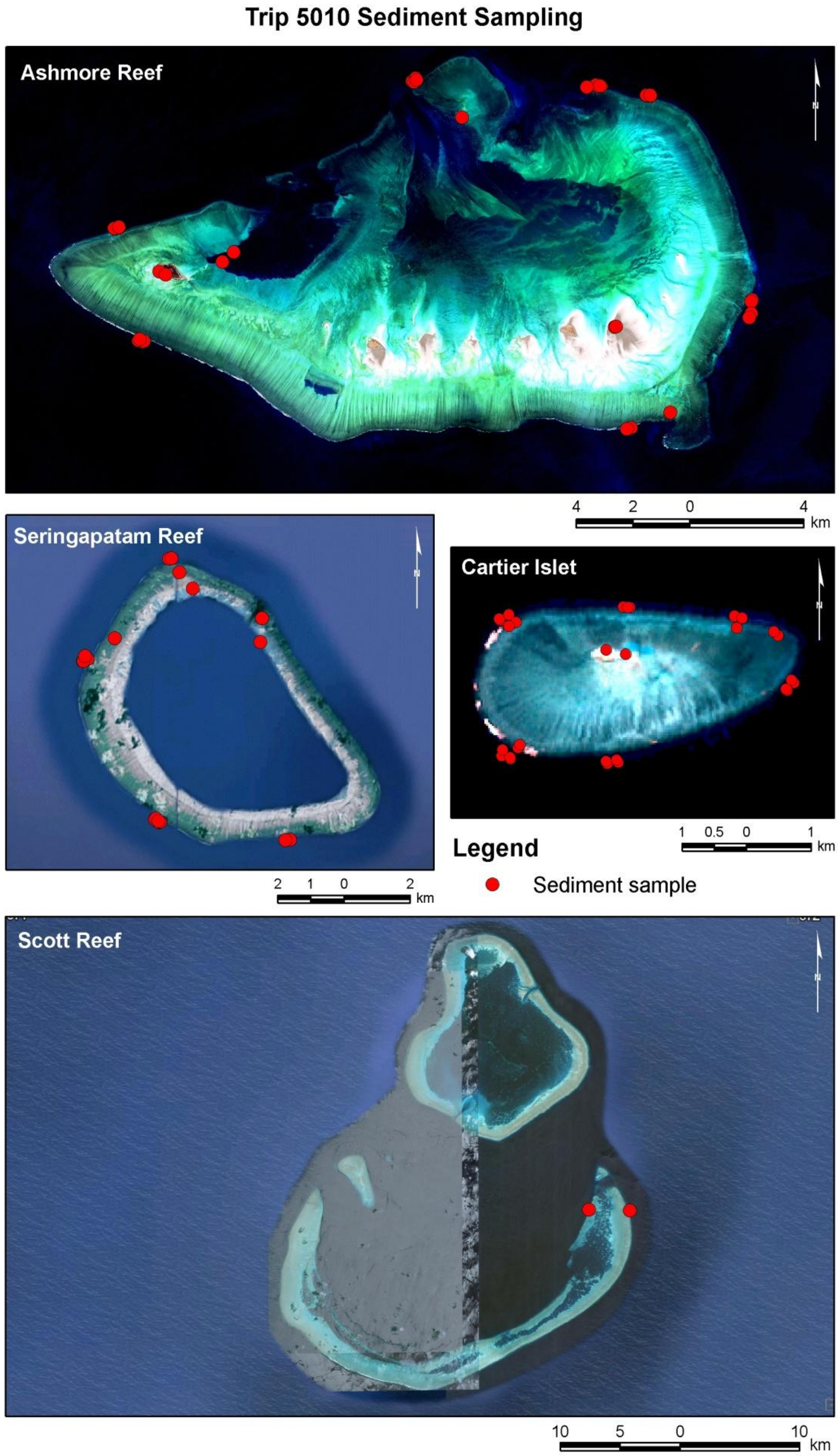


Figure 6. Sediment sampling locations. Each red dot is a duplicate pair collected by hand.

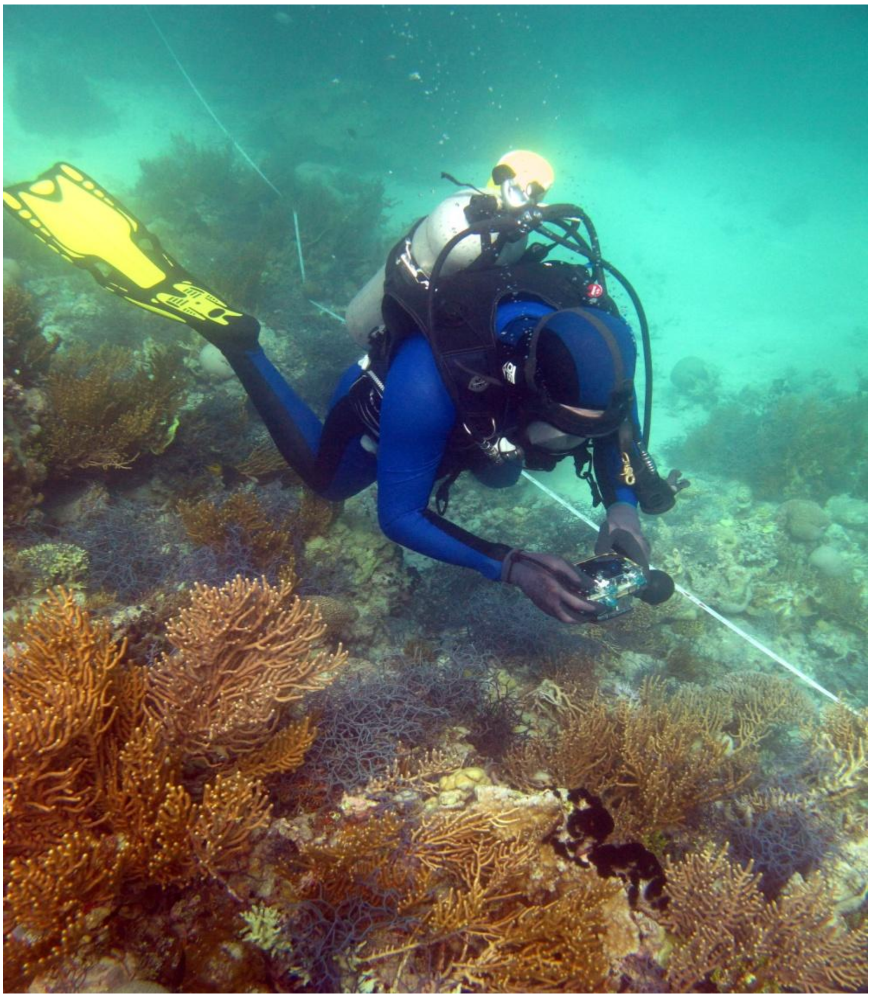


Figure 7. Ashmore Reef – diver based photography along defined transect lines was the primary survey tool used to assess benthic communities.

Figure 8. Cartier Reef shoreline – paired jars of sediments were collected on all dive sites and emergent intertidal strand lines.

Coral reproduction

Coral spawning has not previously been described in any detail for Ashmore Reef, but based on regional patterns it was expected that some spawning would occur in early March 2010 and also in the first week of April 2010 after the preceding full moon, which occurred on 30 March 2010. If colonies with mature gonads were found, a highly probable spawning period was predicted for the nights of 6-8 April. The schedule of the research cruise meant that any spawning in March 2010 would have been missed, but that there would be a window of a few days after arriving at Ashmore Reef in which to detect mature coral colonies ahead of the predicted April 2010 spawning window. Coral reproduction was investigated immediately upon arrival at Ashmore Reef, on 4 April 2010, by collection of a broad range of common species during site surveys and assessment of fresh cross sections for the presence of mature gonads.

Samples of live coral were removed by hand from the reef with hammer and chisel and maintained in flow-through seawater on board the RV Solander pending further assessment. Each coral piece was subsequently cut in at least three places using cold chisel or bone cutters. These pieces were assessed under magnification, using 4 X magnifying glass initially and Leica MS5 dissecting microscope as required, for the presence or absence of gonad. Presence and absence of gonad was noted and voucher samples preserved. Colonies with mature gonads were kept alive in flow through tanks on the RV Solander and checked at night for evidence of spawning, beginning 5 April 2010. If spawning was detected it was planned to collect gametes and assess fertilization rates using accepted laboratory methods, (e.g. Negri and Heyward (2000)).

Results

Reef sampling sites

A total of 8 survey sites, each with data from multiple depth zones, were completed at Ashmore Reef (Fig. 2). Six similarly located sites were completed at Cartier Reef (Fig. 3) and 6 sites at Seringapatam Reef (Fig. 4). In order to confirm the region-wide nature of the coral bleaching observed at the three priority reefs, an additional 2 reference sites were visited on the previously established AIMS LTM sites SL1 and SS1(nominally 6 - 8m depth) inside and outside East Hook at Scott Reef (Fig. 5).

As warm sea surface temperatures were noted at all sites, and were the most likely cause of the coral bleaching observed, previously deployed temperature loggers were collected from Ashmore and Cartier and a number of CTD casts were undertaken at Seringapatam. Temperature data from depth recorders retrieved from the shallow slope and lagoon areas at Ashmore Reef showed abnormally elevated seawater temperatures beginning in March 2010 (Fig. 32). This is very similar to satellite derived sea surface temperature data for the Scott Reef – Seringapatam Reef area (Fig. 33), indicating a region-wide sea surface temperature anomaly. CTD casts conducted during the April 2010 field work showed a surface layer of warm water in the open ocean around Seringapatam extending down to almost 50 m depths. (Fig. 34)

Benthic community analyses

At all three reefs the variation in coral cover and overall benthic community structure was noticeable between sites and between depths within sites, but at the whole reef level there were many similarities (see Figs. 9 - 18). The observation that algae, in particular low turfing species, were dominant across all sites as reported previously along the 3 m contour, extends to the other depths (see Figs. 13, 15, 17). Hard coral was the next most abundant group at all sites, except sites C4 and C5 on the northern side of Cartier, where soft coral was more common (see Figs. 10, 14 and 15). Locations around each reef was not consistently associated with regions of high or low coral cover, with the richest coral site at Ashmore (A8) located on the central northern edge (Fig. 9; Table 2), while on Cartier the most abundant coral community was found at site C2, on the southwest corner (Fig. 10, 14, 15; Table 2)

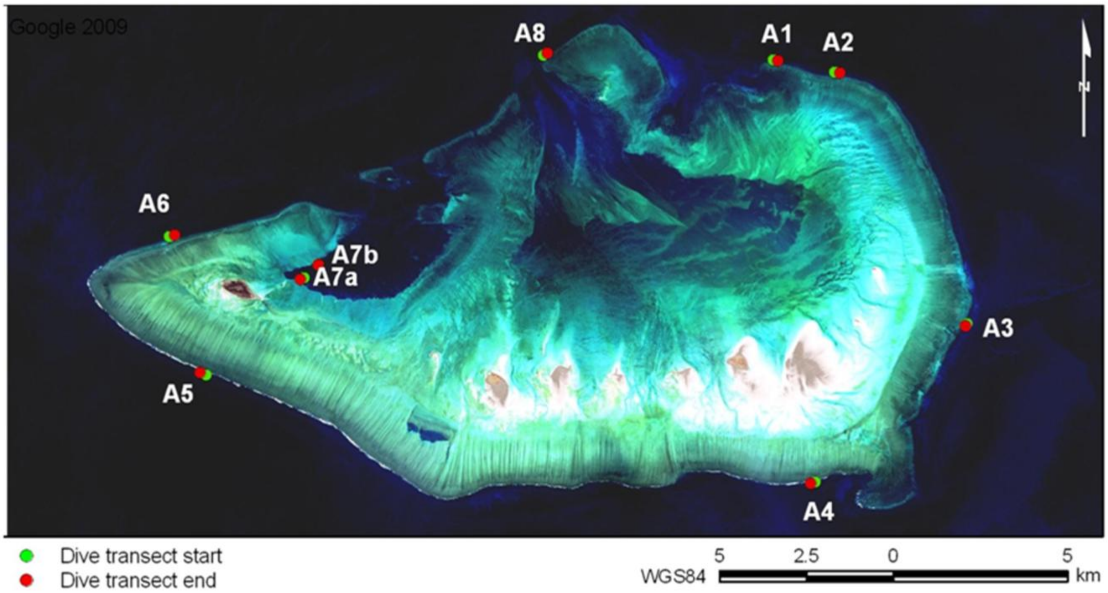
Live coral cover varied from low to very high (Figs. 19 - 24; Table 2), but at overall reef level typically averaged 20 - 25% cover on the slope sites and <10% on the shallow reef crest and flat areas. Acroporid corals were the dominant group at all reefs, but this often consisted of a significant component of the genus *Montipora* (see Heyward *et al.*. 2010). At Ashmore, Favids, Poritids and Pocilloporids were the other most abundant hard coral families. The relative dominance at coral family level was similar at Cartier, but at Seringapatam, *Porites* was more important the *Acropora* and second in overall abundance only to the encrusting *Montipora* spp at certain depths (see Heyward *et al.*. 2010).

The highest coral cover recorded during the survey was at a 6 m deep site C2 (Fig. 10), at Cartier Reef, which supported a mean coral cover of 55.50%, while a 3 m site A8, on the central northern side of Ashmore Reef supported 50.05% mean live coral (Table 2). This sort of coral community would be regarded as a high cover reef on many reef slope sites of the Great Barrier Reef. Site A8 has more abundant coral than previously reported for a survey site on Ashmore Reef (c.f. Richards *et al.*. 2009), with high cover recorded across the depth zones from reef crest to 6 m below tidal datum (see Table 2).

All reefs demonstrated some coral bleaching (Figs. 26 and 27), although it was minor in extent especially at Ashmore and Cartier Reefs and appeared to mostly associate with a subset of more sensitive species, such as *Pocillopora edouxi* and the fire coral *Millepora*. Overall levels of partially or fully bleached corals accounted for between 1.0 and 3.1% of benthic cover, with the highest levels recorded on the 3 m depths at Seringapatam (see Figs. 28 - 31). Although very little coral bleaching was observed on the shallow reef flat sites and most low coral cover reef crest sites, results from the standard 3 m and 6 m transects indicate that no more than 6% of the coral community was affected by bleaching at Ashmore and Cartier Reefs, with most sites and depths less so, but up to 15% of the coral community was at Seringapatam Reef (Table 4). Some coral taxa were more significantly affected (see Figs. 26-30) than others, with the Pocilloporids the most severely bleached family and the majority of species *Pocillopora edouxi* bleached (see Figs. 26 and 27).

In order to further confirm the regional nature of the bleaching phenomena an additional pair of sites at Scott Reef were surveyed, with bleaching found to be at least as common there as at Seringapatam.

Retrieval of long-term AIMS temperature loggers provided a history of seawater temperatures over the preceding year. It is clear that at Ashmore Reef water temperatures climbed above 32°C in mid march, with peaks between 32.5 - 32.75°C. These temperatures are known to cause bleaching in corals elsewhere and seem the most likely cause of stress on the most sensitive species. The Ashmore data agrees well with satellite SST data provided for the Scott Reef area by NOAA, which also indicates a potential SST bleaching period commencing in mid-March 2010. Anecdotal reports subsequently indicate a regional scale bleaching event has occurred throughout at least the eastern half of the Indian Ocean, with reports of some coral bleaching still occurring in Thailand in late July 2010. The selective nature of the bleached coral species will be explored as part of the full analysis for the final report.



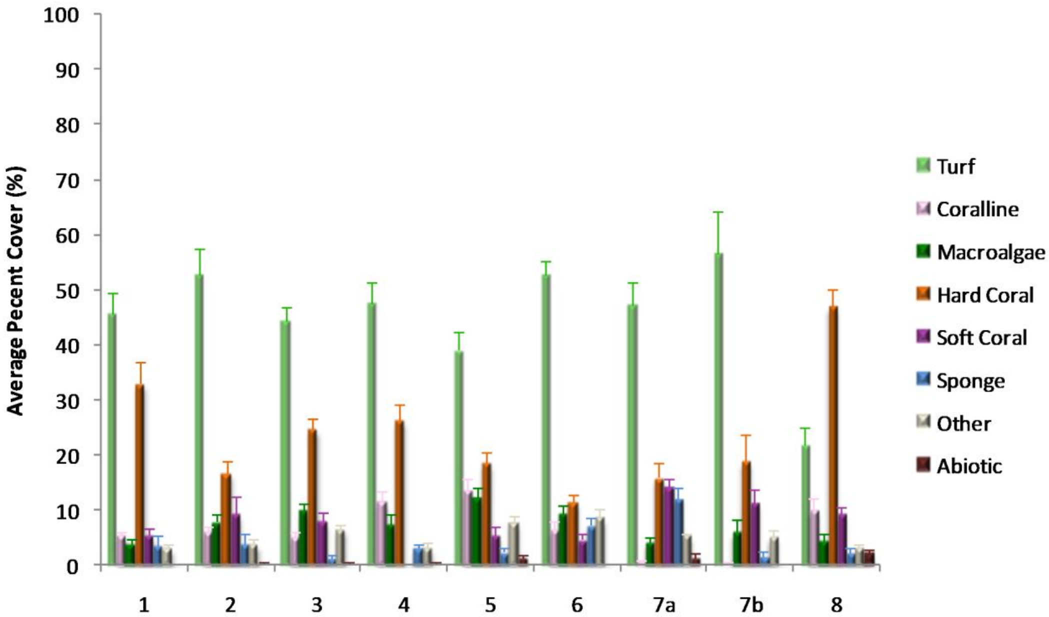
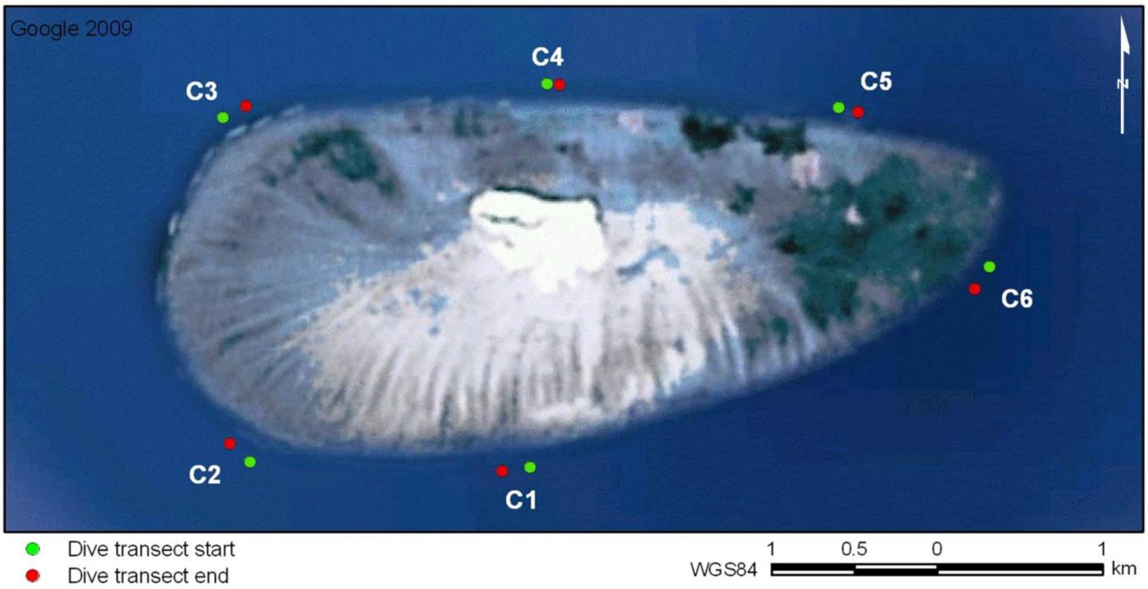


Figure 9. Ashmore Reef- mean abundance (+ SE) expressed as percent cover per 20 m transect, of major benthic groups averaged for all depths at each survey site. Data on the horizontal axis refers to the location of the site A1-A8 on the map above.



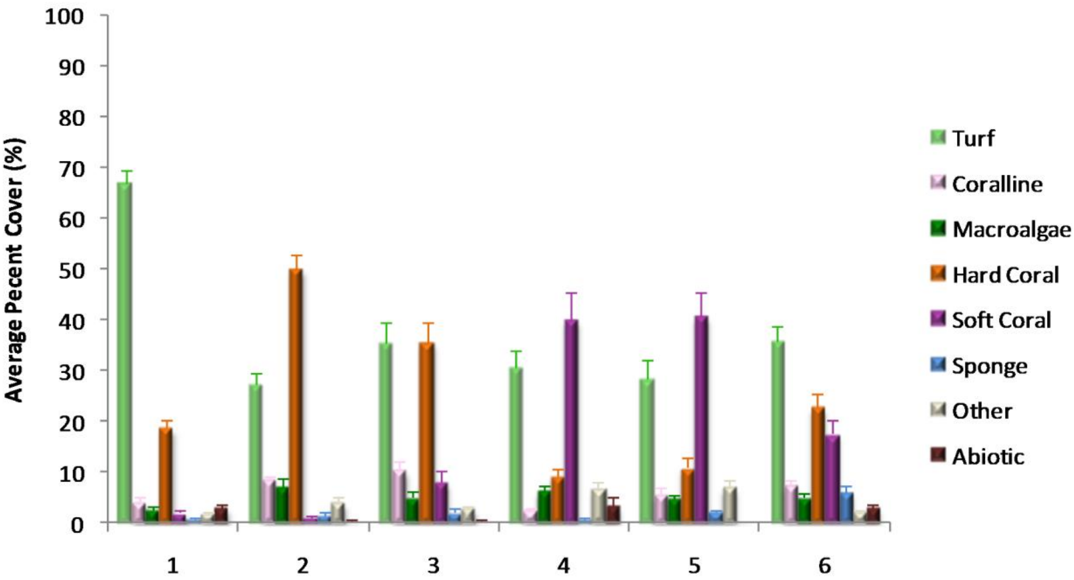
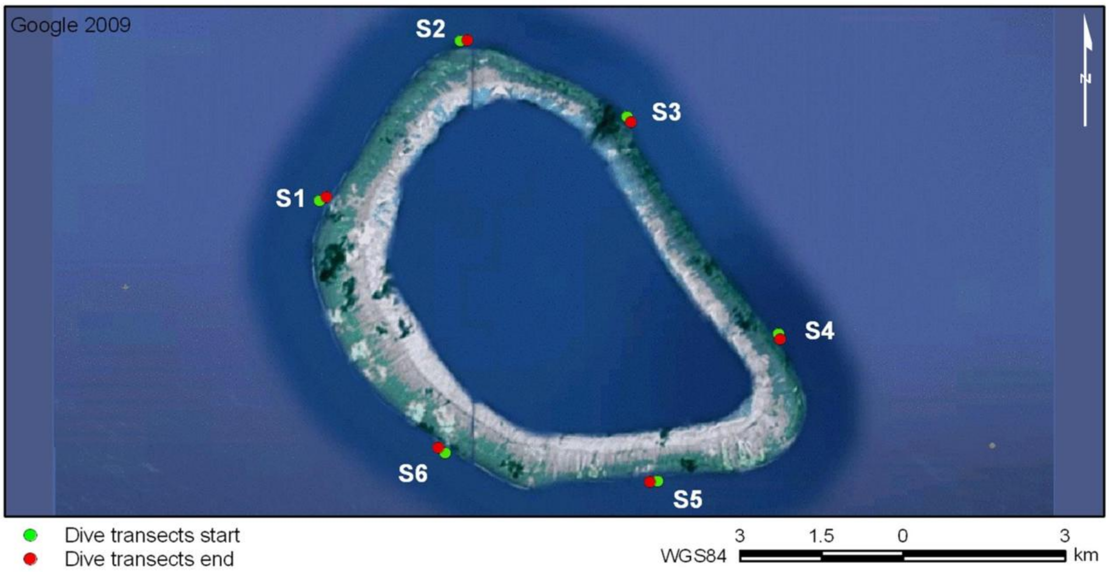


Figure 10. Cartier Reef - mean abundance (+ SE) expressed as percent cover per 20 m transect, of major benthic groups averaged for all depths at each survey site. Data on the horizontal axis refers to the location of the site C1-C6 on the map above.



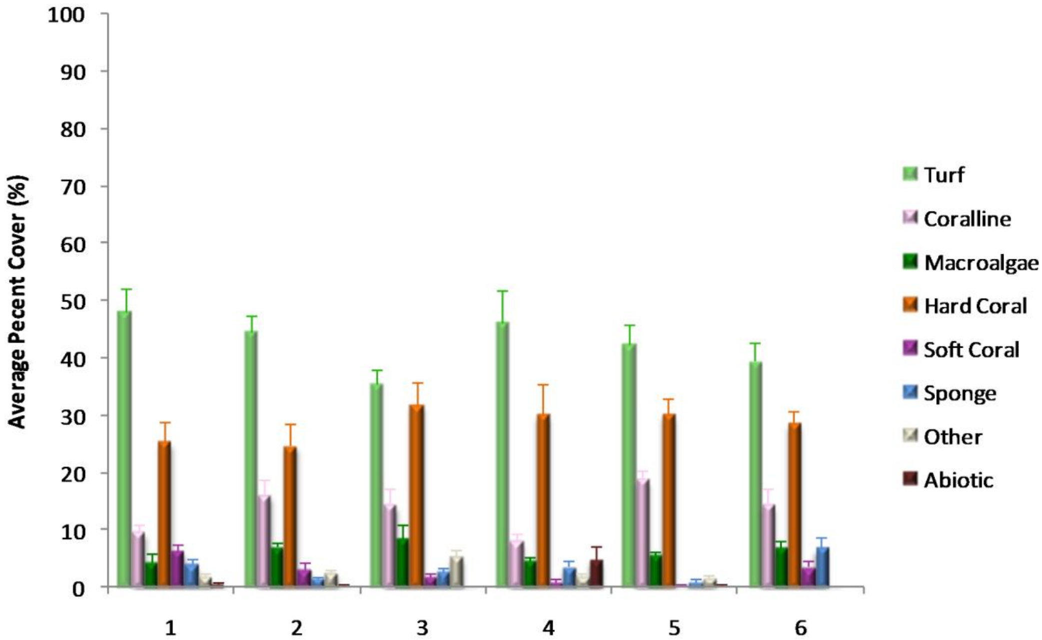


Figure 11. Seringapatam Reef- mean abundance (+ SE) expressed as percent cover per 20 m transect, of major benthic groups at each 3 m survey site. Data on the horizontal axis refers to the location of the site S1-S6 on the map above.

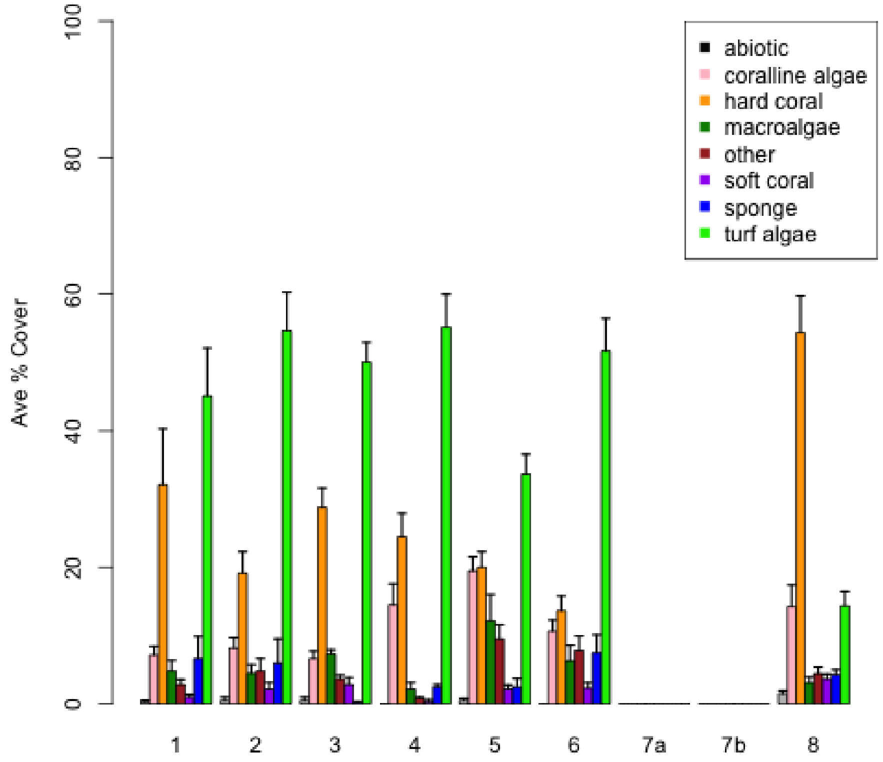


Figure 12. . Ashmore Reef – abundance of major benthic groups on the 3 m transect sites

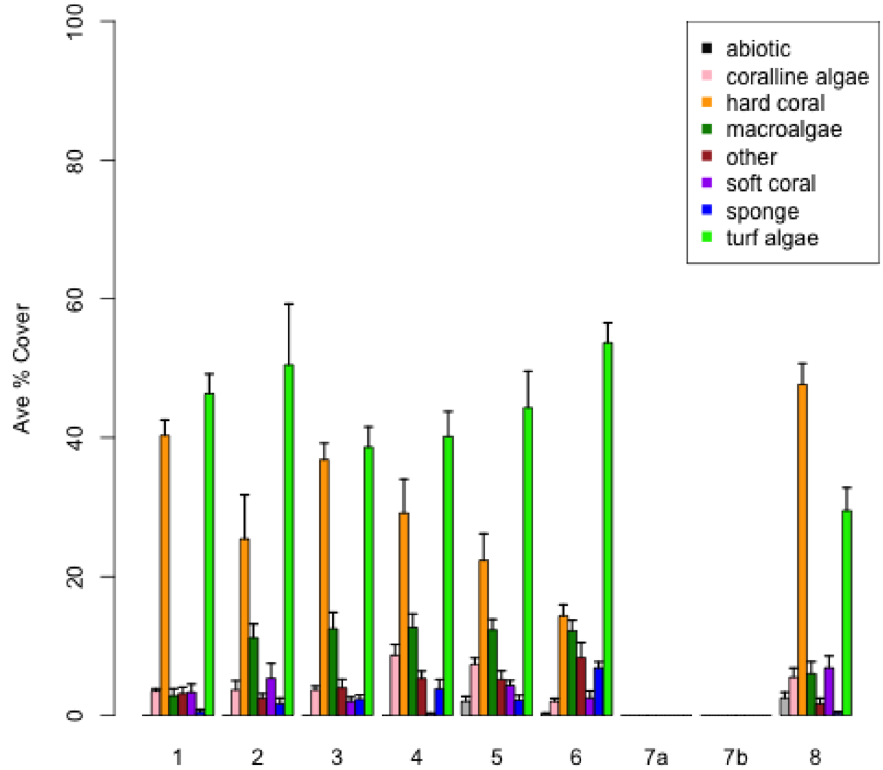


Figure 13. Ashmore Reef – abundance of major benthic groups on the 6 m fixed transects sites

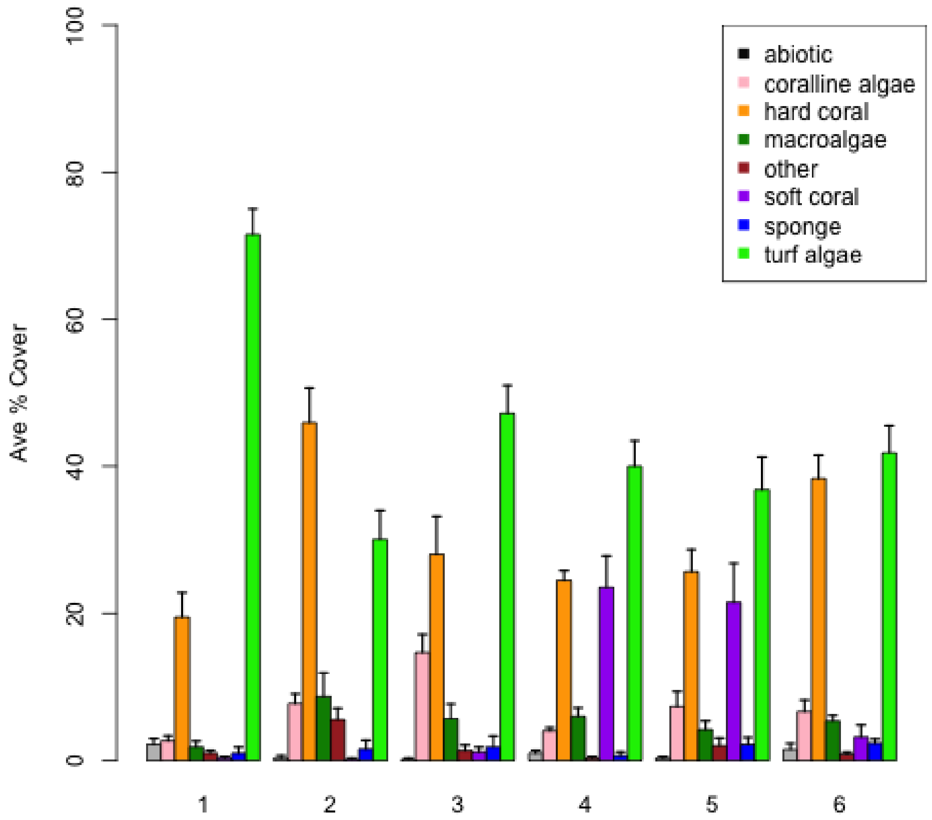


Figure 14. Cartier Reef - major benthic groups on the 3 m fixed transect sites

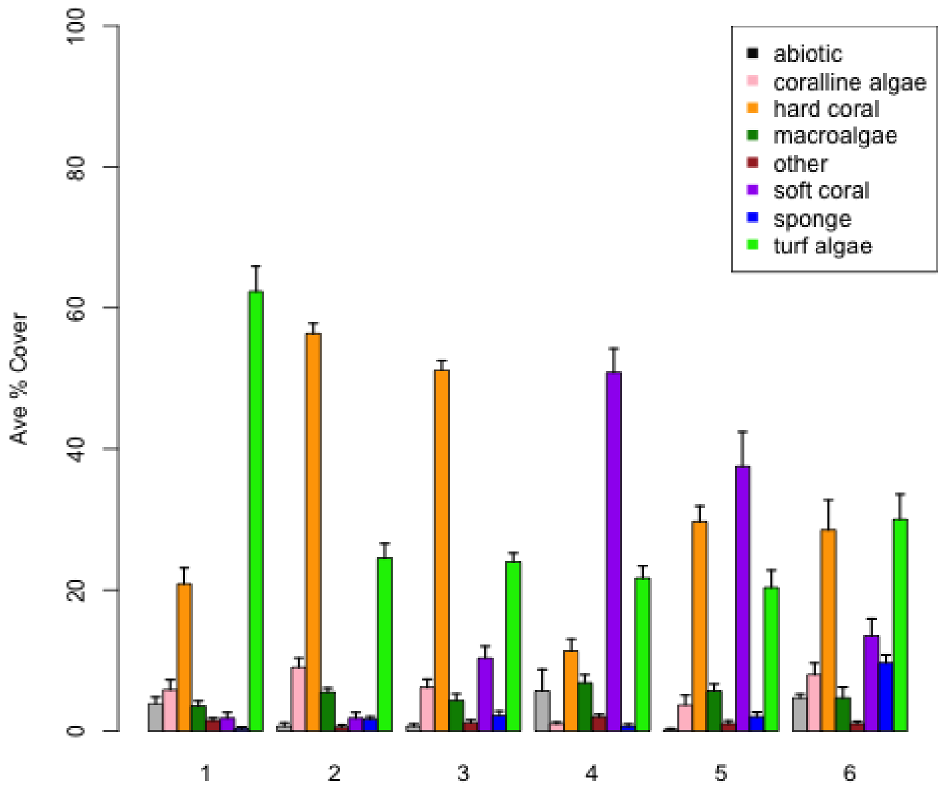


Figure 15. Cartier Reef - major benthic groups on the 6 m fixed transect sites

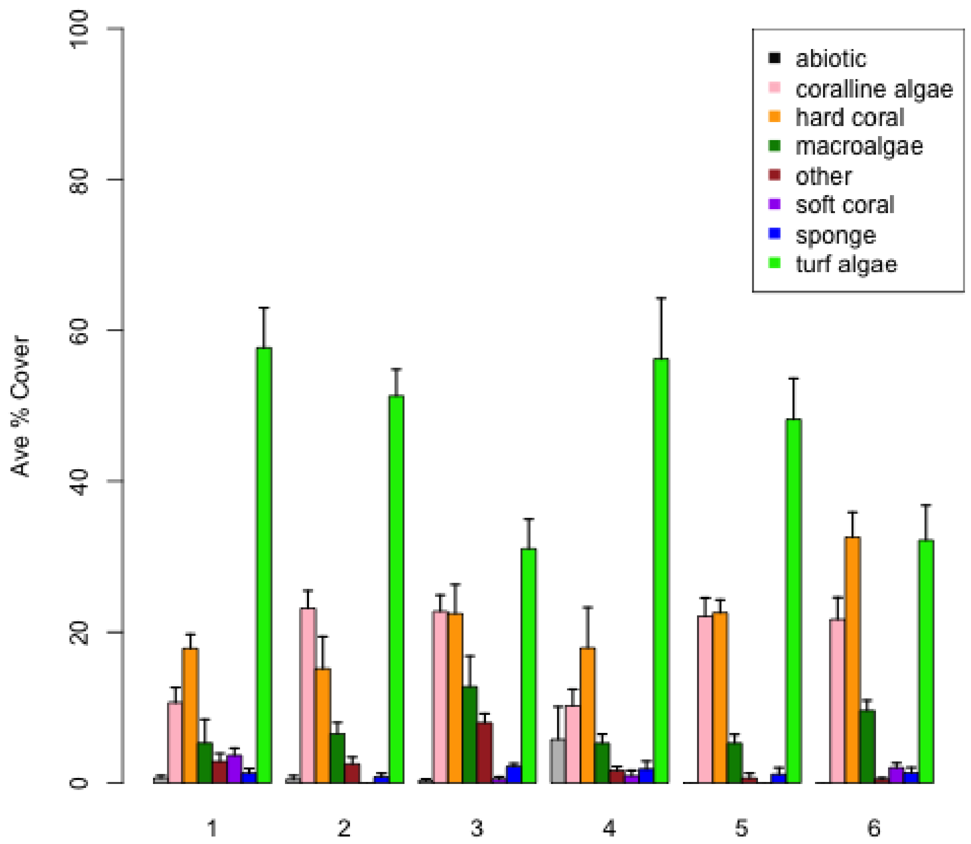


Figure 16. Seringapatam Reef – major benthic groups on the 3 m fixed transect sites

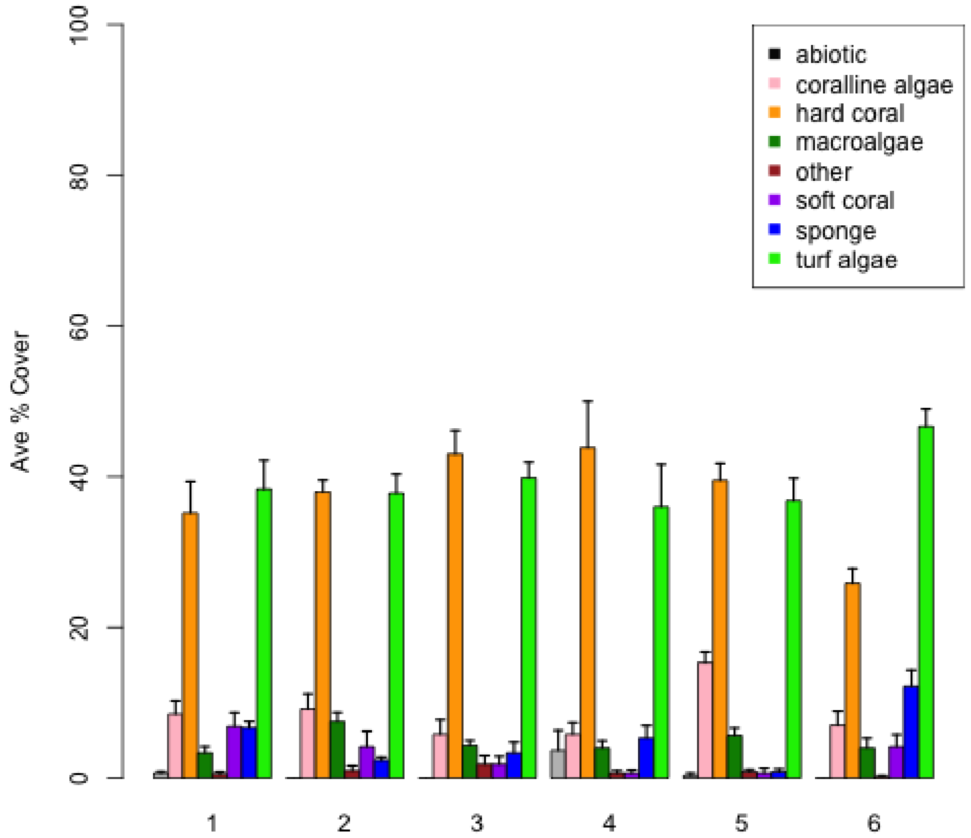


Figure 17. Seringapatam Reef -major benthic groups on the 6 m fixed transect sites

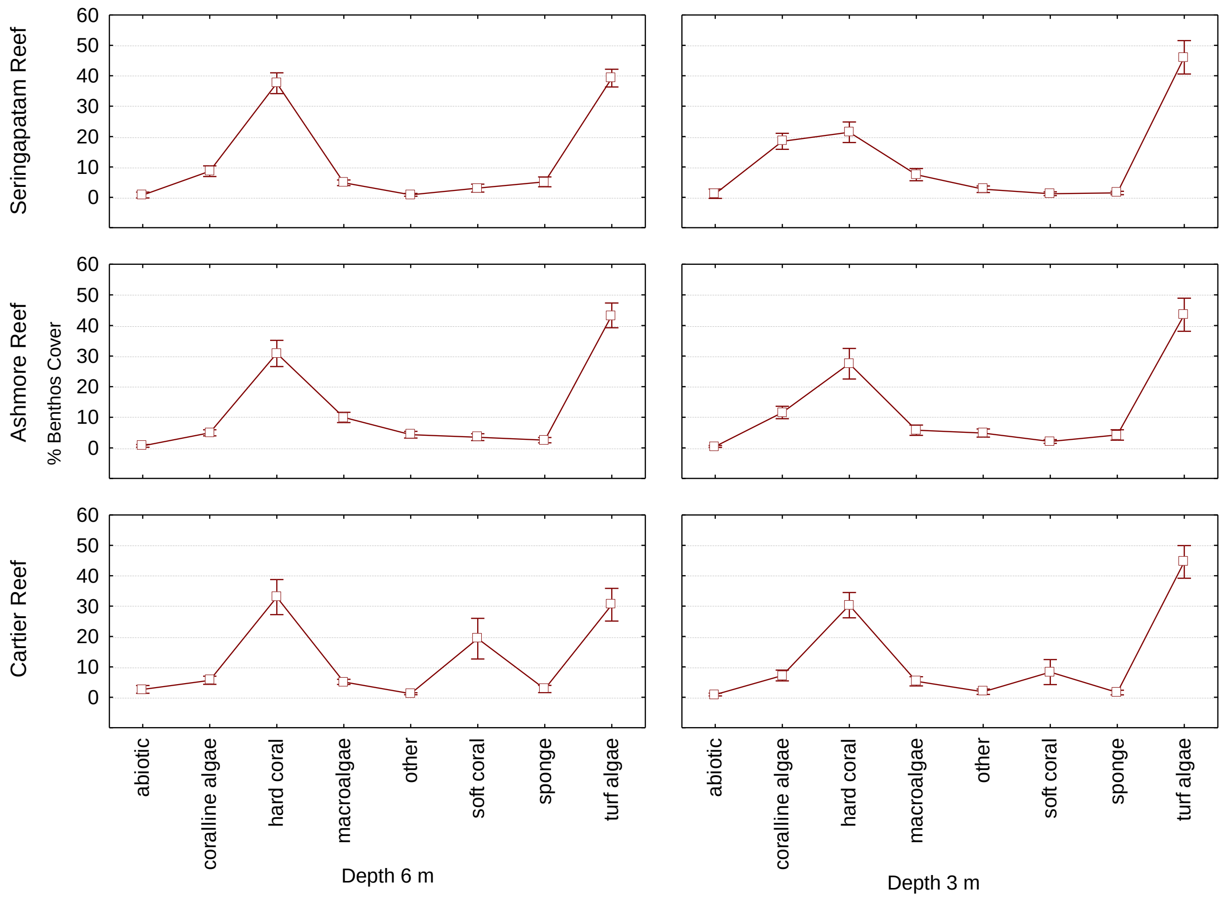


Figure 18. Comparison of mean abundance (% mean benthos cover ± 95% confidence limits.) of major benthic groups at each reef on the 3 m and 6 m sites. Highly significant differences in abundance occur where these confidence intervals do not overlap.

Table 1. GLM Summary table for data shown in Figure. 18 above, comparing benthic cover by main effects and nested factors reef, depth and coral group

Factor	DF	Log-ms	Chi-sq	p
Intercept	1	-33663.8		
Benthos	7	-13483.1	40361.52	0.000000
Depth	4	-13483.1	0.00	1.000000
Reef	2	-13483.1	0.00	0.999973
Depth x Benthos	28	-10918.0	5130.22	0.000000
Reef x Benthos	14	-10131.1	1573.66	0.000000
Reef x Depth	6	-10115.2	31.92	0.000017
Reef x Depth x Benthos	42	-9522.7	1185.00	0.000000

Coral cover and composition

Live coral was second only to turf algae as the dominant component of the benthic community overall (Figs. 12 - 17), but was very scarce (3 - 7% cover) in the reef flat locations on all reefs and on the reef crest adjacent to the wave zone at Cartier and Seringapatam. Ashmore Reef crest supported more coral in this habitat zone than recorded for Cartier and Seringaptam Reefs, likley due to a broader range of geomorphologies on that much larger reef, including a mix of distinct and more gently sloping reef crest areas.

Both Ashmore and Cartier supported a mean of around 25% live cover on the shallow and deep slope sites, which are comparable in general habitat location to the survey transects completed there just under 12 months ealier by Richards *et al.*. (2009). While not all locations could be matched between this survey and the 2009 work, most were and the estimates of live coral are comparable.

The most common families were Acroporidae, Faviidae, Pocilloporiidae, Poritidae and Meruminidae. The relative abundance of each of these varied to a significant degree depending on location around each reef (Figs. 19 - 24). Depth was also an important factor in the coral community structure. Although the Acroporid species were dominant in the majority of sites, regardless of depth. The relative importance of the other common families frequently changed between 3 and 6 m depth zones on the reef slope . Within the Acroporids, a mix of corymbose, branching and tabulate *Acropora* species were encountered on most sites, but encrusting *Montipora* was often equally important in terms of overall cover and was the dominant Acroporid genus at some sites and depths. Examples of this were reported for the 3 m transects in the preliminary report (see Heyward *et al.*. 2010)

At the whole reef level, patterns in mean coral abundance across the most common families were similar between Ashmore, Cartier and Seringaptam Reefs (Fig. 25). The most significant differences noted were between Seringaptam and Ashmore /Cartier. In particular, Seringpatam had more abundant coral on the 6 m depth transects than either of the other two reefs, and these differences were especially associated with Acroporiidae, Pocciiloporidae and Poritiidae (Fig. 25).

Table 2. Mean hard coral cover and associated variances, at the site level (6 X 20 m transects or equivalent) for each depth. Minimum and maximum cover recorded for individual 20 m transects(% Min cover, % Max cover), provide an indication of the range of coral abundance at finer scales within the survey site.

Reef	Site ID	Site Depth	Mean Cover %	Std Dev %	StdErr %	Min % Cover	Max % Cover
ASHMORE REEF	1	DEEP	34.50	5.75	2.35	26.00	43.00
ASHMORE REEF	1	SHALLOW	31.27	19.44	7.93	13.00	64.00
ASHMORE REEF	2	DEEP	17.74	10.44	4.26	7.00	34.00
ASHMORE REEF	2	SHALLOW	15.67	4.68	1.91	11.00	24.00
ASHMORE REEF	3	DEEP	29.50	5.79	2.36	20.00	38.00
ASHMORE REEF	3	SHALLOW	19.80	2.28	0.93	17.00	23.00
ASHMORE REEF	4	DEEP	28.67	11.79	4.81	16.00	47.00
ASHMORE REEF	4	SHALLOW	24.00	8.72	3.56	14.00	34.00
ASHMORE REEF	5	DEEP	17.17	6.74	2.75	12.00	28.00
ASHMORE REEF	5	SHALLOW	20.00	5.59	2.28	11.00	25.00
ASHMORE REEF	6	DEEP	10.83	4.31	1.76	4.00	16.00
ASHMORE REEF	6	SHALLOW	12.00	4.69	1.91	7.00	19.00
ASHMORE REEF	7 B1	BOMMIE	15.83	6.68	2.73	7.00	26.00
ASHMORE REEF	7 B2	BOMMIE	18.83	11.57	4.72	5.00	35.00
ASHMORE REEF	8	DEEP	43.83	8.98	3.66	33.00	57.00
ASHMORE REEF	8	SHALLOW	50.05	11.64	4.75	34.29	64.00
ASHMORE REEF	A1-RC	CREST	1.00	0.89	0.37	0.00	2.00
ASHMORE REEF	A2-RC	CREST	5.05	3.80	1.55	1.00	9.00
ASHMORE REEF	A3-RC	CREST	28.50	4.97	2.03	20.00	34.00
ASHMORE REEF	A4-RF	FLAT	3.58	5.33	2.18	0.00	14.00
ASHMORE REEF	A71-RC	CREST	22.17	5.46	2.23	17.00	30.00
ASHMORE REEF	A8-RC	CREST	50.17	5.64	2.30	44.00	60.00
CARTIER REEF	1	DEEP	19.33	3.72	1.52	13.00	24.00
CARTIER REEF	1	SHALLOW	18.17	7.86	3.21	9.00	27.00
CARTIER REEF	2	DEEP	55.50	3.62	1.48	51.00	60.00
CARTIER REEF	2	SHALLOW	44.74	11.40	4.65	32.00	65.00
CARTIER REEF	3	DEEP	45.33	3.20	1.31	42.00	49.00
CARTIER REEF	3	SHALLOW	26.00	11.58	4.73	12.00	44.00
CARTIER REEF	4	DEEP	5.33	1.97	0.80	2.00	8.00
CARTIER REEF	4	SHALLOW	13.33	3.50	1.43	10.00	20.00
CARTIER REEF	5	DEEP	12.33	8.59	3.51	5.00	28.00
CARTIER REEF	5	SHALLOW	9.50	3.67	1.50	5.00	14.00
CARTIER REEF	6	DEEP	16.50	4.89	2.00	10.00	24.00
CARTIER REEF	6	SHALLOW	29.17	8.28	3.38	22.00	41.00
CARTIER REEF	C1-RC	CREST	4.00	5.29	3.06	0.00	10.00
CARTIER REEF	C2-RC	CREST	7.25	4.99	2.50	0.00	11.00
CARTIER REEF	C2-RF	FLAT	10.33	3.88	1.58	8.00	18.00
CARTIER REEF	C3-RC	CREST	10.68	6.00	3.47	5.05	17.00
CARTIER REEF	C3-RF	FLAT	7.80	4.55	2.03	3.00	14.00
CARTIER REEF	C4-RC	CREST	6.58	2.46	1.00	2.00	9.00
CARTIER REEF	C4-RF	FLAT	0.75	1.50	0.75	0.00	3.00
CARTIER REEF	C6-RC	CREST	16.25	9.67	4.84	9.00	30.00
SERINGAPATAM	1	DEEP	34.00	10.99	4.49	18.00	47.00
SERINGAPATAM	1	SHALLOW	16.67	4.08	1.67	10.00	21.00
SERINGAPATAM	2	DEEP	37.17	3.97	1.62	31.00	42.00
SERINGAPATAM	2	SHALLOW	12.17	6.18	2.52	6.00	23.00
SERINGAPATAM	3	DEEP	42.33	7.28	2.97	30.00	50.00
SERINGAPATAM	3	SHALLOW	21.30	10.73	4.38	7.92	37.00
SERINGAPATAM	4	DEEP	42.67	14.47	5.91	19.00	58.00
SERINGAPATAM	4	SHALLOW	17.58	12.56	5.13	4.00	36.00
SERINGAPATAM	5	DEEP	38.00	5.48	2.24	30.00	47.00
SERINGAPATAM	5	SHALLOW	22.41	4.42	1.81	17.00	27.72
SERINGAPATAM	6	DEEP	24.83	4.79	1.96	17.00	30.00
SERINGAPATAM	6	SHALLOW	32.45	8.22	3.36	23.00	44.71
SERINGAPATAM	SR1-RF	FLAT	8.75	4.31	1.76	4.00	15.00
SERINGAPATAM	SR2-RC	CREST	4.83	1.72	0.70	3.00	7.00
SERINGAPATAM	SR2-RF	FLAT	15.67	6.15	2.51	5.00	23.00
SERINGAPATAM	SR3-RC	CREST	3.00	1.41	0.70	1.01	4.00
SERINGAPATAM	SR4-RF	FLAT	6.71	3.36	1.37	1.00	10.00
SERINGAPATAM	SR5-RF	FLAT	2.17	1.33	0.54	1.00	4.00
SERINGAPATAM	SR6-RF	FLAT	2.33	2.07	0.84	0.00	6.00

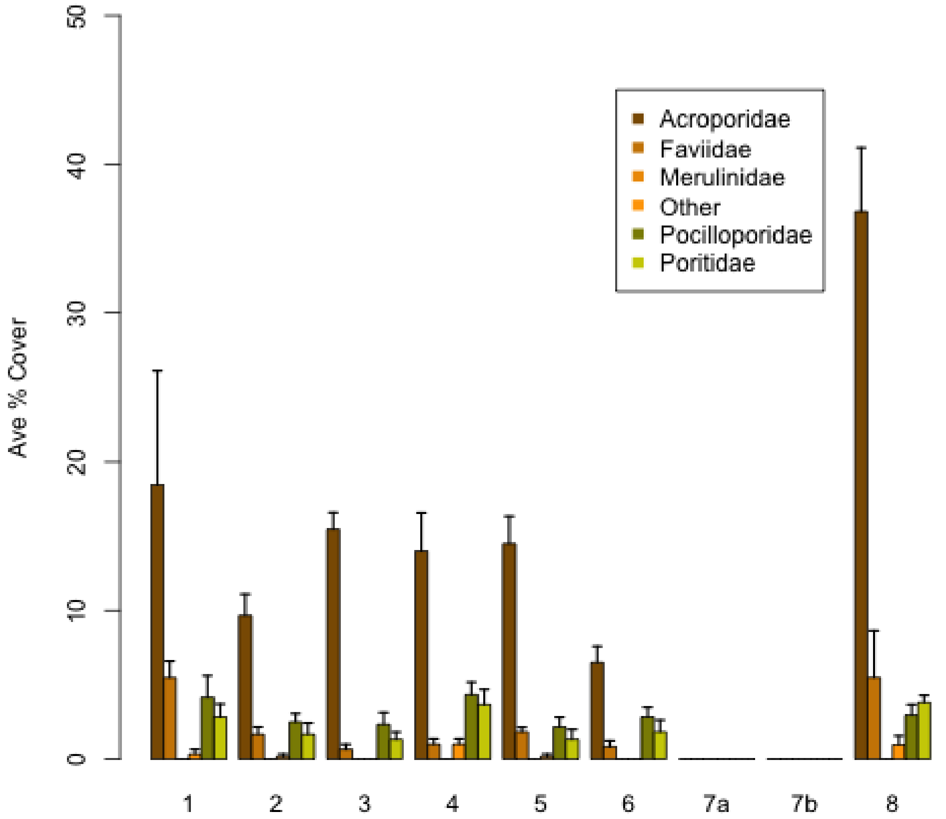


Figure 19. Ashmore Reef –abundance of dominant coral families on the 3 m fixed transects

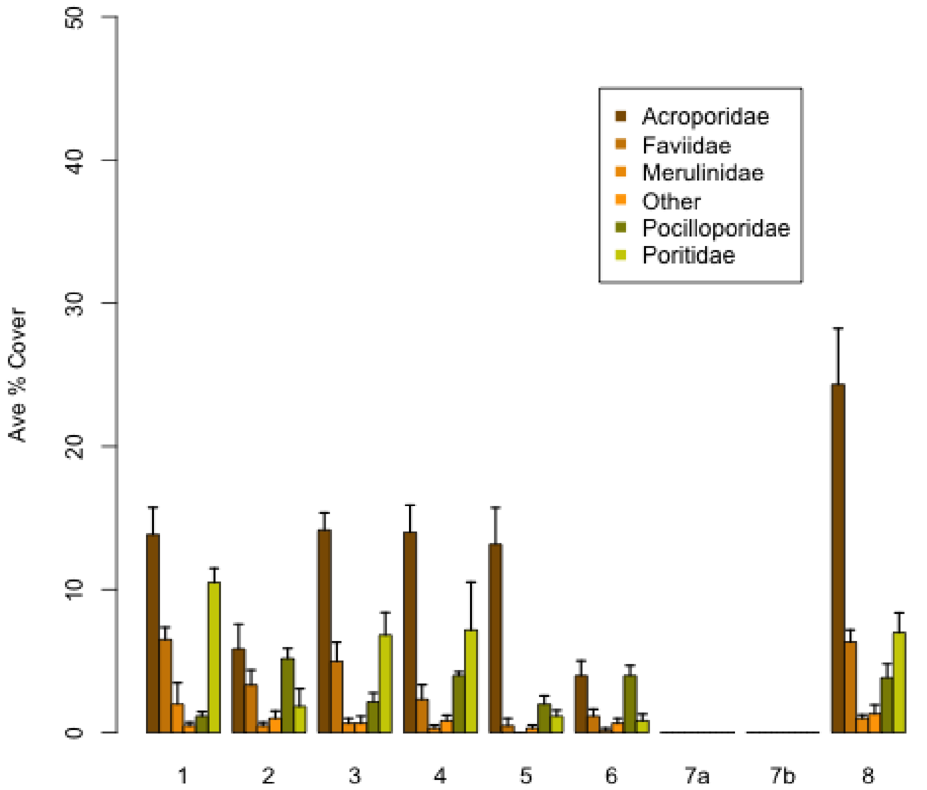


Figure 20. Ashmore Reef –Abundance of dominant coral families on the 6 m fixed transects sites

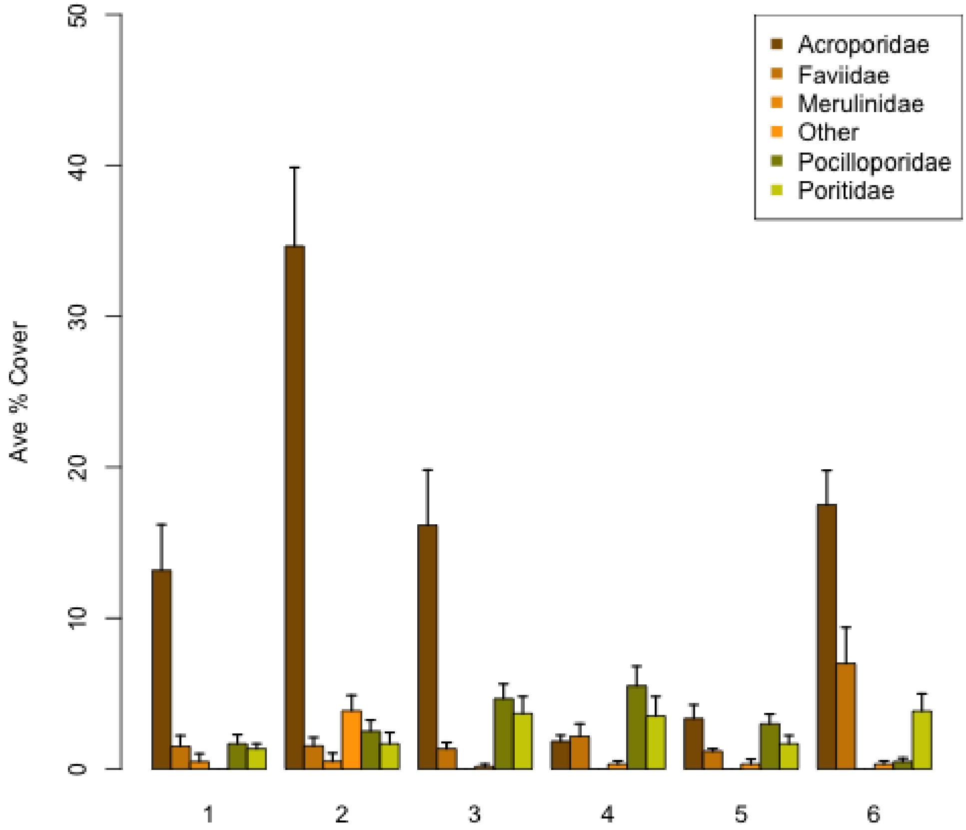


Figure 21. Cartier Reef – Abundance of dominant coral families on the 3 m fixed transects

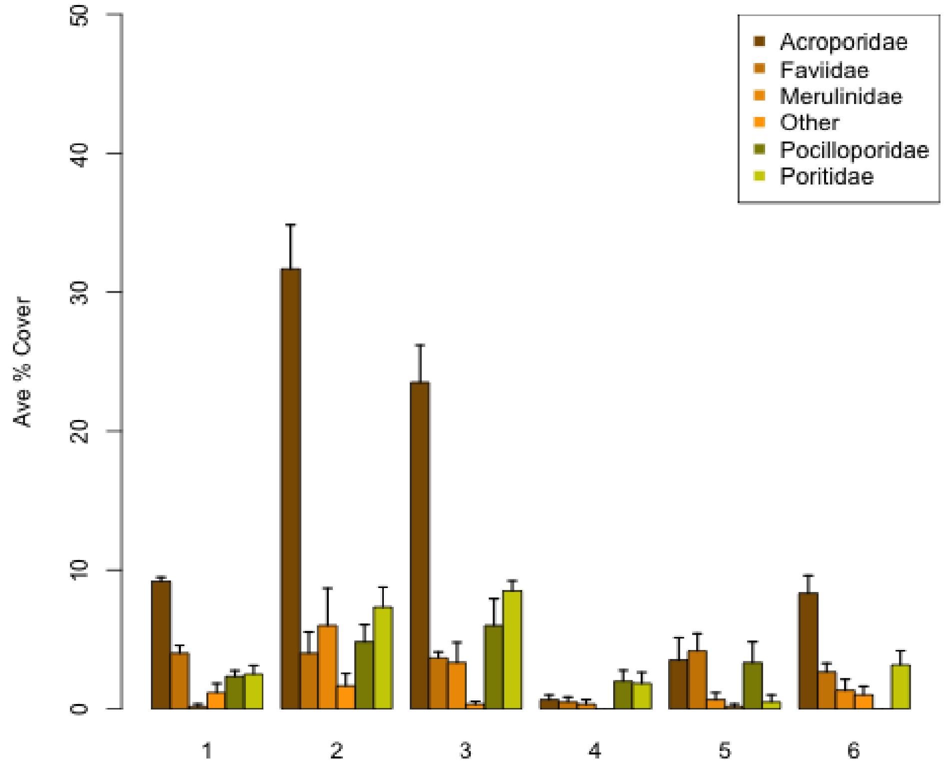


Figure 22. Cartier Reef – abundance of dominant coral families on the 6 m fixed transects sites

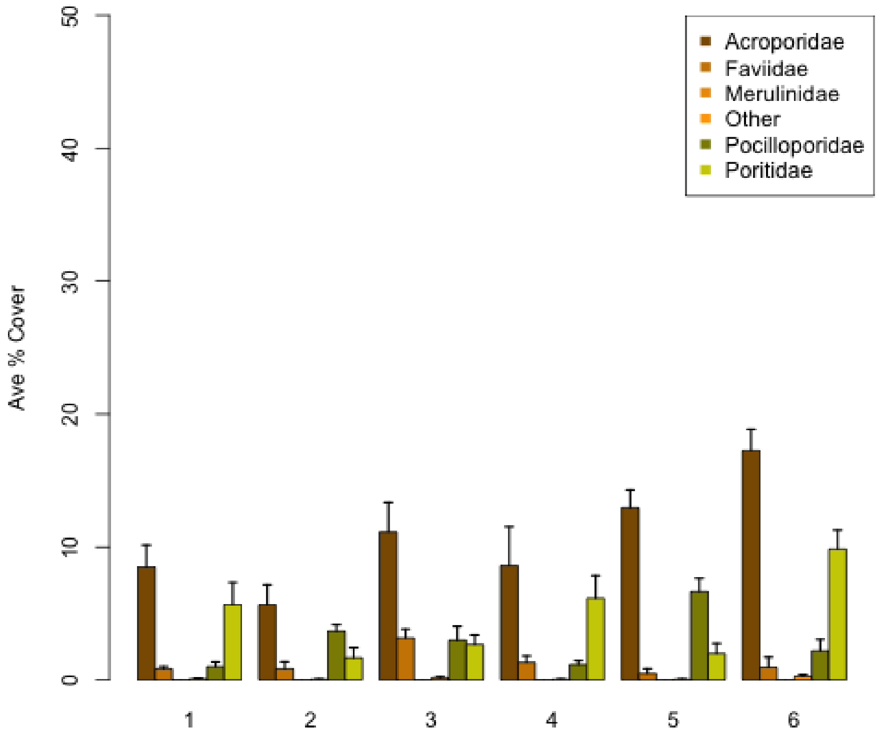


Figure 23. Seringapatam Reef – abundance of the dominant coral families at each of the 3 m fixed transect sites

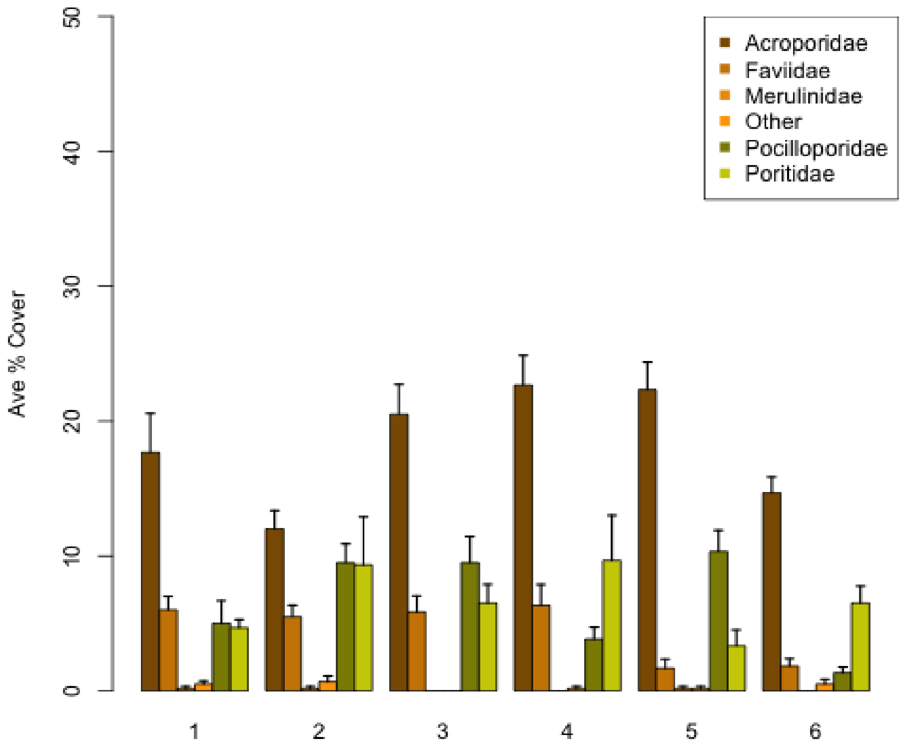


Figure 24. Seringapatam Reef – abundance of the dominant coral families at each of the 6 m fixed transect sites

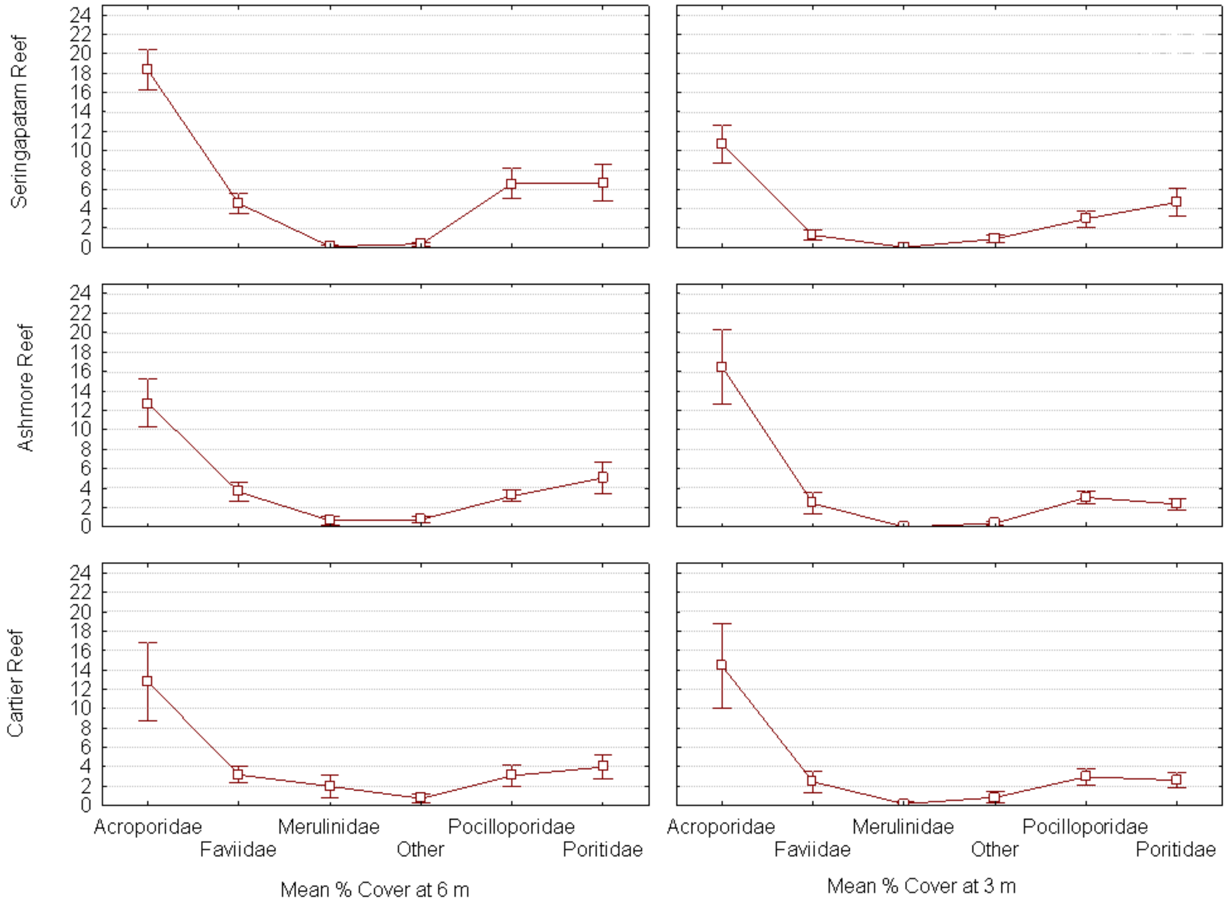


Figure 25. Mean live coral cover comparison between Ashmore, Cartier and Seringapatam Reefs for the major families at 3 m and 6 m depths. Means and error bars generated via a General linear Model using data for all sites on each reef.

Table 3. GLM Summary table for data shown in Fig. 25 above, comparing coral cover by main effects and nested factors reef depth and coral group

Factor	DF	Log-ms	Chi-sq	p
Intercept	1	-9463.16		
Depth	4	-8871.60	1183.130	0.000000***
Reef	2	-8856.64	29.916	0.000000***
Coral Group	5	-5465.65	6781.981	0.000000***
Reef x Depth	6	-5301.07	329.164	0.000000***
Depth x Coral Group	20	-4964.19	673.765	0.000000***
Reef x Coral Group	10	-4862.40	203.567	0.000000***
Reef x Depth x Coral Group	30	-4759.67	205.458	0.000000***

Coral bleaching

While easily observed by divers due to the bright white corals being obvious and eyecatching (Fig. 26), average absolute cover by bleached corals was very low (Table 4), especially at Ashmore (<4.8%) and Cartier Reefs (≤6.0 %), while more common at Seringaptam Reef(≤ 14.9%). There were significant differences associated with both depth and reef in relation to bleaching. As a percentage of the coral community, the 3 m shallow slope sites had significantly more bleaching than either the reef flat or 6 m sites (Table 4). While several species of coral were strongly affected, many common corals were not bleached and occured adjacent to bleaching species (e.g. Figs. 26 and 27). This species selectivity in relation to bleaching was noted at all three reefs studied in detail and also during the brief check on two sites at South Scott Reef. Figures 28 - 31 show the rleative sensitivity to bleaching in the four most common hard coral families. Overwhelmingly the Pocilloporidae, typically represented by numerous colonies of *P. edouxi*, were strongly affected, with up to half of this family bleached at some sites on Seringapatam. The remaining three families, Acroporidae, Faviidae and Poritidae, were all much less affected and similar to each other in relation to the percent bleaching.

Table 4. Mean coral cover and bleached coral summary for each habitat depth at each of the three reefs. Note that reefcrest and reef flat areas had a mixed sampling approach designed mainly to broader the range of habitats surveyed and are less comparable between sites and reefs that the 3 m and(shallow) and 6 m (deep) transect sites

Reef	Site Depth	Mean Cover %	Std Dev %	StdErr %	Min % Cover	Max % Cover	Mean % Cover Bleached	% Coral Bleached
Ashmore Reef	Bommie	17.33	9.14	2.64	5.00	35.00	0.25	1.442307692
Ashmore Reef	Crest	21.38	18.46	3.37	0.00	60.00	0.03	0.140337759
Ashmore Reef	Deep	26.03	13.08	2.02	4.00	57.00	0.07	0.268877598
Ashmore Reef	Flat	3.58	5.33	2.18	0.00	14.00	0.00	0
Ashmore Reef	Shallow	24.68	14.98	2.31	7.00	64.00	1.18	4.780683479
Cartier Reef	Crest	8.88	6.71	1.50	0.00	30.00	0.25	2.816100128
Cartier Reef	Deep	25.72	19.01	3.17	2.00	60.00	0.94	3.654427646
Cartier Reef	Flat	6.93	5.28	1.36	0.00	18.00	0.00	0
Cartier Reef	Shallow	23.48	14.15	2.36	5.00	65.00	1.42	6.046424523
Seringapatam	Crest	4.10	1.79	0.57	1.01	7.00	0.40	9.753694581
Seringapatam	Deep	36.50	10.09	1.68	17.00	58.00	4.00	10.95890411
Seringapatam	Flat	7.13	6.18	1.13	0.00	23.00	0.03	0.42100682
Seringapatam	Shallow	20.43	10.02	1.67	4.00	44.71	3.04	14.88094214

Table 4 summarises the major bleaching effects. It was apparent during dives that the bleaching was also effecting a broader range of less common species consistently. These included the small Occulinid *Galaxea fascicularis* and the fire coral *Millepora*. The majority of these particular species were bleached, but this effect was only apparent in the summary data in locations where they were more abundant.

Figure 26. Seringapatam Reef - selective and significant bleaching of Poccilloporid corals on a 6 m transect, which show as bright white colonies. Acroporid colonies are not bleached.

Figure 27. Seringapatam Reef- close up of selective bleaching. One colony of *Pocillopora edouxi* and the fine branched *Seriatopora hystrix*, both in the family Pocilloporidae are bleached but alive, while the adjacent orange *Acropora* and a smaller *Pocillopora* are unbleached.

Figure 28. Ashmore Reef - coral bleaching averaged at the shallow (3 m) and deeper (6 m) transect sites for the four dominant hard coral families. Corals were classified as healthy in appearance, partially bleaching or fully bleached during the point intercept analyses.

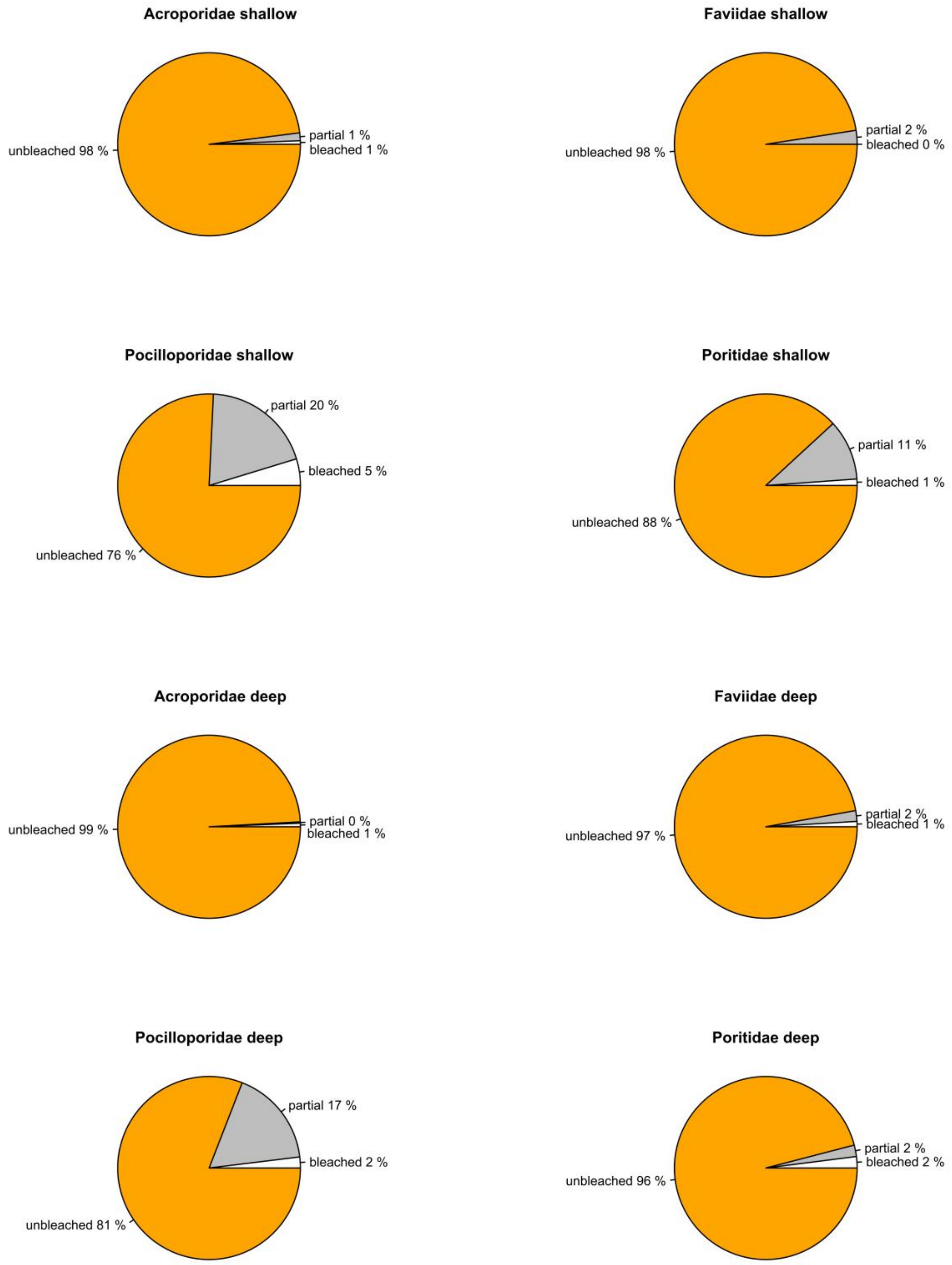


Figure 29. Cartier Reef - coral bleaching averaged at the shallow (3 m) and deeper (6 m) transect sites for the four dominant hard coral families. Corals were classified as healthy in appearance, partially bleaching or fully bleached during the point intercept analyses.

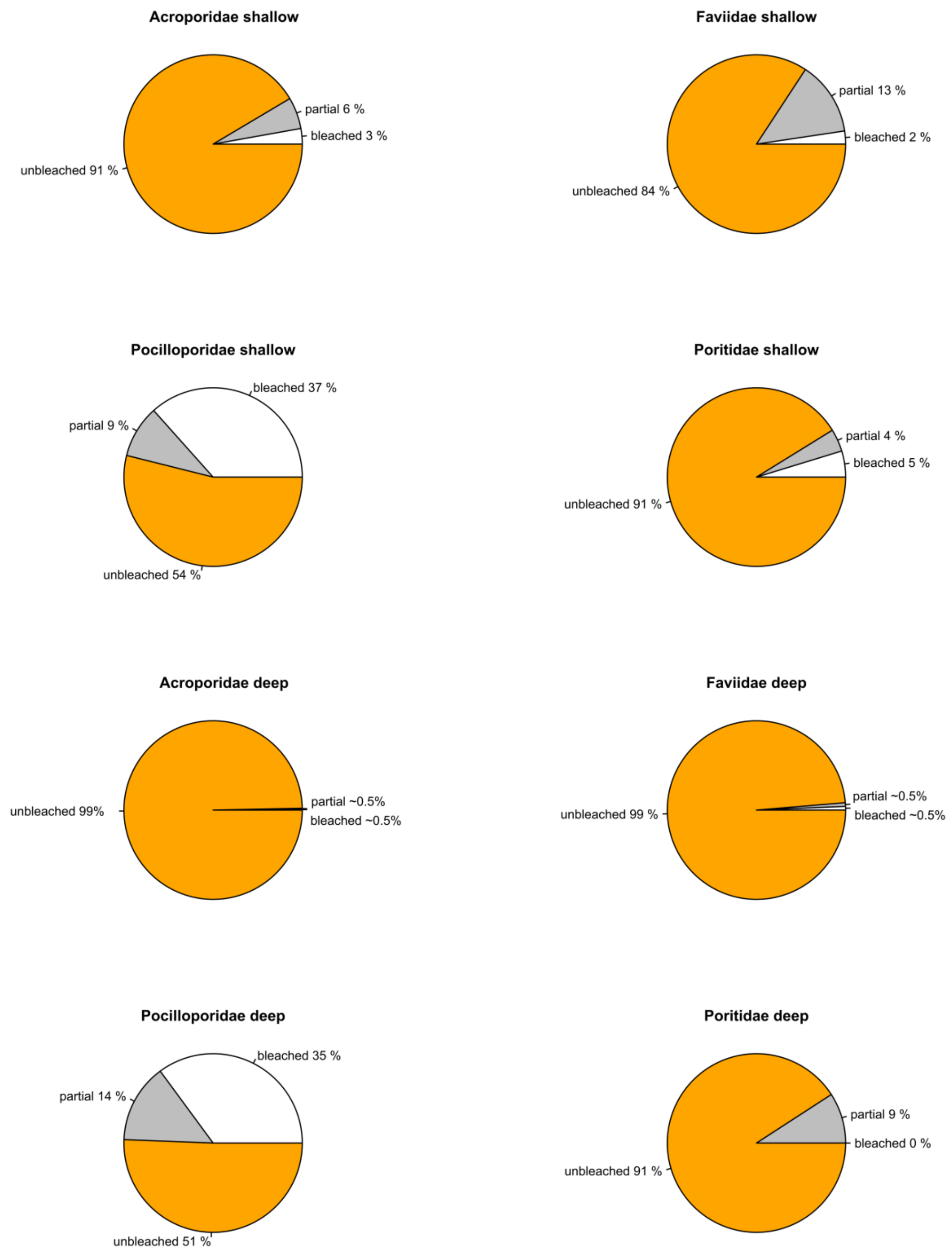


Figure 30. Seringapatam Reef - coral bleaching averaged for the shallow (3 m) and deeper (6 m) transect sites for the four dominant hard coral families. Corals were classified as healthy in appearance, partially bleaching or fully bleached during the point intercept analyses

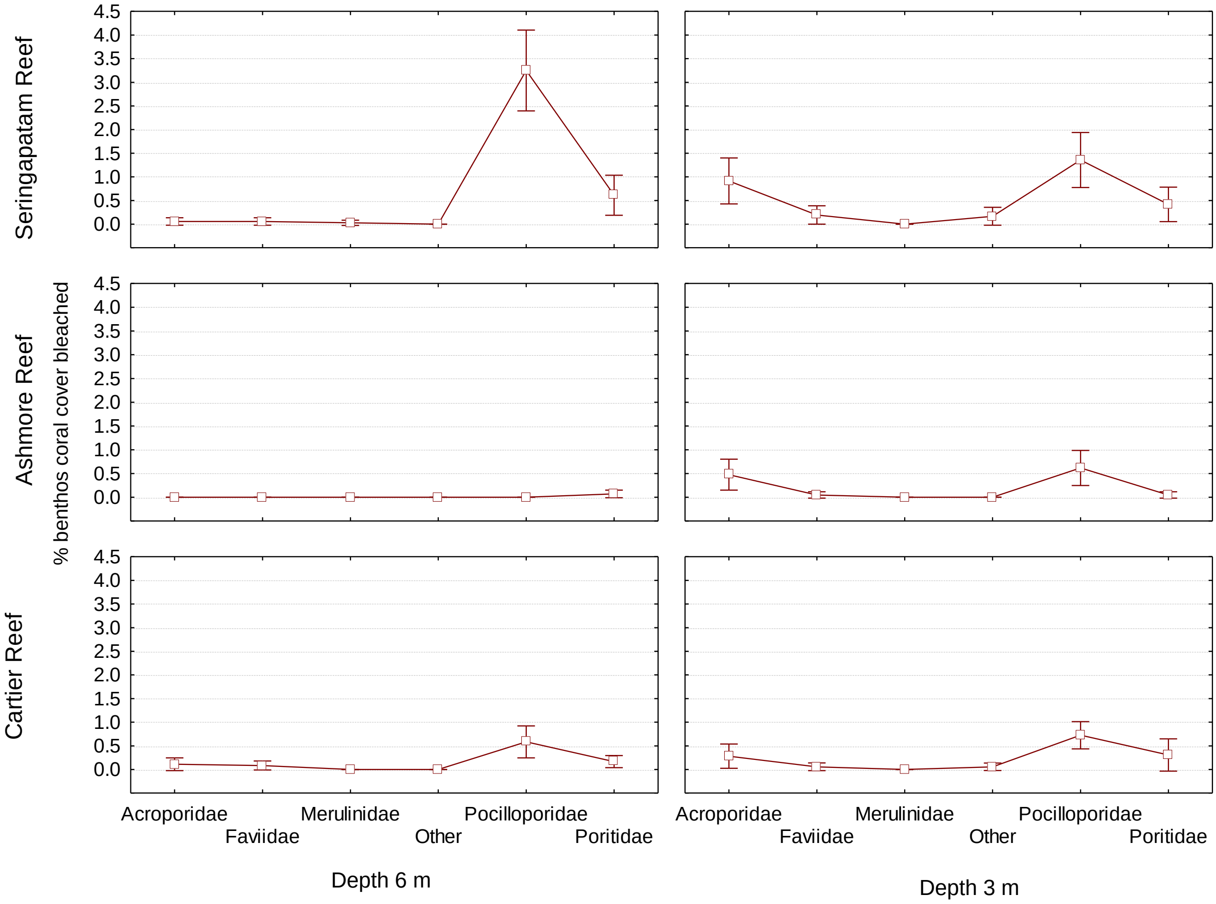


Figure 31. Comparative whole reef summaries of coral bleaching for the major hard coral families at 3 m and 6 m depths

Table 5. GLM Summary table comparing benthic cover bleached (partial bleaching and total bleaching combined) by main effects and nested factors reef, depth and coral group

Factor	DF	Log-ms	Chi-sq	p
Intercept	1	-1295.37		
Depth	5	-1019.47	551.7997	0.000000
Reef	4	-904.04	230.8680	0.000000
Coral Group	2	-809.14	189.8106	0.000000
Reef x Depth	8	-762.77	92.7387	0.000000
Depth x Coral Group	8	-754.09	17.3566	0.026603
Reef x Coral Group	4	-727.73	52.7139	0.000000
Reef x Depth x Coral Group	9	-708.90	37.6677	0.000020

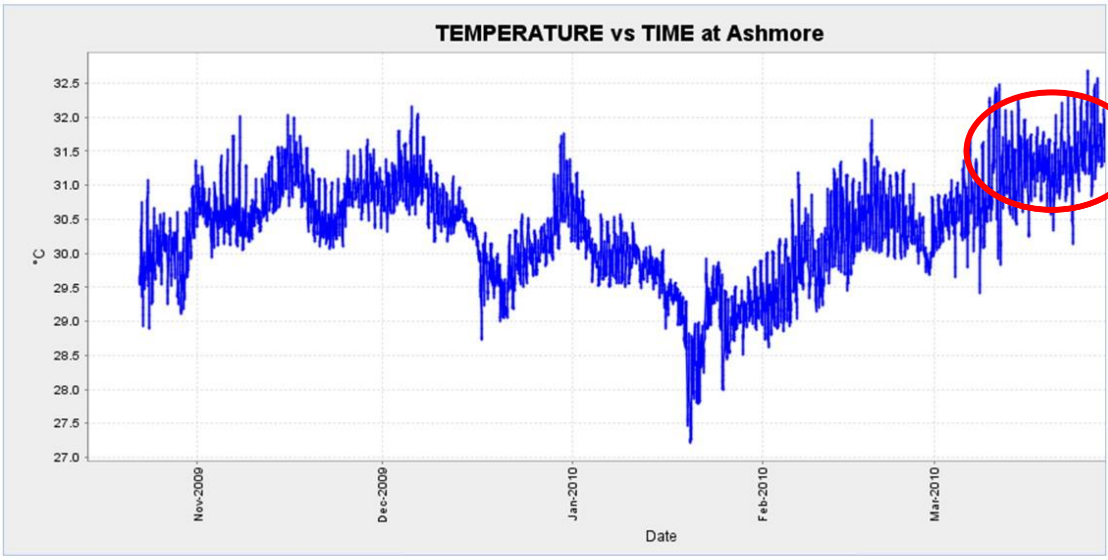


Figure 32. . Ashmore Reef seawater temperature record between March 2009 until this survey in April 2010. The red oval highlights a period of unusually warm water temperature, reaching a maxima of 32.7°C, which is the most likely cause of the observed coral bleaching.

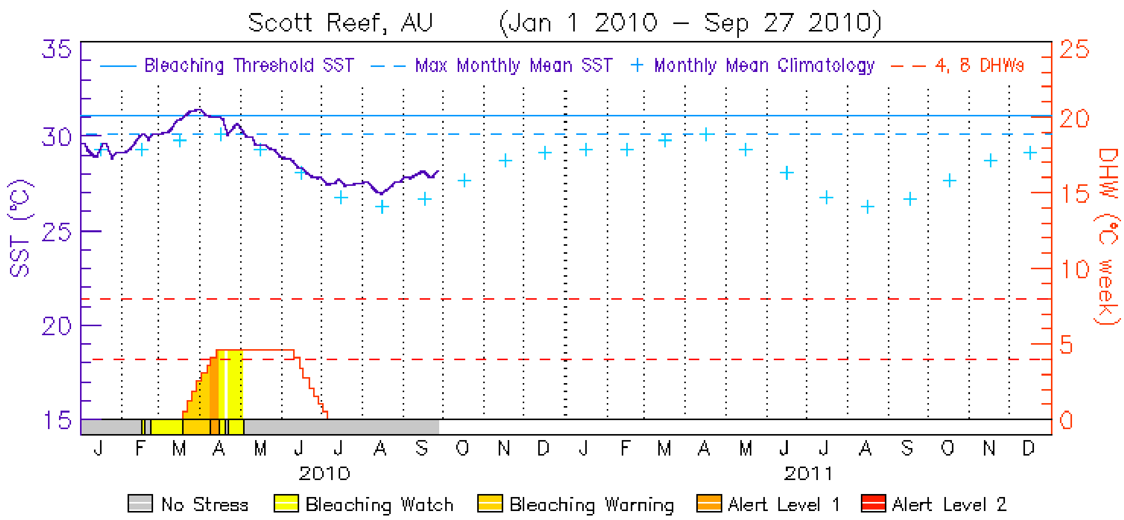


Figure 33. NOAA Satellite derived sea surface temperature data indicates a period of potential thermal stress on corals in the Scott Reef area during March - April, 2010. Graph produced by NOAA - http://coralreefwatch.noaa.gov/satellite/current/sst_series_scott_cur.html

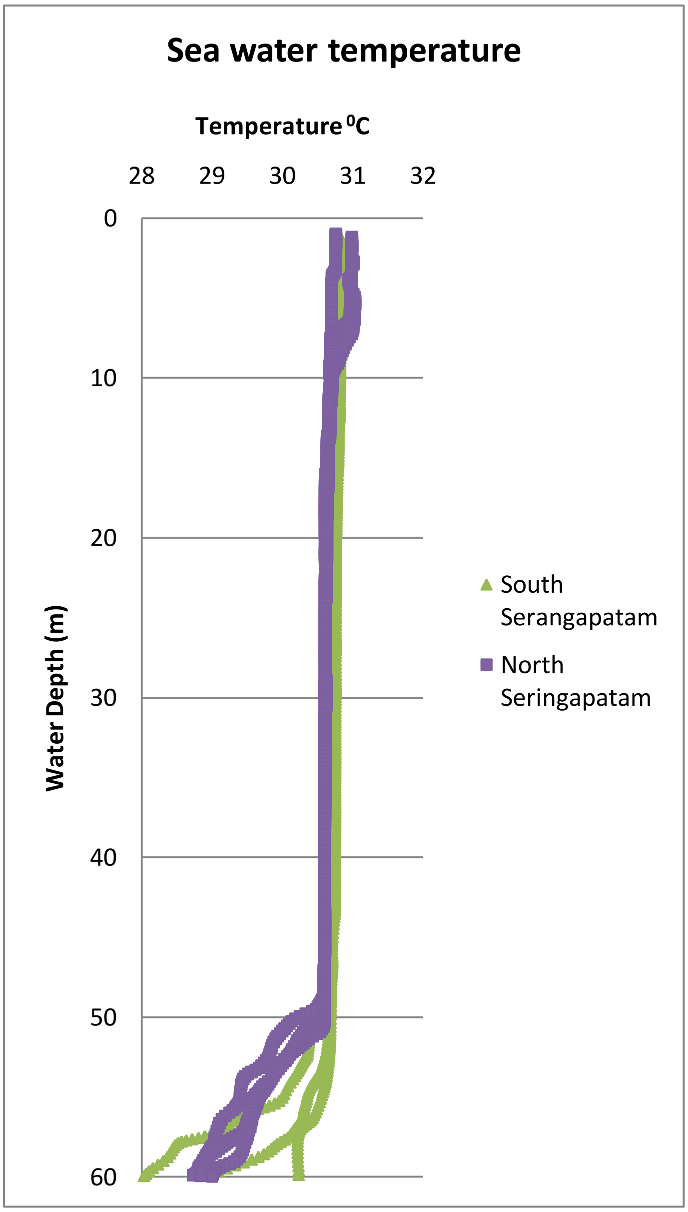


Figure 34. Seawater temperature CTD profiles obtained during April 2010 at stations offshore (see Fig. 4) of Seringapatam Reef.

Sediment analyses

Table 6 contains the results of UVF analysis of the 50 extracts. The oil samples was a light crude oil and matched the NAPL standard reasonably well. Samples were calculated at excitation emission wavelengths of 280nm/330nm and compared to a five point calibration using the NAPL standard. Values ranged from non detectable (< ~ 0.03 µg/g) to 0.58 µg/g at Cartier C1DS. Several samples around Ashmore reef contained 0.09 to 0.49 µg/g. Seven samples which had UVF spectra similar to the standard were selected for further analysis.

Table 7 contains the summary hydrocarbon results for the seven samples determined by GCMS. Values of total Hydrocarbons (THC) ranged from 0.7 to 2.9 µg/g. Significant amounts of the

THC were unresolved complex material (UCM) typical of residual petroleum. The sum of oil PAHs ranged from 1.9 to 4.5 ng/g.

Reconstructed ion chromatographs (RICs) of samples overlain with the analytical blank as reference are shown in Appendix 3 (Appendix 3 - Figures 1- 7) for the seven samples examined. All the samples contained a pattern showing degraded crude oil. Many of the volatile fractions had been removed by evaporation and solution processes. They all had the same pattern with high molecular weight alkanes visible over the unresolved complex mixture of hydrocarbons typical of a degraded oil pattern.

Tables 9 and 10 contain the summary PAH and biomarker data calculated for the seven sediment extracts. All the extracts contained the full suite of PAHs, sterane and triterpane biomarkers expected for a degraded crude oil. Within each PAH group the higher molecular weight alkyl substituted compounds predominated as the lower molecular weight compounds had been removed by natural weathering processes. Note the presence of flourenone which is a photo-oxidation marker for petroleum (Ehrhardt and Burns, 1993), meaning the oil had undergone significant amount of photo oxidation before being incorporated into the sediments.

Figure 35 shows the general agreement between the UVF and the GCMS analyses for these seven samples. Concentrations are very low in concentration and the trend is of general agreement, but too few samples to be significant.

Table 6. Location and depths of samples plus UVF oil determination in µg/g.

Sample	Date	Site name	Site	Lat °S	Long °E	Depth (m)	UVF oil µg/g
3B	4-Apr	Ashmore	A1DS	-12.184	123.105	6	ND
12B	6-Apr	Ashmore	A3DS	-12.256	123.155	6	ND
14B	6-Apr	Ashmore	A4DS	-12.291	123.116	6	ND
9A	5-Apr	Ashmore	A2DE	-12.187	123.122	6	0.49
19B	7-Apr	Ashmore	A5DS	-12.265	122.958	6	0.49
26B	8-Apr	Ashmore	A6DE	-12.229	122.950	6	0.36
32B	9-Apr	Ashmore	A8DE	-12.182	123.046	6	0.33
1B	4-Apr	Ashmore	A1SS	-12.185	123.105	3	ND
7A	5-Apr	Ashmore	A2SE	-12.188	123.122	3	ND
10B	5-Apr	Ashmore	A3SS	-12.251	123.155	3	ND
28B	7-Apr	Ashmore	A6SE	-12.229	122.950	3	ND
35B	10-Apr	Ashmore	A8SE	-12.183	123.047	3	ND
21B	7-Apr	Ashmore	A5SS	-12.264	122.958	3	0.09
30B	8-Apr	Ashmore	A7S2S	-12.236	122.987	3	0.08
5B	4-Apr	Ashmore	A1RC	-12.185	123.102	2	ND
16B	6-Apr	Ashmore	A4RC	-12.287	123.129	1	0.45
18B	6-Apr	Ashmore	SI1	-12.260	123.111	0	ND
24B	7-Apr	Ashmore	WI	-12.243	122.965	0	ND
33B	10-Apr	Ashmore	SI2	-12.194	123.061	0	ND
51B	12-Apr	Cartier	C3DE	-12.525	123.540	6	ND
55B	13-Apr	Cartier	C4DE	-12.524	123.558	6	ND
69B	14-Apr	Cartier	C5DE	-12.526	123.574	6	ND
36B	11-Apr	Cartier	C1DS	-12.545	123.556	6	0.58
43B	11-Apr	Cartier	C2DE	-12.545	123.539	6	0.07
58B	13-Apr	Cartier	C6DS	-12.534	123.581	6	0.03
40A	11-Apr	Cartier	C1SS	-12.545	123.556	3	ND
46B	12-Apr	Cartier	C2SS	-12.545	123.540	3	ND
49B	12-Apr	Cartier	C3SE	-12.525	123.540	3	ND
57B	13-Apr	Cartier	C4SE	-12.524	123.557	3	ND
67B	14-Apr	Cartier	C5SE	-12.526	123.573	3	ND
62B	14-Apr	Cartier	C6SS	-12.534	123.581	3	0.15
64B	14-Apr	Cartier	C5RF	-12.527	123.573	1	0.15
61B	13-Apr	Cartier	RF1 Reef Flat	-12.527	123.578	0.3	0.05
52B	12-Apr	Cartier	C3RF	-12.526	123.541	0.2	ND
45B	11-Apr	Cartier	C2L	-12.543	123.542	0.2	0.10

38B	11-Apr	Cartier	CI1	-12.530	123.554	0	ND
89B	25-Apr	Scott	SS1-1	-14.080	121.978	6	ND
90B	25-Apr	Scott	SL1-1	-14.079	121.948	6	0.05
75B	20-Apr	Seringapatam	SR1DE	-13.650	121.975	6	ND
76B	21-Apr	Seringapatam	SR6DS	-13.694	121.995	6	ND
86	23-Apr	Seringapatam	SR2DE	-13.623	121.998	6	0.09
71B	20-Apr	Seringapatam	SR1SE	-13.650	121.976	3	0.15
81B	21-Apr	Seringapatam	SR5SS	-13.699	122.031	3	0.06
79A	21-Apr	Seringapatam	SR6SS	-13.694	121.995	3	0.04
72B	20-Apr	Seringapatam	SR1RF	-13.645	121.983	1	ND
87B	24-Apr	Seringapatam	SR3RF	-13.639	122.023	1	0.23
88B	24-Apr	Seringapatam	88A_88B	-13.646	122.023	1	0.09
78B	21-Apr	Seringapatam	SR6RF	-13.694	121.995	1	0.06
84B	23-Apr	Seringapatam	SR2RF	-13.627	122.001	1	0.04
83B	23-Apr	Seringapatam	Forward	-13.631	122.004	0	ND

Note: ND was not detectable when sample was less than 3 X blank analysis.

Blank for samples up to 58B was 1.01 μg total. Blank for second set was 0.35 ug total. Blanks were subtracted from samples for final calculations.

Table 7. Summary hydrocarbon composition determined by GCMS

Site	A2DE	A4RC	A5DS	A5SS	A6DE	A8DE	C1DS
Sample Number	9A	16B	19B	21B	26B	32B	36B
Dry Wt Extracted (g)	31.9	43.5	41.5	29.0	30.4	31.5	30.5
Total Extractable Lipid (EOM) (ug/g)	65.9	86.6	46.0	34.8	90.2	49.8	57.3
UVF Oil (ug/g)	0.49	0.45	0.49	0.09	0.36	0.33	0.58
Total Hydrocarbons (ug/g)	2.01	0.69	1.11	1.30	1.26	1.22	2.91
%UCM	19	41	40	63	64	64	37
Total n-Alkanes C11-C38 (ng/g)	665	162	261	193	155	333	309
Sum Oil PAHS (ng/g)[1]	4.48	2.78	2.36	1.89	2.53	2.08	3.35
Sum Combustion PAHs (ng/g)[2]	0.06	0.04	0.05	0.07	0.03	0.04	0.08
Sum Triterpanes (ng/g)	2.04	0.73	1.10	0.35	1.25	1.15	1.78
Sum Steranes (ng/g)	0.18	0.11	0.10	0.03	0.16	0.11	0.17
Fluorenone (pg/g)	5590	1938	2968	2671		2195	991

[1] Sum of Oil PAHs in the sum of naphthalene, phenanthrene, anthracene, biphenyl, acenaphthylene, acenephthene, fluorene, DBT, fluoranthene, pyrene, benz(a)anthracene, chrysene, series of parent and alkylated PAHS.

[2] Sum combustion PAHs is the sum of the benzofluoranthene, benzopyrene, indenopyrene, dibenzanthracene, and benzoperylene series of parent PAHs.

Table 8. Summary PAHs in sediment extracts.

Parent and Alkyl PAHs (pg/g)	9A	16B	19B	21B	26B	32B	36B
naphthalene							
C1-naphthalenes			0.4	59.7	24.2	30.5	68.8
C2-napthalenes	98	27	62	129	102	115	197
C3-naphthalenes	158	67	105	159	99	78	137
C4-naphthalenes	1167	460	303	269	270	353	317
biphenyl							
C1-biphenyls	45.8	10.0	24.6	22.6	13.9		7.8
C2-biphenyls	49.9	12.2	23.3	18.5	18.3	23.5	18.7
acenaphthylene	22.5			25.8		26.2	33.3
acenaphthene				2.6			4.8
fluorene							
C1-fluorenes	113.4	14.4	7.3	8.2	21.2	7.9	12.8
C2-fluorenes	261.9	209.2	164.9	93.1	129.3	206.7	127.5
DBT	20.1	32.3	16.0	14.4	15.3	13.1	21.8
C1-DBTs	15.3	27.8	12.0				8.9
C2-DBTs	69.3	87.6	58.0	14.5	4.5	28.3	80.7
C3-DBTs	133.6	149.7	126.3	20.8	100.3	75.6	199.0
phenanthrene							
anthracene		35.2					
C1-phenanthrenes/anthracenes	227.2	228.8	148.5	31.1	103.6	92.8	121.5
C2-phenanthrenes/anthracenes	319.3	364.0	165.2	41.9	280.7	191.6	354.7
C3-phenanthrenes/anthracenes	881.2	454.9	491.6	314.1	839.1	360.1	686.1
C4-phenanthrenes/anthracenes	104.6	127.0	131.4	47.6	97.9	70.0	422.3
fluoranthene	103.7	86.4	104.9	86.5			
pyrene	283.1	228.6	264.9	188.0		60.4	56.9
C1-fluoranthenes/pyrenes	20.4	22.7	17.9	22.9	7.8	11.9	44.5
C2-fluoranthenes/pyrenes	58.2	78.3	71.3	35.1	38.9	28.3	83.0
C3-fluoranthenes/pyrenes	20.8	19.1	8.1	2.4	2.7	2.7	34.6
benz(a)anthracene							
chrysene	1.7	1.9		2.7			1.6
C1-benz(a)anthracenes/chrysenes	15.4	14.7	8.2	14.3		13.9	37.9
C2-benz(a)anthracenes/chrysenes	49.1	8.0	10.5	13.1	13.6	10.3	21.6
C3-benz(a)anthracenes/chrysenes	12.0	6.5	2.4	0.5	0.4	7.3	12.6
C4-benz(a)anthracenes/chrysenes	51.3	4.8	6.6		2.7	8.2	2.5
benzo(b)fluoranthene	12.5	8.7	11.5	16.4	10.1	14.6	16.9
benzo(k)fluoranthene	17.3	5.5	9.5	9.0	10.8	15.8	12.4
benzo(e)pyrene	20.1	13.7	16.6	27.4			36.7

benzo(a)pyrene							
perylene				204.1	311.5	241.0	237.6
indeno(1,2,3-cd)pyrene	6.6	4.8	6.9	9.8	6.6	6.5	8.8
dibenz(a,h)anthracene		2.4	2.6	3.6	2.9		3.8

Note: Missing values were non detectable meaning less than 3 times the analytical blank for each individual compound. Blank ranged generally were less than 1- 2 pg/g.

Table 9. Individual petroleum biomarkers.

Individual Biomarkers (pg/g)	9A	16B	19B	21B	26B	32B	36B
bicadinane					4.2		
fluorenone	5590	1938	2968	2671		2195	991
diploptene	63.2						
Ts C27 22,29,30 trisnorneohopane	140.3	59.3	78.7	24.2	96.3	89.2	115.3
Tm C27 22,29,30-trisnorhopane	131.9	51.6	69.6	25.9	69.4	79.9	98.3
C29H-17a,21B-30-norhopane	349.8	121.7	180.4	59.3	196.3	189.1	292.8
C30H-17a(H)21B(H)-hopane	645.8	231.2	374.9	101.2	387.2	337.0	523.3
C31HS	192.0	68.8	107.8	32.4	109.5	100.7	196.5
C31HR	150.5	52.4	80.6	24.3	95.1	81.5	153.1
C32HS	80.8	35.6	49.1	16.7	58.7	52.5	99.5
C32HR	103.8	35.2	50.6	20.3	69.9	55.2	89.4
C33HS	87.5	23.0	38.5	23.0	53.6	34.4	68.0
C33HR	39.2	14.8	22.0	7.2	22.5	30.6	45.9
C34HS	28.9	12.1	17.5	2.6	17.0	20.1	38.8
C34HR	70.4	12.4	18.1	15.3	65.8	61.6	24.1
C35HS	7.1	4.1	5.0		5.2	5.8	17.0
C35HR	11.7	6.7	8.0		8.3	7.8	20.1
C27ba20S	19.8	6.9	11.9	4.4	12.7	11.9	15.8
C27ba20R	13.4	4.5	7.1	2.6	7.2	8.1	9.2
C27abb20R	38.4	21.4	14.5		48.8	21.7	35.6
C27abb20S	14.0	5.5	7.0	3.6	7.5	10.1	15.0
C28abb20R	17.6	9.4	11.5	4.4	12.8	12.0	19.9
C28abb20S	11.7	8.0	8.7	3.4	14.7	9.2	14.2
C29abb20R	43.8	49.4	32.2	8.0	38.2	28.7	45.8

Note: Missing values were non detectable meaning less than 3 times the analytical blank for each individual compound. Blank ranged generally were less than 1 -2 pg/g.

Table 10. Ratios of DBT/1367C4N based on SIM acquisition of ion 184.

MS File	Sample	Area ratio	PH ratio
MS100444	Montara NAPL oil	1.10	1.02
MS100446	Montara NAPL oil	1.10	1.05
MS100493	Montara NAPL oil	1.10	1.92
MS100460	9A Ashmore A2DE	2.88	2.16
MS100462	16B Ashmore A4RC	3.90	3.19
MS100464	19 B Ashmore A5DS	3.48	2.51
MS100466	21B Ashmore A5SS	3.96	2.87
MS100468	26B Ashmore A6DE	6.89	2.49
MS100470	32B Ashmore A8DE	2.99	2.51
MS100472	36C1DSB Cartier	3.91	2.60

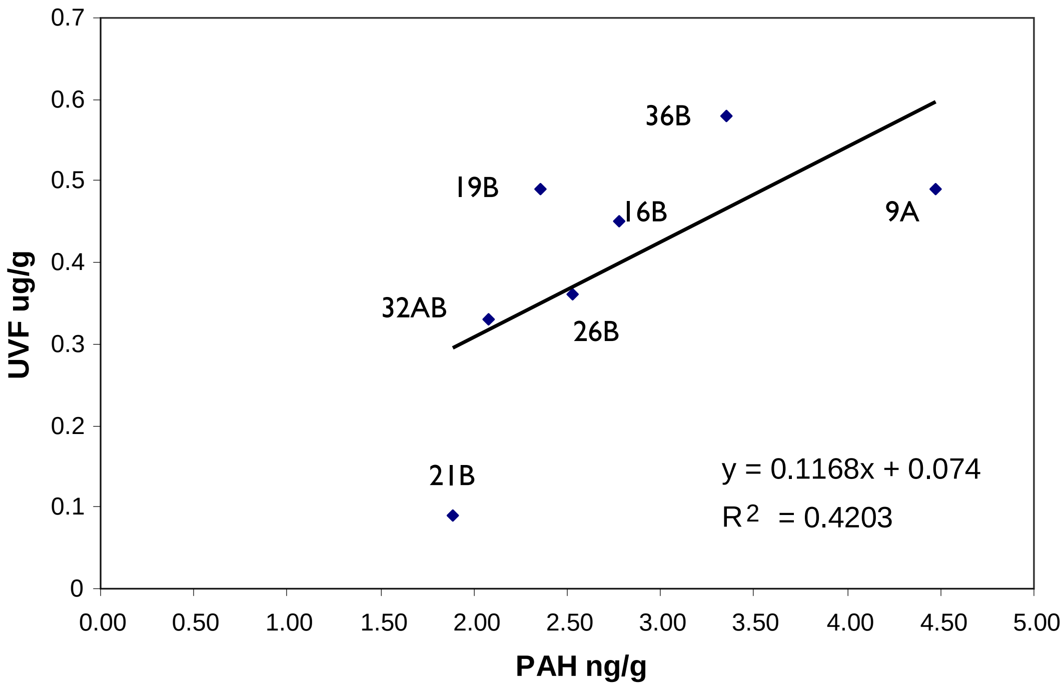


Figure 35 Plot of UVF results vs GCMS results for seven sediment extracts.

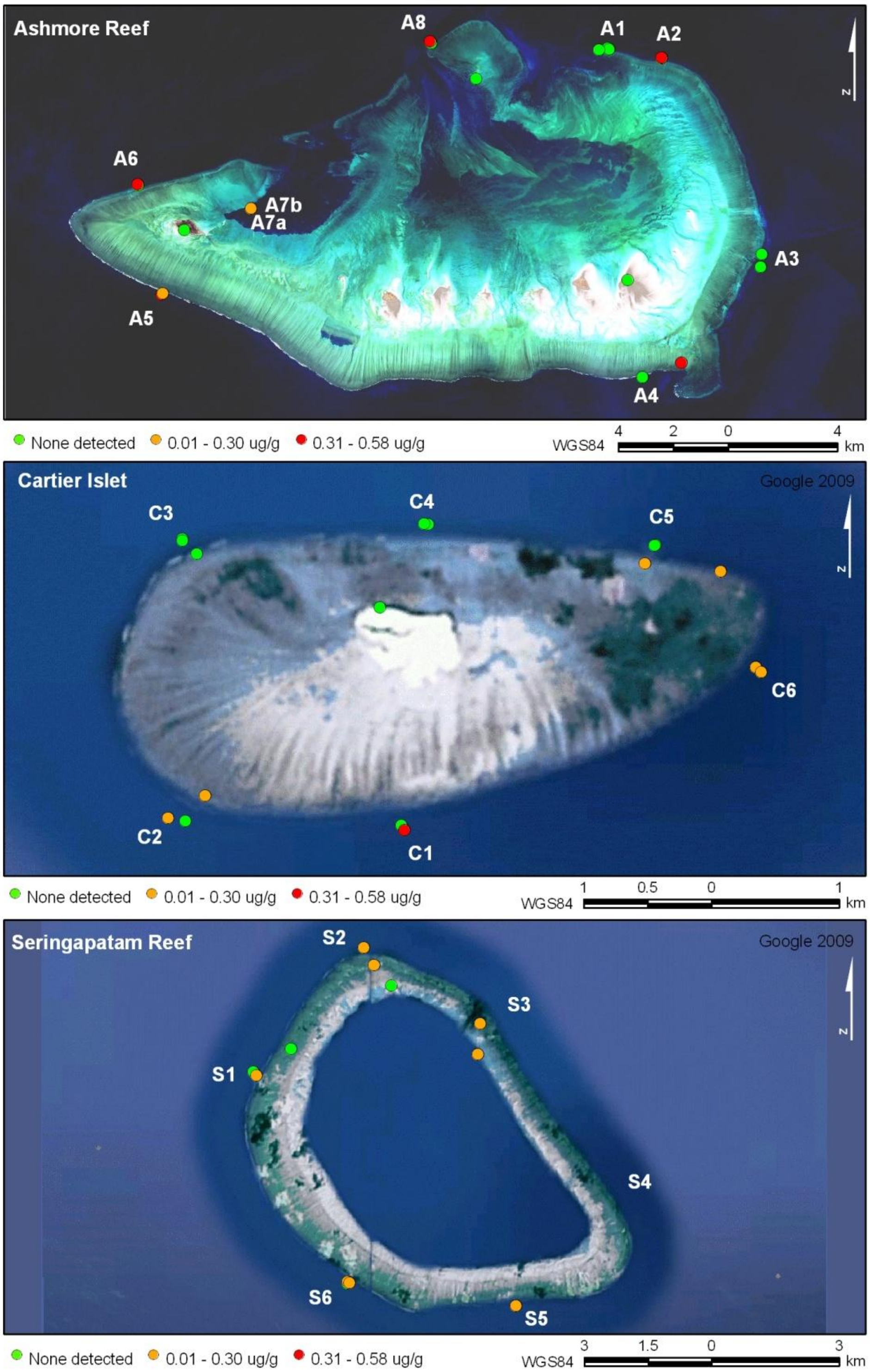


Figure 36. Sediment sample analyses – map of hydrocarbon signals from initial analysis of sediments by UVF. Samples marked in red had the highest concentrations and were further analysed using GCMS. See Table 5 for details.

Coral reproduction

Upon arrival at Ashmore Reef an intensive sampling of dominant Acroporid corals detected no sign of mature gonads. This suggests either there was no reproduction or that the Acroporids had already spawned in March 2010 or in the first few days after the 30 March 2010 full moon. A significant spawning in early March 2010 is the most likely situation, given significant spawning has been noted in March 2010 at Ningaloo (Heyward unpublished obs.), Dampier (Stoddart pers. comm. to Heyward) and Scott Reef (Gilmour pers. comm. to Heyward). Further sampling of other representative species resulted in detection of mature gonads in a portion of the *Favites* and *Goniastrea* (Fig. 37) population, as well as one soft coral species *Lobophytum* sp.(Fig. 38) . Spawning was noted by *Favites abdita* maintained in seawater systems aboard the RV Solander on the night of 6 April 2010. Gametes from three colonies were mixed *in vitro* in the ship's laboratory and successful fertilization recorded (Fig. 39). Approximately 2 hours after insemination, fertilisation rates averaged close to 90% (89.3 ± 1.3%, mean ± SE) which is very high and comparable to upper levels of laboratory fertilisation rates published for other parts of the world (e.g. Heyward & Negri 2000). The resulting embryos were cultured through to larvae and settled, demonstrating their competency.

Figure 37. Cross section through a mature colony of the brain coral *Goniastrea retiformis* – the pink spheres are mature oocytes approximately 350μm diameter. Colony sampled 5 April 2010.

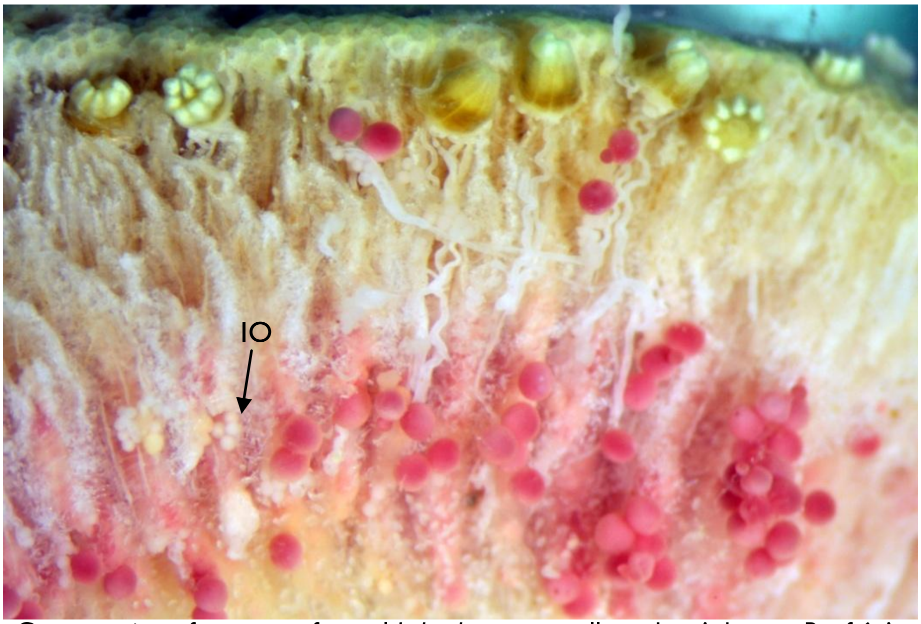


Figure 38. Cross section of mature soft coral *Lobophytum* sp, collected at Ashmore Reef 6 April, 2010. This type of coral is known to have separate sexes and also some species in this genus have been found elsewhere to have an overlapping 2 year oogenic cycle, with both year classes of gametes present in the same colony. The large pink oocytes are mature and ready to spawn. Much smaller, pale spheres are immature oocytes (IO) and will mature 12 months later.

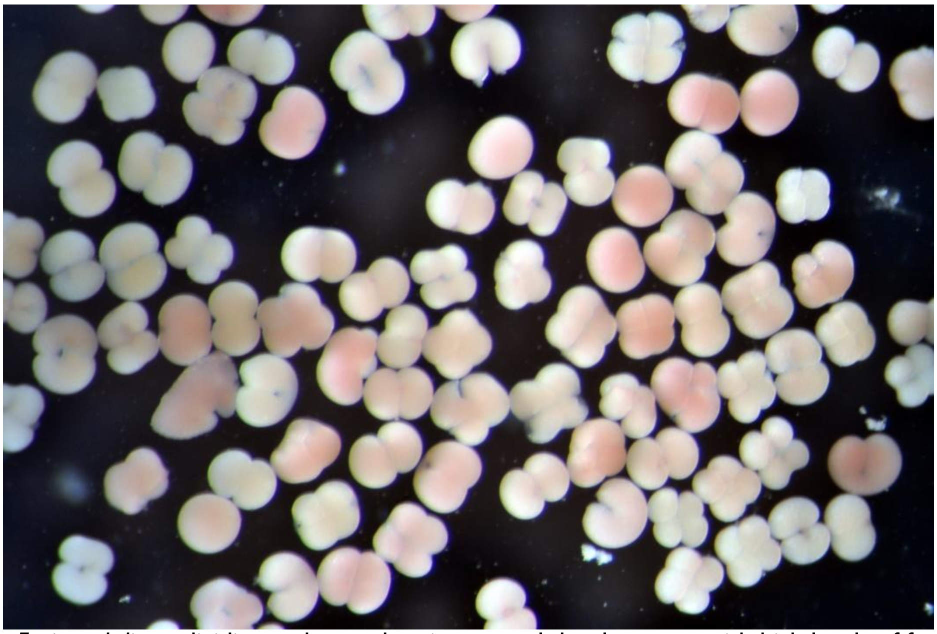


Figure 39. *Favites abdita* – dividing embryos showing normal development, with high levels of fertilization overall on the night of 6 April 2010.

Discussion

This survey captured a comprehensive record of the condition of shallow reef communities at Ashmore, Cartier and Seringapatam Reefs in April 2010. These three emergent reefs support typical coral reef benthic habitats, with hard coral and various algae making up the two dominant groups, as reported previously (see Richards *et al.*. 2009; Heyward *et al.*. 2010). Coral cover varied with depth and location within reefs, but the general patterns were similar between all three locations. Most sites at Ashmore and Cartier Reefs supported low to medium live coral cover similar to that reported by Richards *et al.*. (2009) from the previous year, although it is not clear if coral cover has changed significantly in a statistical sense. The differences in methods between the two studies (c.f. Kospartov *et al.*. 2006) may account for some variation in estimates of coral cover and composition. In this report, quantitative data from multiple depth zones are presented. An analysis of benthic communities shows the majority of survey sites at all three reefs loosely grouping together. Some distinctive sites were noted for Ashmore Reef, comprising two locations inside the lagoon area near the main anchorage (A7) and a high coral cover site on the central northern edge of the reef (A8) which was not included in the previous survey of Ashmore in 2009 (Richard *et al.*. 2009). Live coral cover across depths on the reef slope at that site exceeded 50%, which is above average for Australian reefs. At Cartier Reef a similar high coral cover site was noted on the southern western edge, while two sites on the north eastern rim feature well above average soft coral abundance.

The overall appearance of biota at all three reefs was normal and no overt signs of severe pollution stress or major recent disturbance were noted, either localised at individual sites or more generally at whole reef scale, with the exception of some active coral bleaching. The survey occurred in the midst of a low to moderate intensity coral bleaching event that was noted at all three reefs. At all sites around Ashmore Reef, a selective number of species were bleached to varying degrees, with *Pocillopora edouxi* , *Galaxea fascicularis* and *Millepora* among those particularly affected. This same pattern was subsequently recorded at Cartier Reef and the type of coral and the degree of overall bleaching was very similar between these two reefs. Seringapatam Reef, which was selected as a control reef well away from likely trajectories from the Montara spill site, had similar but much worse bleaching underway during the April 2010 survey. These differences between the two reefs closest to the Montara well head (Ashmore and Cartier Reefs) and Seringapatam are likely to be due to a combination of differential thermal stress history in the two locations, but also relative differences in the abundance of susceptible species between the three reefs, in particular species in the coral family Pocilloporidae.

The survey of coral reproduction indicated a very low level of mature corals in spawning condition. As significant coral spawning occurred throughout the NW region in March 2010, it is reasonable to infer that the same occurred at Ashmore Reef. However, it is impossible to infer if coral spawning was in any way compromised in March 2010 due to effects from the Montara spill. Nonetheless, one of the few species with remaining mature gonad was observed to spawn and fertilize successfully at normal levels observed for healthy corals.

During the April 2010 field expedition, there was no visual sign of oil or waxy oil on the ocean surface around the reefs or during shoreline walks on sandy islets at each reef. A total of 90 paired seabed sediment samples were collected. Preliminary hydrocarbon analysis of 50 samples has been completed. Although no detectable amounts were recorded for many locations, some hydrocarbons were detected at multiple sites at all three reefs,

Burns *et al*.. (2010) published the hydrocarbon composition of deep sea sediments in the Timor Sea. Their study was of an active oil gas seep at the 84 m deep Cornea seep site. The on-line data with the publication show that near the active seep site sediment THC ranged from 1.2 to 1.7 µg/g and sum oil PAHs ranged from 1.2 to 7.5 ng/g in surface segments of Kasten cores near the active seep. Deeper layers had even lower concentrations. Sediment cores taken in deeper water from the Cartier Trough, which was still influenced by the active seep, ranged from THC 1.3 to 2.2 µg/g, sum oil PAH 32 to 79 ng/g. Concentrations in most distant areas at 400 to 500 m depth to the east and west of Cartier trough ranged from THC <0.1 to 0.2 µg/g, sum oil PAH 6.9 to 16.8 ng/g. By means of a sediment trap study Burns *et al*.. (2010) showed that the rate of degradation of oil in the water column and surface sediments of the Timor Sea was efficient enough, under non-spill conditions, to reduce the oil content of settling particles to background levels so low that is not possible to extract enough material for source matching. Rather, source matching had to be based on sediment trap material. The concentrations of oil in the seven sediment extracts from this shallow reefs study was within the range seen near the active seep site at Cornea. Thus the concentrations of oil in the shoals sediments were above the background for this area of the Timor Sea. However, concentrations were too low to enable source matching. The patterns were degraded by natural attenuation. The higher molecular weight aromatic hydrocarbons were the most persistent fractions of the oil. Both GCMS and UVF analysis showed the oil in the sediments was a degraded light crude oil, not a heavy Bunker C or a lighter diesel fuel.

Liu *et al*..,(2005) proposed the ratio of DBT/1367C4-Naphthalene might be a good diagnostic ratio to distinguish the Montara oil from other light oils on the North West Shelf. Analysis of the reference oil and extracting the184 ion for computing the ratio of DBT to 1367C4N showed the ratio was 1.1 with DBT the larger peak on the AIMS GCMS system. The ratio for the oil and the samples is shown in Table 3. The ratios of DBT/C4N of the degraded patterns did not match the oil standard; which is to be expected. DBT is much more persistent in crude oiled sediments than the naphthalene series (Burns and Yelle-Simmons 1995). Thus the ratio would go up with weathering . The conclusion, based on this chemical evidence of a degraded crude oil (not bunker C or light diesel) above the background concentrations for the Timor Sea and the observations during the spill event that triggered this study, is that Ashmore and, to a lesser degree, Cartier Reefs were contaminated during the Montara uncontrolled release. However, natural attenuation processes had reduced the concentrations and changed the patterns so that source matching, as is commonly performed on undegraded oils, is not possible on the sediment samples collected approximately six months after the oil spill was stopped.

The shallow reefs surveys detected no evidence of unusual major disturbance to the sessile benthic organisms, which displayed the levels of diversity and abundance of a normal emergent reef in this bioregion. The detection of coral bleaching, which was minor in terms of the overall

coral community, but significant for a subset of species, seems likely to have been caused by abnormally warm seawater temperatures throughout the region during March - April 2010. This thermal stress caused more impact on reef communities at Seringapatam Reef, well away from the Montara release site, than at Ashmore and Cartier Reefs.

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Appendix 1. **Metadata summary of all sampling site locations**

Date	Technique	Site	Sample	Time start	Time end	Lat_start	Long_start	Depth	Lat_end	Long_end
4-Apr	Coral collection	A1RC	A1RC_coral	11:23:31	0:10:32	-12.1877	123.1054	4	N/A	N/A
4-Apr	Dive Transect	A1S	A1D1	10:48:00 AM	11:42:00	-12.1846	123.1052	3	-12.1846	123.1064
4-Apr	Dive Transect	A1D	A1D2	14:36:00	15:31:00	-12.1842	123.1047	6	-12.1844	123.1060
4-Apr	Sediment	A1SS	1A_1B	11:25:00	N/A	-12.1846	123.1052	3	N/A	N/A
4-Apr	Sediment	A1SE	2A_2B	11:35:00	N/A	-12.1846	123.1064	3	N/A	N/A
4-Apr	Sediment	A1DS	3A_3B	15:15:00	N/A	-12.1842	123.1047	6	N/A	N/A
4-Apr	Sediment	A1DE	4A_4B	15:25:00	N/A	-12.1844	123.1060	6	N/A	N/A
4-Apr	Sediment	A1RC	5A_5B	17:20:00	17:24:00	-12.1848	123.1018	2	N/A	N/A
4-Apr	Snorkel Camera	A1RC	A1RC_cam1	16:53:48	17:14:32	-12.1859	123.1043	3	-12.1848	123.1018
4-Apr	Snorkel Camera	A1RC	A1RC_cam2	16:51:06	17:14:06	-12.1866	123.1042	2	-12.1850	123.1017
5-Apr	Coral collection	A2RC	A2RC_coral	9:00:20	9:35:32	-12.1878	123.1235	3	N/A	N/A
5-Apr	Dive Transect	A2S	A2S	11:16:00	0:11:00	-12.1875	123.1211	3	-12.1877	123.1224
5-Apr	Dive Transect	A2D	A2D	8:41:00	9:32:00	-12.1874	123.1211	6	-12.1874	123.1223
5-Apr	Dive Transect	A3S	A3S	14:47:00	15:44:00	-12.2513	123.1553	3	-12.2519	123.1550
5-Apr	Sediment	A2SS	6A_6B	9:25:00	N/A	-12.1875	123.1211	3	N/A	N/A
5-Apr	Sediment	A2SE	7A_7B	9:15:00	N/A	-12.1877	123.1224	3	N/A	N/A
5-Apr	Sediment	A2DS	8A_8B	12:05:00	N/A	-12.1874	123.1211	6	N/A	N/A
5-Apr	Sediment	A2DE	9A_9B	11:55:00	N/A	-12.1874	123.1223	6	N/A	N/A
5-Apr	Sediment	A3SS	10A_10B	15:30:00	N/A	-12.2513	123.1553	3	N/A	N/A
5-Apr	Sediment	A3SE	11A_11B	15:40:00	N/A	-12.2519	123.1550	3	N/A	N/A
5-Apr	Snorkel Camera	A2RC	A2RC_cam1	8:46:00	9:08:16	-12.1882	123.1216	2	-12.1878	123.1235
5-Apr	Snorkel Camera	A2RC	A2RC_cam2	8:44:38	9:00:20	-12.1884	123.1217	3	-12.1882	123.1234
6-Apr	Coral collection	A3RC	A3RC	9:15:54	10:05:54	-12.2541	123.1528	3	N/A	N/A
6-Apr	Coral collection	A4RC	A4RC_cam2	16:42:36	N/A	-12.2902	123.1193	3	N/A	N/A
6-Apr	Dive Transect	A3D	A3D	8:52:00	9:44:00	-12.2555	123.1550	6	-12.2569	123.1544
6-Apr	Dive Transect	A4D	A4D	11:50:00	0:39:00	-12.2914	123.1161	6	-12.2917	123.1147
6-Apr	Dive Transect	A4S	A4S	15:05:00	16:15:00	-12.2913	123.1161	3	-12.2916	123.1149
6-Apr	Sediment	A3DS	12A_12B	9:30:00	N/A	-12.2555	123.1550	6	N/A	N/A
6-Apr	Sediment	A3DE	13A_13B	9:40:00	N/A	-12.2569	123.1544	6	N/A	N/A
6-Apr	Sediment	A4DS	14A_14B	11:24:00	N/A	-12.2914	123.1161	6	N/A	N/A
6-Apr	Sediment	A4DE	15A_15B	11:34:00	N/A	-12.2917	123.1147	6	N/A	N/A
6-Apr	Sediment	A4RC	16A_16B	12:34:58	N/A	-12.2866	123.1288	1	N/A	N/A
6-Apr	Sediment	SI1 (island)	17A_17B	14:41:44	N/A	-12.2598	123.1108	0	N/A	N/A
6-Apr	Sediment	SI1 (island)	18A_18B	14:33:29	N/A	-12.2597	123.1113	0	N/A	N/A
6-Apr	Snorkel Camera	A3RC	A3RC_cam1	8:58:18	9:08:38	-12.2543	123.1528	2	-12.2546	123.1526
6-Apr	Snorkel Camera	A3RC	A3RC_cam2	9:01:08	9:15:54	-12.2549	123.1530	2	-12.2544	123.1529
6-Apr	Snorkel Camera	A4RC	A4RC_cam2	12:36:28	12:54:18	-12.2865	123.1288	1	-12.2867	123.1288
7-Apr	Coral collection	A6RF	A6RF	16:27:20	N/A	-12.2294	122.9489	3	N/A	N/A
7-Apr	Dive Transect	A5D	A5D	8:45:00	9:42:00	-12.2645	122.9580	6	-12.2640	122.9567
7-Apr	Dive Transect	A5S	A5S	11:37:00	12:51:00	-12.2642	122.9584	3	-12.2637	122.9570

7-Apr	Dive Transect	A6S	A6S	15:45:00	16:43:00	-12.2291	122.9489	3	-12.2289	122.9503
7-Apr	Sediment	A5DS	19A_19B	9:22:00	N/A	-12.2645	122.9580	6	N/A	N/A
7-Apr	Sediment	A5DE	20A_20B	9:32:00	N/A	-12.2640	122.9567	6	N/A	N/A
7-Apr	Sediment	A5SS	21A_21B	12:31:00	N/A	-12.2642	122.9584	3	N/A	N/A
7-Apr	Sediment	A5SE	22A_22B	12:41:00	N/A	-12.2637	122.9570	3	N/A	N/A
7-Apr	Sediment	WI (island)	23A_23B	15:06:50	N/A	-12.2426	122.9633	0	N/A	N/A
7-Apr	Sediment	WI (island)	24A_24B	15:00:01	N/A	-12.2435	122.9655	0	N/A	N/A
7-Apr	Sediment	A6SS	27A_27B	16:23:00	N/A	-12.2291	122.9489	3	N/A	N/A
7-Apr	Sediment	A6SE	28A_28B	16:33:00	N/A	-12.2289	122.9503	3	N/A	N/A
7-Apr	Snorkel Camera	A5RC	A5RC_cam1	11:36:04	11:49:28	-12.2642	122.9592	3	-12.2629	122.9596
7-Apr	Snorkel Camera	A5RC	A5RC_cam2	11:33:04	12:00:16	-12.2644	122.9591	3	-12.2643	122.9592
8-Apr	Coral collection	A7RC1	A7RC1	15:10:16	N/A	-12.2392	122.9838	2	N/A	N/A
8-Apr	Coral collection	A7RC2	A7RC2	17:24:44	N/A	-12.2359	122.9873	2	N/A	N/A
8-Apr	Dive Transect	A6D	A6D	8:26:00	9:18:00	-12.2291	122.9488	6	S12.22864	E122.95022
8-Apr	Dive Transect	A7S1	A7S1	14:27:00	15:23:00	-12.2396	122.9839	3	-12.2401	122.9828
8-Apr	Dive Transect	A7S2	A7S2	15:58:00	16:53:00	-12.2364	122.9874	3	-12.2363	122.9875
8-Apr	Sediment	A6DS	25A_25B	9:00:00	N/A	-12.2291	122.9488	6	N/A	N/A
8-Apr	Sediment	A6DE	26A_26B	9:10:00	N/A	-12.2286	122.9502	6	N/A	N/A
8-Apr	Sediment	A7S1S	29A_29B	15:03:00	N/A	-12.2396	122.9839	3	N/A	N/A
8-Apr	Sediment	A7S2S	30A_30B	16:43:00	N/A	-12.2364	122.9874	3	N/A	N/A
8-Apr	Snorkel Camera	A6RC	A6RC_cam1	8:31:50	8:39:04	-12.2296	122.9487	2	-12.2293	122.9496
8-Apr	Snorkel Camera	A6RC	A6RC_cam2	8:27:48	8:42:14	-12.2292	122.9489	2	-12.2292	122.9494
8-Apr	Snorkel Camera	A7RC1	A7RC1_cam1	12:03:00	N/A	-12.2392	122.9828	2	N/A	N/A
8-Apr	Snorkel Camera	A7RC1	A7RC1_cam1	14:34:12	15:03:14	-12.2392	122.9838	2	-12.2392	122.9837
8-Apr	Snorkel Camera	A7RC1	A7RC1_cam2	14:36:40	15:00:16	-12.2393	122.9838	2	-12.2393	122.9837
8-Apr	Snorkel Camera	A7RC2	A7RC2_cam2	16:18:00	17:14:44	-12.2360	122.9873	2	-12.2238	123.0023
9-Apr	Dive Transect	A8D	A8D	15:08:00	16:08:00	-12.1830	123.0452	6	-12.1821	123.0463
9-Apr	Sediment	A8DS	31A_31B	15:50:00	N/A	-12.1830	123.0452	6	N/A	N/A
9-Apr	Sediment	A8DE	32A_32B	16:00:00	N/A	-12.1821	123.0463	6	N/A	N/A
9-Apr	Snorkel Camera	A8RC	A8RC_cam1	15:05:15	16:00:30	-12.1840	123.0460	3	-12.1838	123.0456
9-Apr	Snorkel Camera	A8RC_1	A8RC_cam2	14:31:54	14:34:56	-12.2061	123.0672	2	-12.2059	123.0670
9-Apr	Snorkel Camera	A8RC	A8RC_cam2	15:05:15	16:04:04	-12.1841	123.0461	2	-12.1835	123.0463
9-Apr	Temperature Logger	A7S2TL	A7S2TL	10:08:18	N/A	-12.2357	122.9873	3	N/A	N/A
10-Apr	Dive Transect	A8S	A8S	8:17:00	9:18:00	-12.1833	123.0458	3	-12.1827	123.0467
10-Apr	Sediment	A8SS	34A_34B	8:58:00	N/A	-12.1833	123.0458	3	N/A	N/A
10-Apr	Sediment	A8SE	35A_35B	9:08:00	N/A	-12.1827	123.0467	3	N/A	N/A
10-Apr	Sediment	SI2 (island)	33A_33B	10:09:07	N/A	-12.1943	123.0614	0	N/A	N/A
10-Apr	Snorkel Camera	A8RC2	A8RC2_cam1	8:33:34	9:04:59	-12.1833	123.0461	2	N/A	N/A
11-Apr	Dive Transect	C1D	C1D	8:37:00	9:23:00	-12.5455	123.5559	6	-12.5457	123.5544
11-Apr	Dive Transect	C1S	C1S	11:10:00	0:03:00	-12.5452	123.5556	3	-12.5454	123.5541
11-Apr	Dive Transect	C2D	C2D	14:31:00	15:17:00	-12.5451	123.5405	6	-12.5446	123.5392
11-Apr	Sediment	C1DS	36A_36B	9:03:00	N/A	-12.5455	123.5559	6	N/A	N/A
11-Apr	Sediment	C1DE	37A_37B	9:13:00	N/A	-12.5457	123.5544	6	N/A	N/A
11-Apr	Sediment	CI1 (island)	38A_38B	8:47:18	N/A	-12.5300	123.5541	0	N/A	N/A
11-Apr	Sediment	CI2 (island)	39A_39B	8:58:44	N/A	-12.5306	123.5569	0	N/A	N/A

11-Apr	Sediment	C1SS	40A_40B	11:43:00	N/A	-12.5452	123.5556	3	N/A	N/A
11-Apr	Sediment	C1SE	41A_41B	11:53:00	N/A	-12.5454	123.5541	3	N/A	N/A
11-Apr	Sediment	C2DS	42A_42B	15:00:00	N/A	-12.5451	123.5405	6	N/A	N/A
11-Apr	Sediment	C2DE	43A_43B	15:10:00	N/A	-12.5446	123.5392	6	N/A	N/A
11-Apr	Sediment	C2L	44A_44B	16:04:38	N/A	-12.5435	123.5416	0.2	N/A	N/A
11-Apr	Sediment	C2L	45A_45B	16:09:48	N/A	-12.5431	123.5418	0.2	N/A	N/A
11-Apr	Snorkel Camera	C1RC	C1RC_cam1	11:50:06	11:58:11	-12.5449	123.5555	2	-12.5449	123.5546
11-Apr	Snorkel Camera	C1RC	C1RC_cam2	11:54:13	12:03:23	-12.5446	123.5555	2	-12.5446	123.5541
11-Apr	Snorkel Camera	C2RC	C2RC_cam1	15:25:15	15:38:55	-12.5448	123.5411	3	-12.5445	123.5409
11-Apr	Snorkel Camera	C2RC	C2RC_cam2	15:24:42	15:39:02	-12.5450	123.5410	2	-12.5439	123.5401
11-Apr	Snorkel Camera	C2L	C2L_cam2	16:05:18	16:17:09	N/A	N/A		N/A	N/A
12-Apr	Dive Transect	C2S	C2S	8:11:00	9:14:00	-12.5449	123.5404	3	-12.5438	123.5394
12-Apr	Dive Transect	C3S	C3S	10:55:00	12:03:00	-12.5260	123.5390	3	-12.5253	123.5402
12-Apr	Dive Transect	C3D	C3D	14:28:00	15:38:00	-12.5258	123.5389	6	-12.5252	123.5402
12-Apr	Sediment	C2SS	46A_46B	8:54:00	N/A	-12.5449	123.5404	3	N/A	N/A
12-Apr	Sediment	C2SE	47A_47B	9:04:00	N/A	-12.5438	123.5394	3	N/A	N/A
12-Apr	Sediment	C3SS	48A_48B	11:43:00	N/A	-12.5260	123.5390	3	N/A	N/A
12-Apr	Sediment	C3SE	49A_49B	11:53:00	N/A	-12.5253	123.5402	3	N/A	N/A
12-Apr	Sediment	C3DS	50A_50B	15:18:00	N/A	-12.5258	123.5389	6	N/A	N/A
12-Apr	Sediment	C3DE	51A_51B	15:28:00	N/A	-12.5252	123.5402	6	N/A	N/A
12-Apr	Sediment	C3RF	52A_52B	15:41:36	N/A	-12.5262	123.5412	0.2	N/A	N/A
12-Apr	Sediment	C3RF	53A_53B	15:49:37	N/A	-12.5268	123.5402	0.2	N/A	N/A
12-Apr	Snorkel Camera	C2RF	C2RF_cam1	9:22:37	9:45:24	-12.5419	123.5422	1	-12.5420	123.5423
12-Apr	Snorkel Camera	C2RF	C2RF_cam2	9:24:39	9:50:31	-12.5422	123.5421	1	-12.5428	123.5426
12-Apr	Snorkel Camera	C3RC	C3RC_cam1	11:33:59	11:50:22	-12.5257	123.5404	2	-12.5259	123.5397
12-Apr	Snorkel Camera	C3RC	C3RC_cam2	11:32:44	11:49:27	-12.5258	123.5404	2	-12.5259	123.5396
12-Apr	Snorkel Camera	C3RF	C3RF_cam1	12:04:29	12:16:39	-12.5274	123.5416	1	-12.5276	123.5414
12-Apr	Snorkel Camera	C3RF	C3RF_cam2	12:00:31	12:13:13	-12.5273	123.5417	1	-12.5280	123.5406
13-Apr	Dive Transect	C4D	C4D	8:18:00	8:57:00	-12.5241	123.5567	6	-12.5242	123.5575
13-Apr	Dive Transect	C4S	C4S	9:40:00	10:20:00	-12.5241	123.5566	3	-12.5242	123.5572
13-Apr	Dive Transect	C6D	C6D	14:22:00	15:10:00	-12.5345	123.5810	6	-12.5355	123.5800
13-Apr	Sediment	C4DS	54A_54B	8:37:00	N/A	-12.5241	123.5567	6	N/A	N/A
13-Apr	Sediment	C4DE	55A_55B	8:47:00	N/A	-12.5242	123.5575	6	N/A	N/A
13-Apr	Sediment	C4SS	56A_56B	10:00:00	N/A	-12.5241	123.5566	3	N/A	N/A
13-Apr	Sediment	C4SE	57A_57B	10:10:00	N/A	-12.5242	123.5572	3	N/A	N/A
13-Apr	Sediment	C6DS	58A_58B	14:50:00	N/A	-12.5345	123.5810	6	N/A	N/A
13-Apr	Sediment	C6DE	59A_59B	15:00:00	N/A	-12.5355	123.5800	6	N/A	N/A
13-Apr	Sediment	RF1	60A_60B	15:46:59	N/A	-12.5280	123.5787	0.3	N/A	N/A
13-Apr	Sediment	RF1	61A_61B	15:55:41	N/A	-12.5275	123.5781	0.3	N/A	N/A
13-Apr	Snorkel Camera	C4RC	C4RC_cam1	8:41:53	9:01:05	-12.5243	123.5565	2.5	-12.5245	123.5564
13-Apr	Snorkel Camera	C4RC	C4RC_cam2	8:44:51	8:52:43	-12.5243	123.5566	2.5	-12.5244	123.5575
13-Apr	Snorkel Camera	C4RF	C4RF_cam1	9:09:48	9:15:56	-12.5255	123.5564	3.5	-12.5253	123.5557
13-Apr	Snorkel Camera	C4RF	C4RF_cam2	8:54:52	9:19:57	-12.5247	123.5575	3.5	-12.5253	123.5566
13-Apr	Temperature Logger	SL1	56496	10:10:00	N/A	-12.5242	123.5565	5	N/A	N/A
13-Apr	Temperature Logger	SL1	U-07131	11:10:00	N/A	-12.5242	123.5565	5	N/A	N/A

13-Apr	Temperature Logger	FL2	56499	16:24:46	N/A	-12.5259	123.5741	5	N/A	N/A
13-Apr	Temperature Logger	FL2	U-07137	17:24:46	N/A	-12.5259	123.5741	5	N/A	N/A
13-Apr	Temperature Logger	SL2	56495	17:00:01	N/A	-12.5245	123.5606	5	N/A	N/A
13-Apr	Temperature Logger	RF1	56500	17:40:25	N/A	-12.5267	123.5799	5	N/A	N/A
14-Apr	Dive Transect	C6S	C6S	8:00:00	8:50:00	-12.5341	123.5806	3	-12.5353	123.5798
14-Apr	Dive Transect	C5S	C5S	9:36:00	10:28:00	-12.5254	123.5724	3	-12.5256	123.5735
14-Apr	Dive Transect	C5D	C5D	13:36:00	14:47:00	-12.5253	123.5725	6	-12.5256	123.5735
14-Apr	Habitat Check	RF_site1	RF_site1	13:49:23	13:53:08	-12.5335	123.5780	1	-12.5330	123.5780
14-Apr	Habitat Check	RF_site2	RF_site2	13:56:42	14:03:01	-12.5300	123.5762	1	-12.5294	123.5763
14-Apr	Habitat Check	RF_site3	RF_site3	14:06:31	14:10:54	-12.5266	123.5753	1	-12.5266	123.5752
14-Apr	Habitat Check	RF_site4	RF_site4	14:14:36	14:17:22	-12.5256	123.5700	2	N/A	N/A
14-Apr	Habitat Check	RF_site5	RF_site5	14:27:39	14:34:18	-12.5249	123.5655	2.5	-12.5249	123.5655
14-Apr	Sediment	C6SS	62A_62B	8:30:00	N/A	-12.5341	123.5806	3	N/A	N/A
14-Apr	Sediment	C6SE	63A_63B	8:40:00	N/A	-12.5353	123.5798	3	N/A	N/A
14-Apr	Sediment	C5SS	66A_66B	10:08:00	N/A	-12.5254	123.5724	3	N/A	N/A
14-Apr	Sediment	C5SE	67A_67B	10:18:00	N/A	-12.5256	123.5735	3	N/A	N/A
14-Apr	Sediment	C5DS	68A_68B	14:27:00	N/A	-12.5253	123.5725	6	N/A	N/A
14-Apr	Sediment	C5DE	69A_69B	14:37:00	N/A	-12.5256	123.5735	6	N/A	N/A
14-Apr	Sediment	C5RF	64A_64B	14:53:12	N/A	-12.5269	123.5728	1	N/A	N/A
14-Apr	Snorkel Camera	C6RC	C6RC_cam1	8:10:48	8:21:49	-12.5340	123.5802	2.5	-12.5331	123.5808
14-Apr	Snorkel Camera	C6RC	C6RC_cam2	8:12:38	8:23:32	-12.5341	123.5801	2.5	-12.5333	123.5808
14-Apr	Snorkel Camera	C5RC	C5RC_cam1	8:55:43	9:08:06	-12.5261	123.5722	2.5	-12.5262	123.5723
14-Apr	Snorkel Camera	C5RC	C5RC_cam2	9:01:14	9:09:27	-12.5261	123.5732	2.5	-12.5259	123.5725
15-Apr	Habitat Check	SL1	SL1	7:55:48	8:04:26	-12.1993	123.0424	3	-12.1991	123.0424
15-Apr	Habitat Check	LSR	Lagoon (rubble)	8:13:19	8:16:24	-12.2026	123.0434	2	-12.2026	123.0431
15-Apr	Habitat Check	LSA_1	Lagoon (algae)	8:25:46	8:28:07	-12.2031	123.0406	2	-12.2031	123.0408
15-Apr	Habitat Check	LSA_2	Lagoon (algae)	8:32:45	8:32:50	-12.2029	123.0399	2	-12.2029	123.0399
15-Apr	Habitat Check	DRF	Deep Reef Flat	8:38:09	8:41:35	-12.1995	123.0369	3	-12.1997	123.0370
15-Apr	Habitat Check	SL4	SL4	9:21:11	9:29:14	-12.2396	122.9818	2	-12.2396	122.9818
15-Apr	Habitat Check	SL4	SL4	9:54:05	9:54:05	-12.2471	122.9764	2	-12.2471	122.9764
15-Apr	Habitat Check	SL_1 (algae)	Shallow lagoon	9:58:20	10:01:58	-12.2511	122.9710	2	-12.2511	122.9709
15-Apr	Habitat Check	RF1	Reef Flat 1	10:07:54	10:09:01	-12.2562	122.9649	2	-12.2560	122.9651
15-Apr	Habitat Check	RF2	Reef Flat 2	10:12:56	10:13:52	-12.2587	122.9716	2	-12.2585	122.9716
15-Apr	Habitat Check	BH	Blue Hole	10:34:06	10:42:25	-12.2777	123.0109	3	-12.2773	123.0105
15-Apr	Habitat Check	SCRS	SCRS	11:04:52	11:08:17	-12.2933	123.0310	2	-12.2933	123.0312
15-Apr	Middle Island	Check	N/A	10:49:59	10:50:41	-12.2656	123.0304	N/A	N/A	N/A
15-Apr	Temperature Logger	SL1	SL1	7:47:00	N/A	-12.1990	123.0423	3	N/A	N/A
15-Apr	Temperature Logger	SL4	SL4	9:14:51	N/A	-12.2395	122.9817	3	N/A	N/A
15-Apr	Temperature Logger	SL2	SL2	9:13:50	N/A	-12.2244	122.9996	3	N/A	N/A
15-Apr	Temperature Logger	Sl3	SL3	10:09:45	N/A	-12.2243	122.9697	3	N/A	N/A
20-Apr	Dive Transect	SR1D	SR1D	14:18:00	15:16:00	-13.6509	121.9744	6	-13.6496	121.9749
20-Apr	Dive Transect	SR1S	SR1S	15:18:00	15:32:00	-13.6509	121.9744	3	-13.6503	121.9756
20-Apr	Sediment	SR1DS	70A_70B	10:31:00	N/A	-13.6509	121.9744	6	N/A	N/A
20-Apr	Sediment	SR1SE	71A_71B	10:41:00	N/A	-13.6503	121.9756	3	N/A	N/A

20-Apr	Sediment	SR1SS	74A_74B	15:12:00	N/A	-13.6509	121.9744	3	N/A	N/A
20-Apr	Sediment	SR1DE	75A_75B	15:22:00	N/A	-13.6496	121.9749	6	N/A	N/A
20-Apr	Sediment	SR1RF	72A_72B	13:22:35	N/A	-13.6448	121.9830	1	N/A	N/A
20-Apr	Snorkel Camera	SR1RC	SR1RC_cam1	10:19:43	10:29:46	-13.6513	121.9749	3	-13.6508	121.9753
20-Apr	Snorkel Camera	SR1RC	SR1RC_cam2	10:14:57	10:25:22	-13.6513	121.9747	2	-13.6509	121.9757
20-Apr	Snorkel Camera	SR1RF	SR1RF_cam1	13:25:06	13:29:53	-13.6448	121.9830	1	-13.6445	121.9834
20-Apr	Snorkel Camera	SR1RF	SR1RF_cam2	13:25:00	13:35:32	-13.6448	121.9829	1	-13.6449	121.9829
21-Apr	CTD	CTD_SR_1	CTD_SR_1	13:04:18	N/A	-13.7092	121.9874	584	N/A	N/A
21-Apr	CTD	CTD_SR_2	CTD_SR_2	13:13:08	N/A	-13.7107	121.9860	591	N/A	N/A
21-Apr	CTD	CTD_SR_3	CTD_SR_3	13:20:11	N/A	-13.7119	121.9848	594	N/A	N/A
21-Apr	Dive Transect	SR6D	SR6D	8:40:00	9:30:00	-13.6939	121.9950	6	-13.6931	121.9939
21-Apr	Dive Transect	SR6S	SR6S	10:19:00	11:15:00	-13.6938	121.9954	3	-13.6928	121.9942
21-Apr	Dive Transect	SR5S	SR5S	14:30:00	15:10:00	-13.6986	122.0306	3	-13.6987	122.0293
21-Apr	Sediment	SR6DS	76A_76B	9:10:00	N/A	-13.6939	121.9950	6	N/A	N/A
21-Apr	Sediment	SR6DE	77A_77B	9:20:00	N/A	-13.6931	121.9939	6	N/A	N/A
21-Apr	Sediment	SR6SS	79A_79B	10:55:00	N/A	-13.6938	121.9954	3	N/A	N/A
21-Apr	Sediment	SR6SE	80A_80B	11:05:00	N/A	-13.6928	121.9942	3	N/A	N/A
21-Apr	Sediment	SR5SS	81A_81B	14:50:00	N/A	-13.6986	122.0306	3	N/A	N/A
21-Apr	Sediment	SR5SE	82_82B	15:00:00	N/A	-13.6987	122.0293	3	N/A	N/A
21-Apr	Sediment	SR6RF	78A_78B	14:45:00	N/A	-13.6936	121.9949	1	N/A	N/A
21-Apr	Snorkel Camera	SR6RC	SR6RC_cam1	9:02:13	9:16:12	-13.6935	121.9950	3	-13.6927	-121.9939
21-Apr	Snorkel Camera	SR6RC	SR6RC_cam2	9:02:23	9:13:04	-13.6932	121.9951	2	-13.6925	-121.9941
21-Apr	Snorkel Camera	SR6RF	SR6RF	14:23:32	14:28:39	-13.6894	121.9954	2	-13.6896	121.9959
21-Apr	Snorkel Camera	SR6RF	SR6RF	14:24:42	14:44:32	-13.6893	121.9955	2	-13.6893	121.9955
21-Apr	Snorkel Camera	SR5RF	SR5RF	15:12:09	15:17:34	-13.6954	122.0294	2	-13.6954	122.0303
21-Apr	Snorkel Camera	SR5RF	SR5RF	15:11:48	15:17:18	-13.6953	122.0295	2	-13.6953	122.0303
22-Apr	Dive Transect	SR5D	SR5D	8:26:00	9:22:00	-13.6988	122.0305	6	-13.6990	122.0293
22-Apr	Dive Transect	SR4D	SR4D	10:48:00	11:26:00	-13.6726	122.0503	6	-13.6734	122.0509
22-Apr	Dive Transect	SR4S	SR4S	14:29:00	15:18:00	-13.6735	122.0507	3	-13.6744	122.0509
22-Apr	Snorkel Camera	SR5RC	Inaccessible	N/A	N/A	N/A	N/A	N/A	N/A	N/A
22-Apr	Snorkel Camera	SR4RC	SR4RC_cam1	10:53:05	10:59:12	-13.6728	122.0497	2	-13.6731	122.0501
22-Apr	Snorkel Camera	SR4RC	SR4RC_cam2	10:52:01	11:01:35	-13.6728	122.0497	2	-13.6739	122.0501
22-Apr	Snorkel Camera	SR4RF	SR4RF_cam1	14:35:34	14:38:44	-13.6741	122.0481	1	-13.6740	122.0475
22-Apr	Snorkel Camera	SR4RF	SR4RF_cam2	14:37:42	14:47:47	-13.6741	122.0481	1	-13.6742	122.0481
23-Apr	CTD	CTD_SR_4	CTD_SR_4	12:23:23	N/A	-13.6223	122.0029	240	N/A	N/A
23-Apr	CTD	CTD_SR_5	CTD_SR_5	12:29:26	N/A	-13.6216	122.0020	246	N/A	N/A
23-Apr	CTD	CTD_SR_6	CTD_SR_6	12:38:31	N/A	-13.6213	122.0004	272	N/A	N/A
23-Apr	Dive Transect	SR2D	SR2D	8:30:00	9:07:00	-13.6236	121.9978	6	-13.6235	121.9983
23-Apr	Dive Transect	SR2S	SR2S	9:58:00	10:45:00	-13.6237	121.9978	3	-13.6236	121.9990
23-Apr	Habitat Check	HC1	HC1	14:47:00	15:47:00	-13.6390	122.0272	2	N/A	N/A
23-Apr	Sediment	SR2DS	85	8:47:00	N/A	-13.6236	121.9978	6	N/A	N/A
23-Apr	Sediment	SR2DE	86	8:57:00	N/A	-13.6235	121.9983	6	N/A	N/A
23-Apr	Sediment	83A_83B	Sandy Islet	15:45:47	N/A	-13.6315	122.0041	0	N/A	N/A
23-Apr	Sediment	84A_84B	SR2RF	16:05:10	N/A	-13.6272	122.0005	1	N/A	N/A
23-Apr	Snorkel Camera	SR2RC	SR2RC	9:09:13	9:29:05	-13.6240	121.9987	2	-13.6241	121.9987
23-Apr	Snorkel Camera	SR2RC	SR2RC	9:09:45	9:26:41	-13.6242	121.9987	2	-13.6243	121.9983

23-Apr	Snorkel Camera	SR2RF	SR2RF_cam1	16:02:35	16:14:58	-13.6272	122.0005	1	-13.6273	122.0007
23-Apr	Snorkel Camera	SR2RF	SR2RF_cam2	16:02:29	16:16:26	-13.6272	122.0005	1	-13.6271	122.0005
24-Apr	Dive Transect	SR3S	SR3D	8:53:00	9:39:00	-13.6366	122.0256	3	-13.6375	122.0261
24-Apr	Dive Transect	SR3D	SR3S	10:18:00	10:55:00	-13.6366	122.0262	6	-13.6374	122.0267
24-Apr	Habitat Check	HC2	HC2	14:00:00	15:00:00	-13.6372	122.0266	2	N/A	N/A
24-Apr	*Pavona* bommie	PB	PB	10:28:35	10:41:55	-13.6429	122.0197	8	-13.6430	122.0198
24-Apr	Sediment	SR3RF	87A_87B	9:46:47	N/A	-13.6394	122.0230	1	N/A	N/A
24-Apr	Sediment	88A_88B	88A_88B	10:47:42	N/A	-13.6459	122.0225	1	N/A	N/A
24-Apr	Snorkel Camera	SR3RC	SR3RC_cam1	9:11:32	9:25:02	-13.6368	122.0253	2	N/A	N/A
24-Apr	Snorkel Camera	SR3RC	SR3RC_cam2	9:09:51	9:24:50	-13.6369	122.0251	2	-13.6384	122.0263
24-Apr	Snorkel Camera	SR3RF	SR3RF_cam1	9:58:45	10:04:34	-13.6392	122.0232	0.5	-13.6393	122.0238
24-Apr	Snorkel Camera	SR3RF	SR3RF_cam2	9:55:42	10:12:41	-13.6394	122.0230	0.5	-13.6395	122.0230
24-Apr	Temperature Logger	SS3-1	SS3-1	13:56:41	N/A	-13.6372	122.0266	3	N/A	N/A
25-Apr	Dive Transect	SS1-1	SS1-1	9:14:00	10:15:00	-14.0789	121.9783	6	-14.0796	121.9784
25-Apr	Dive Transect	SL1-1	SL1-1	14:22:00	15:40:00	-14.0791	121.9477	6	-14.0780	121.9483
25-Apr	Sediment	SS1-1	89A_89B	10:05:00	N/A	-14.0796	121.9784	6	N/A	N/A
25-Apr	Sediment	SL1-1	90A_90B	15:30:00	N/A	-14.0791	121.9477	6	N/A	N/A
25-Apr	Snorkel Camera	SS1-1_RC1	SS1-1_RC1_cam1	9:21:28	9:35:52	-14.0797	121.9775	2	-14.0805	121.9779
25-Apr	Snorkel Camera	SS1-1_RC1	SS1-1_RC1_cam2	9:22:05	9:35:28	-14.0797	121.9776	3	-14.0805	121.9779
25-Apr	Snorkel Camera	SS1-1_RF	SS1-1_RF_cam1	9:42:31	9:46:03	-14.0812	121.9741	2	-14.0807	121.9739
25-Apr	Snorkel Camera	SS1-1_RF	SS1-1_RF_cam2	9:42:18	9:47:40	-14.0812	121.9741	2	-14.0818	121.9743
25-Apr	Snorkel Camera	SS1-1_RC2	SS1-1_RC2_cam1	9:55:04	10:05:36 AM	-14.0801	121.9771	1	-14.0815	121.9770
25-Apr	Snorkel Camera	SS1-1_RC2	SS1-1_RC2_cam2	9:53:31	10:05:31	-14.0800	121.9772	1	-14.0815	121.9771
25-Apr	Snorkel Camera	SL1-D1	SL1-D1_a_cam1	15:19:14	15:25:06	-14.0798	121.9484	1	-14.0796	121.9488
25-Apr	Snorkel Camera	SL1-D2	SL1-D2_cam1	15:25:55	15:38:45	-14.0796	121.9488	2	-14.0793	121.9482
25-Apr	Snorkel Camera	SL1-D3	SL1-D3_a_cam1	15:43:31	15:47:41	-14.0791	121.9483	3	-14.0793	121.9481
25-Apr	Snorkel Camera	SL1-D3	SL1-D3_cam2	15:20:33	15:27:38	-14.0795	121.9483	3	-14.0793	121.9487
25-Apr	Snorkel Camera	SL1-D3	SL1-D3_a_cam2	15:36:48	15:47:46	-14.0791	121.9482	3	-14.0793	121.9481
26-Apr	Habitat Check	SL1-1	SL1-2	14:50:00	16:00:00	-14.0791	121.9477	6	-14.0791	121.9477
26-Apr	Snorkel Camera	HCSS	HCSS	10:30:00	11:15:00	-14.1880	121.7990	3	N/A	N/A
26-Apr	Snorkel Camera	HCSS	HCSS	15:30:00	16:40:00	-14.0630	121.7710	4	N/A	N/A

Appendix 2. Number and locations of shallowest habitat images, collected by snorkel divers on the adjacent reef crest/flat for each survey site and grouped post-hoc into 20 m equivalent transects, used in analyses.

Ashmore Reef - Reefmon Snorkel transects replicate images (Table A2.1)

Site Name	Transect No.	T1	T2	T3	T4	T5	T6
A1 Reef Crest (RC)		20	20	20	20	20	20
A2 Reef Crest (RC)		20	19	20	18	19	20
A3 Reef Crest (RC)		20	20	20	20	20	20
A4 Reef Flat (RF)		20	20	20	20	20	8
A71 Reef Crest (RC)		20	20	20	20	20	20
A8 Reef Crest (RC)		20	20	20	20	20	20

Cartier Reef - Reefmon Snorkel transects replicate images

Site Name	Transect No.	T1	T2	T3	T4	T5	T6
C1 Reef Crest (RC)		20	20	18			
C2 Reef Crest (RC)		20	20	20	6		
C2 Reef Flat (RF)		20	20	20	20	20	10
C3 Reef Crest (RC)		20	20	20			
C3 Reef Flat (RF)		20	20	20	20	20	
C4 Reef Crest (RC)		20	20	20	20	20	8
C4 Reef Flat (RF)		20	20	20	20		
C6 Reef Crest (RC)		20	20	20	20		

Seringapatam Reef - Reefmon Snorkel transects replicate images

Site Name	Transect No.	T1	T2	T3	T4	T5	T6
SR1 Reef Flat (RF)		20	20	20	20	20	16
SR2 Reef Crest (RC)		20	20	20	20	20	20
SR2 Reef Flat (RF)		20	20	20	20	20	20
SR3 Reef Crest (RC)		20	20	20	20		
SR4 Reef Flat (RF)		20	20	20	19	20	20
SR5 Reef Flat (RF)		20	20	20	20	20	20
SR6 Reef Flat (RF)		20	20	20	20	20	20

Ashmore selected snorkel transects

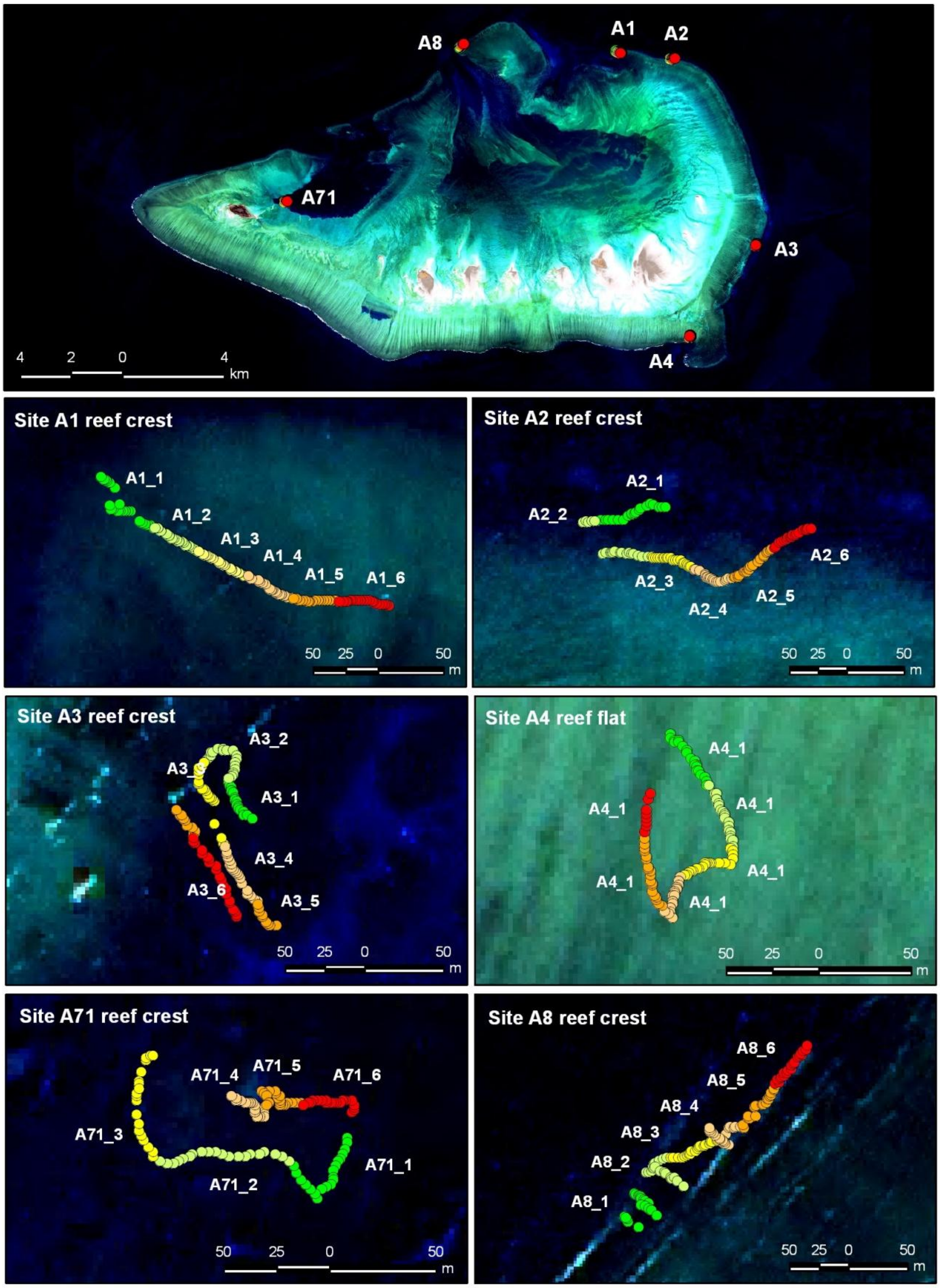


Figure A2.1 Ashmore Reef -location of images listed in Table A2.1 used in analysis of reef flat and crest habitats. Photos were analyzed individually but data then pooled into groups of up to 20 adjacent images as indicated by the different colours

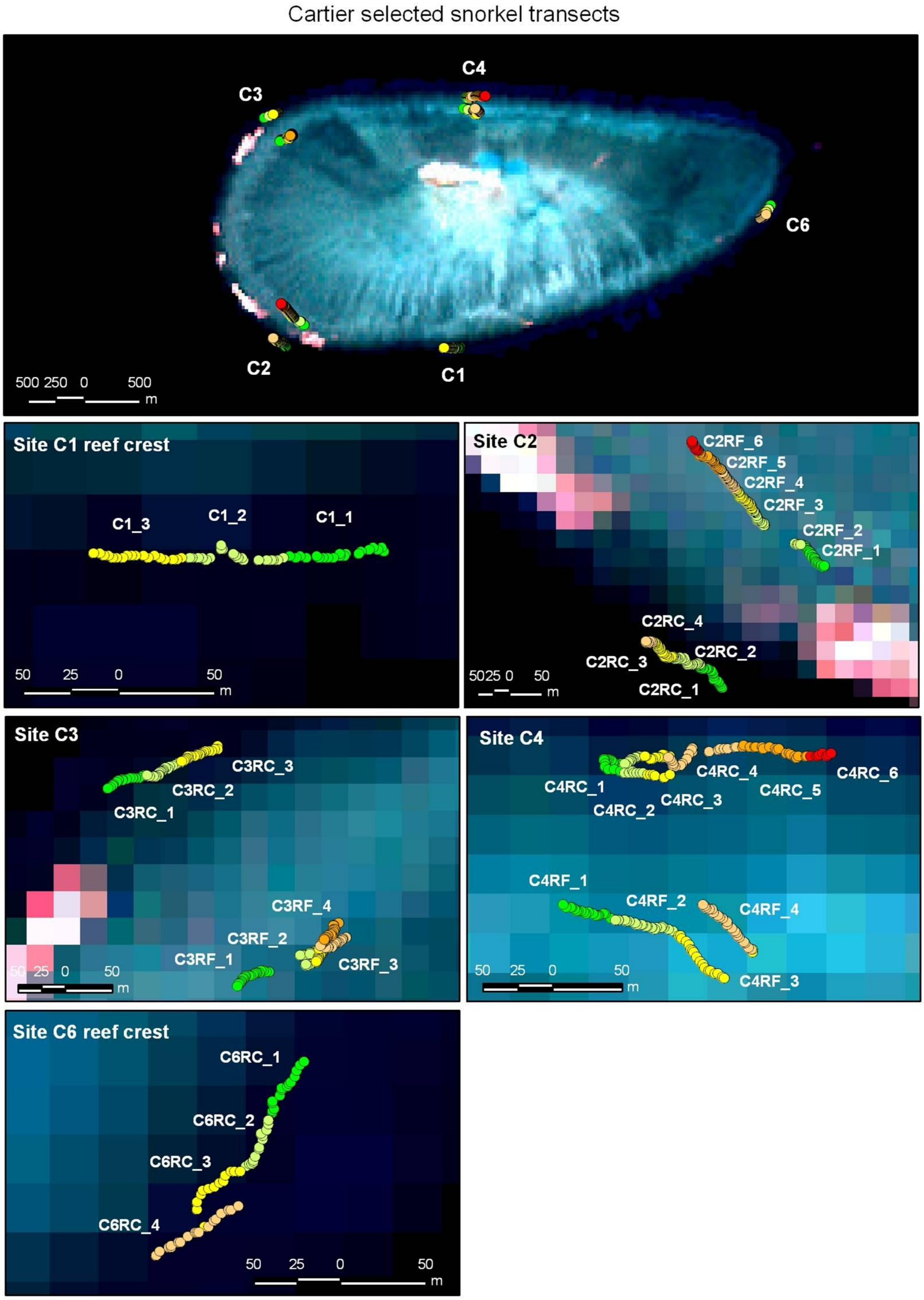


Figure A2.2. Cartier Reef -location of images listed in Table A2.1 used in analysis of reef flat and crest habitats. Photos were analyzed individually but data then pooled into groups of up to 20 adjacent images as indicated by the different colours

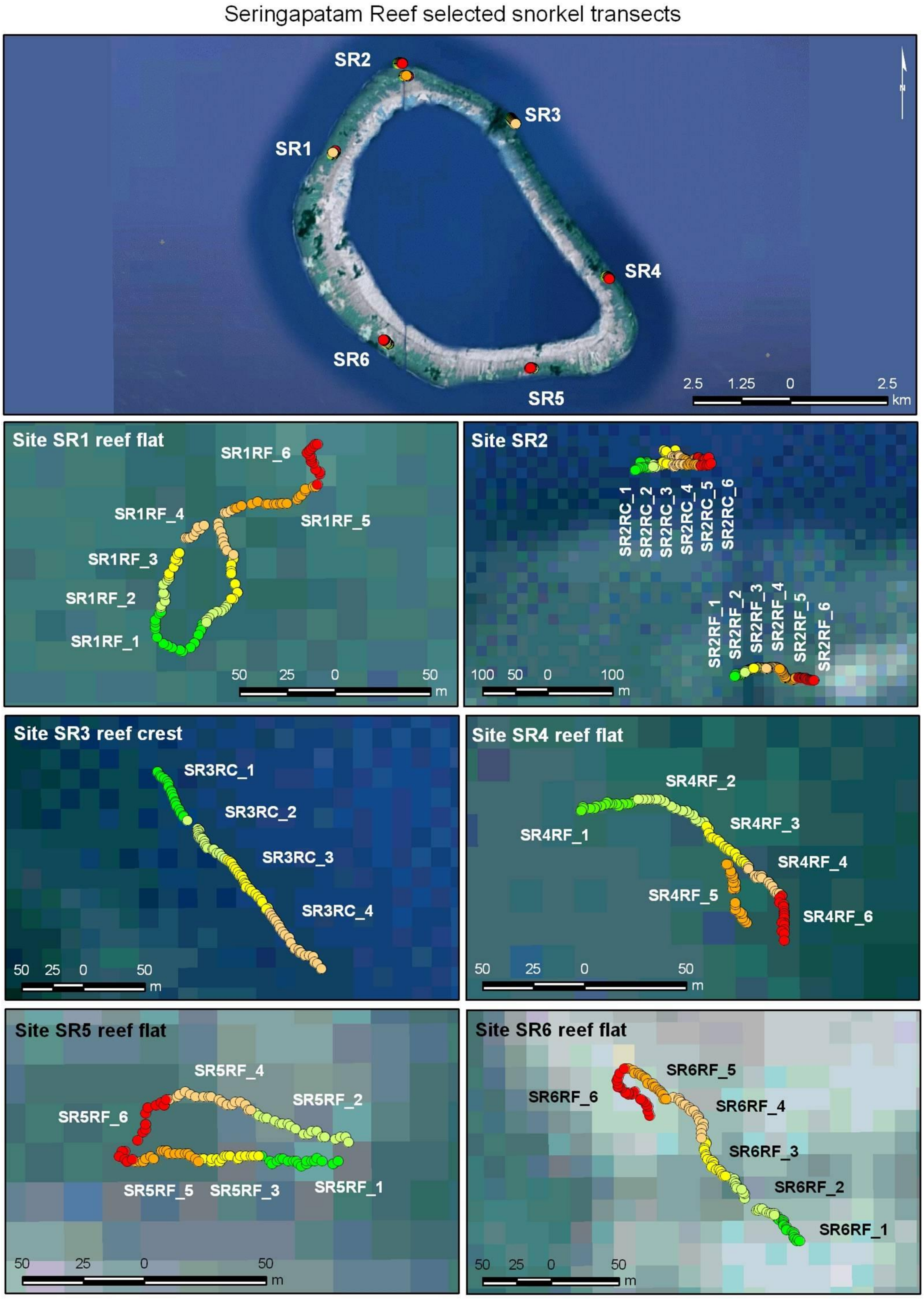


Figure A2.3. Seringpatam Reef -location of images listed in Table A2.1 used in analysis of reef flat and crest habitats. Photos were analyzed individually but data then pooled into groups of up to 20 adjacent images as indicated by the different colours

Appendix 3. Sediment analysis GCMS reconstructed chromatograms

Figure A3.1.

Sample 9 A Total Ion Reconstructed Chromatogram with analytical blank underneath.

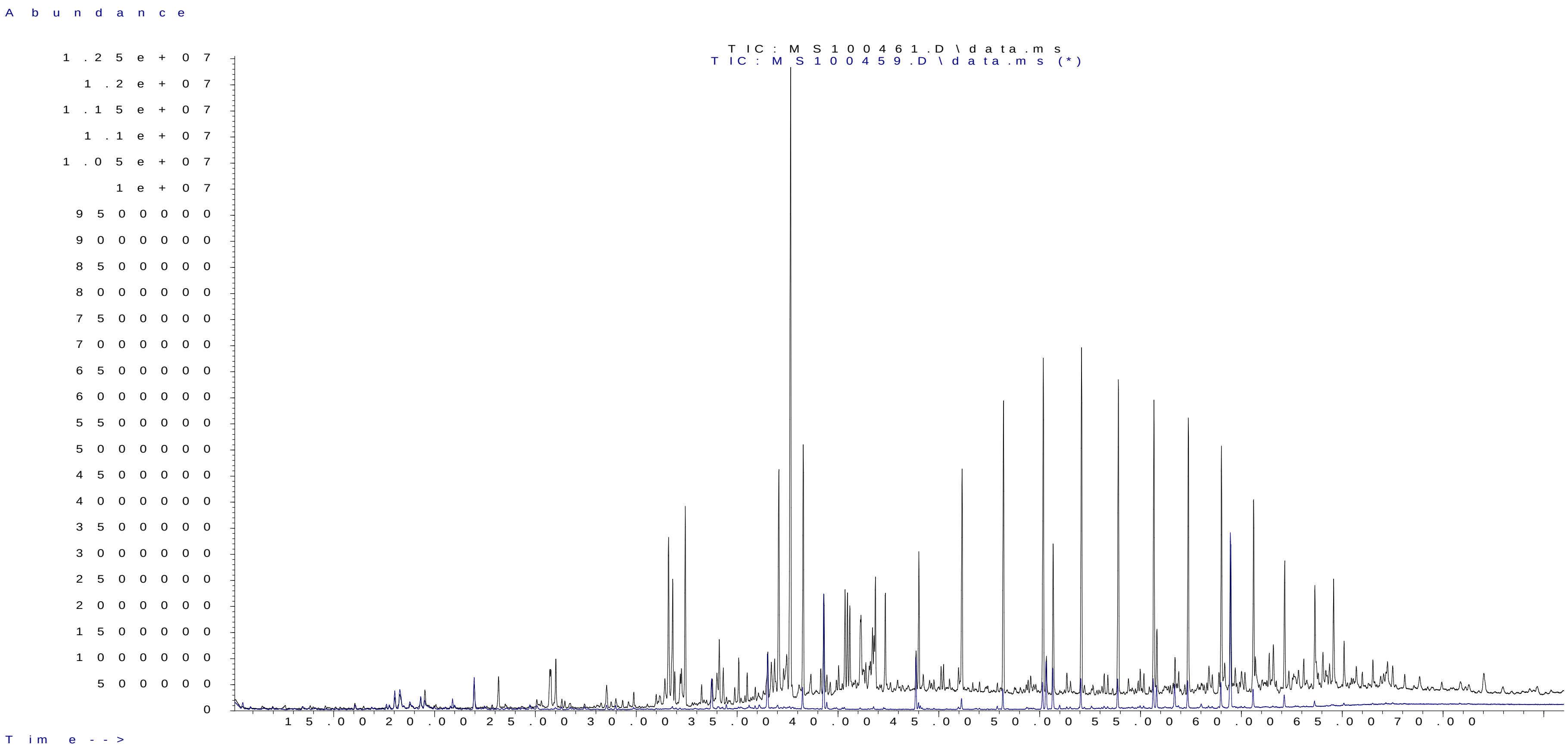


Figure A3.2. Sample 16 B Total Ion Reconstructed Chromatogram with analytical blank underneath.

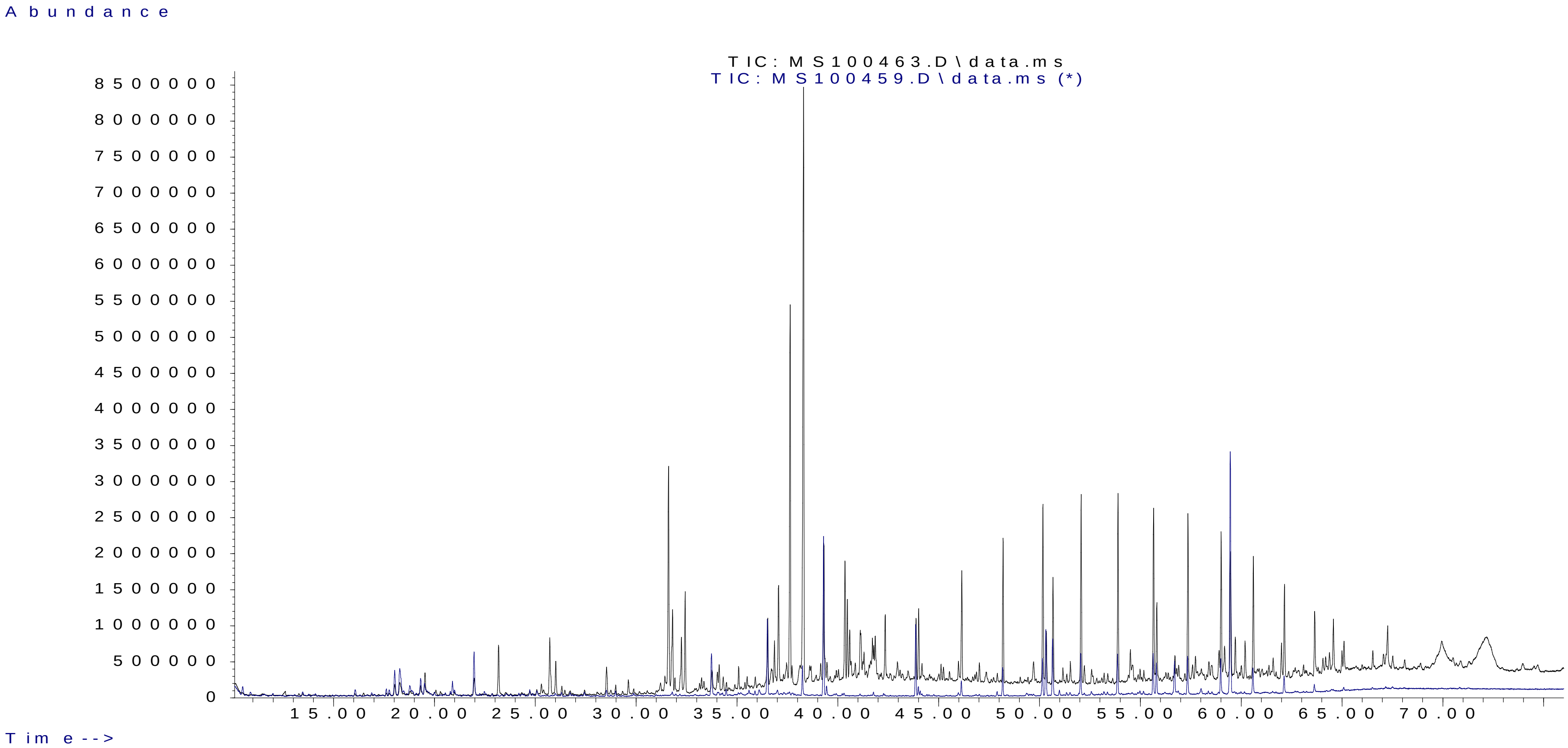


Figure A3.3 Sample 19 B Total Ion Reconstructed Chromatogram with analytical blank underneath.

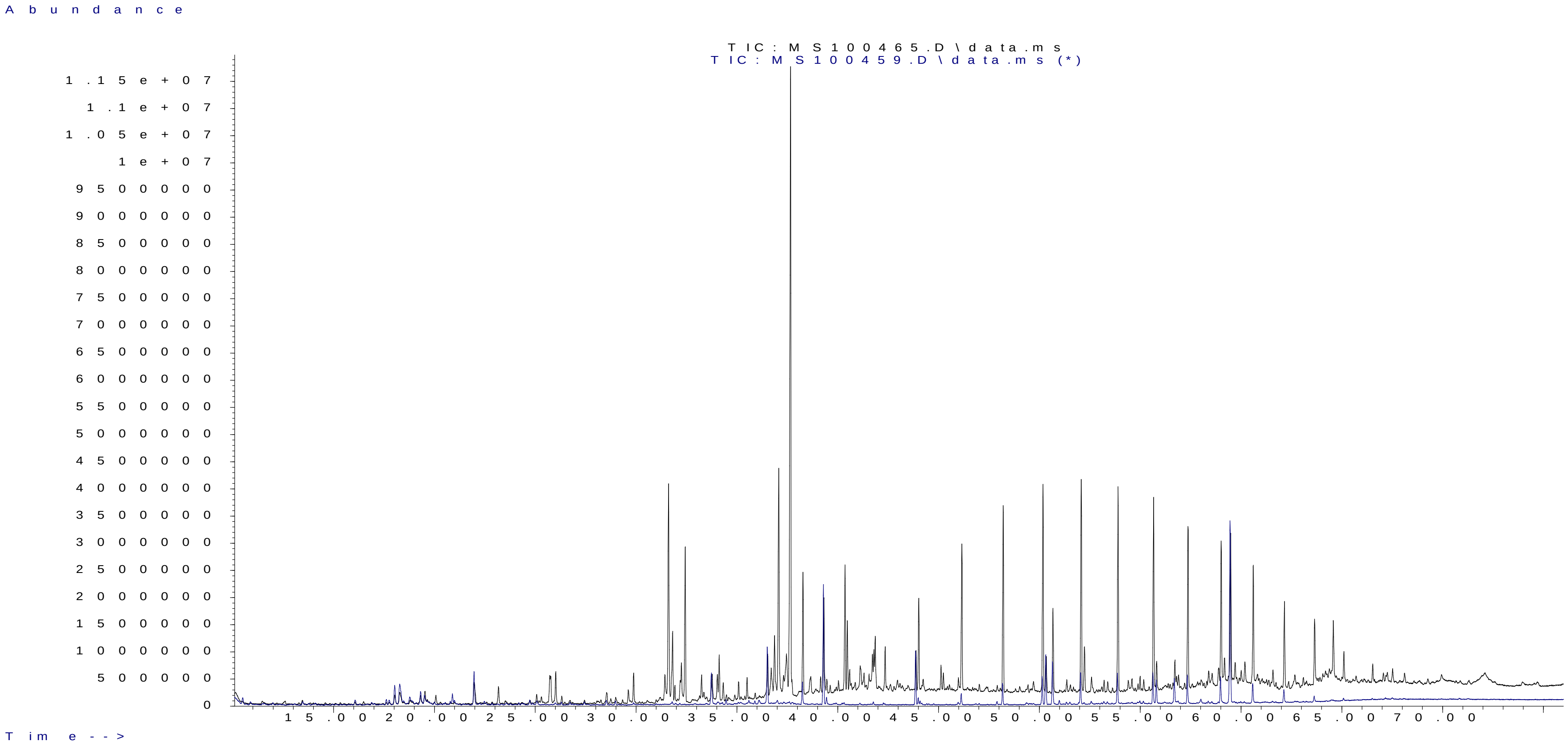
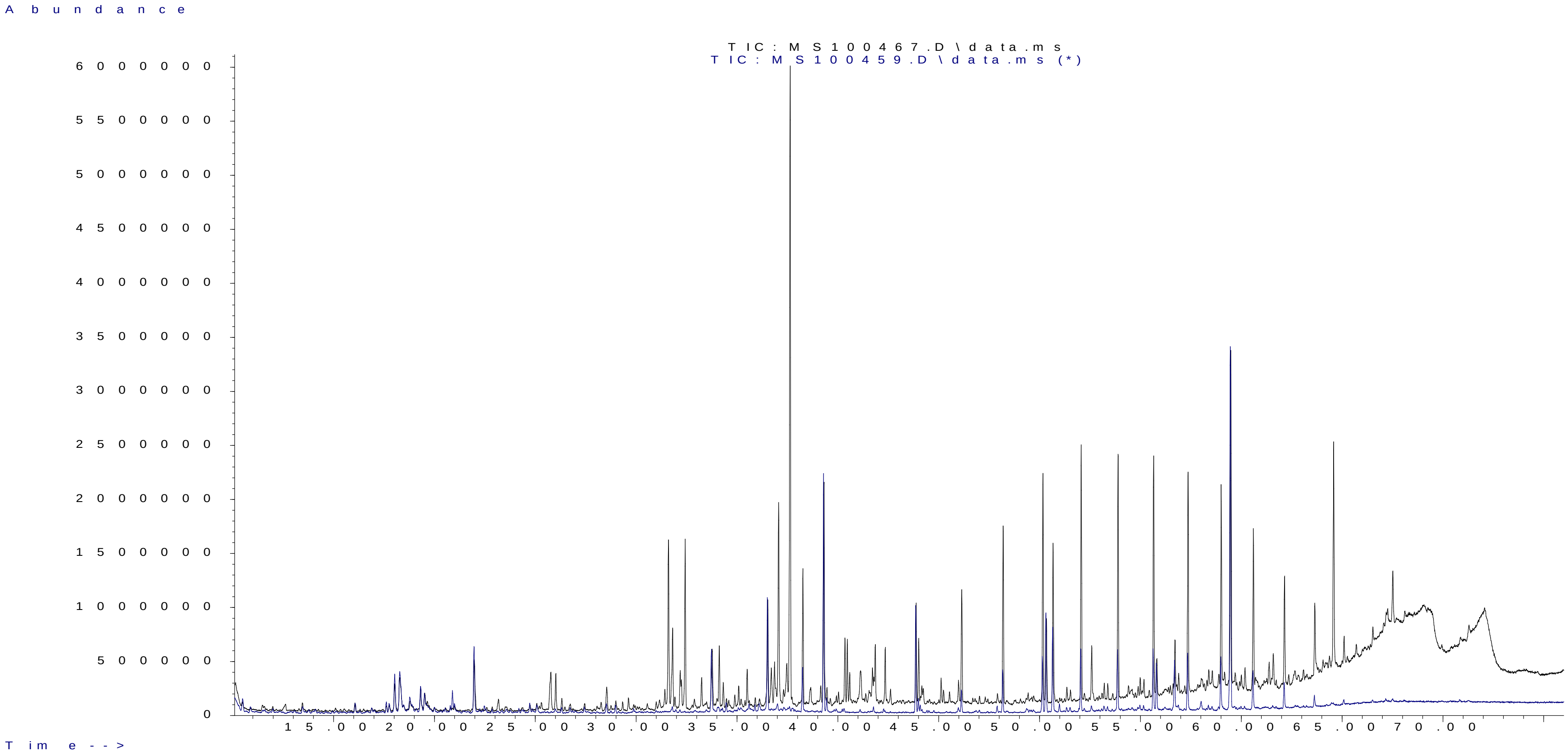


Figure A3.4. Sample 21 B Total Ion Reconstructed Chromatogram with analytical blank underneath.



FigureA3.5 Sample 26 B Total Ion Reconstructed Chromatogram with analytical blank underneath.

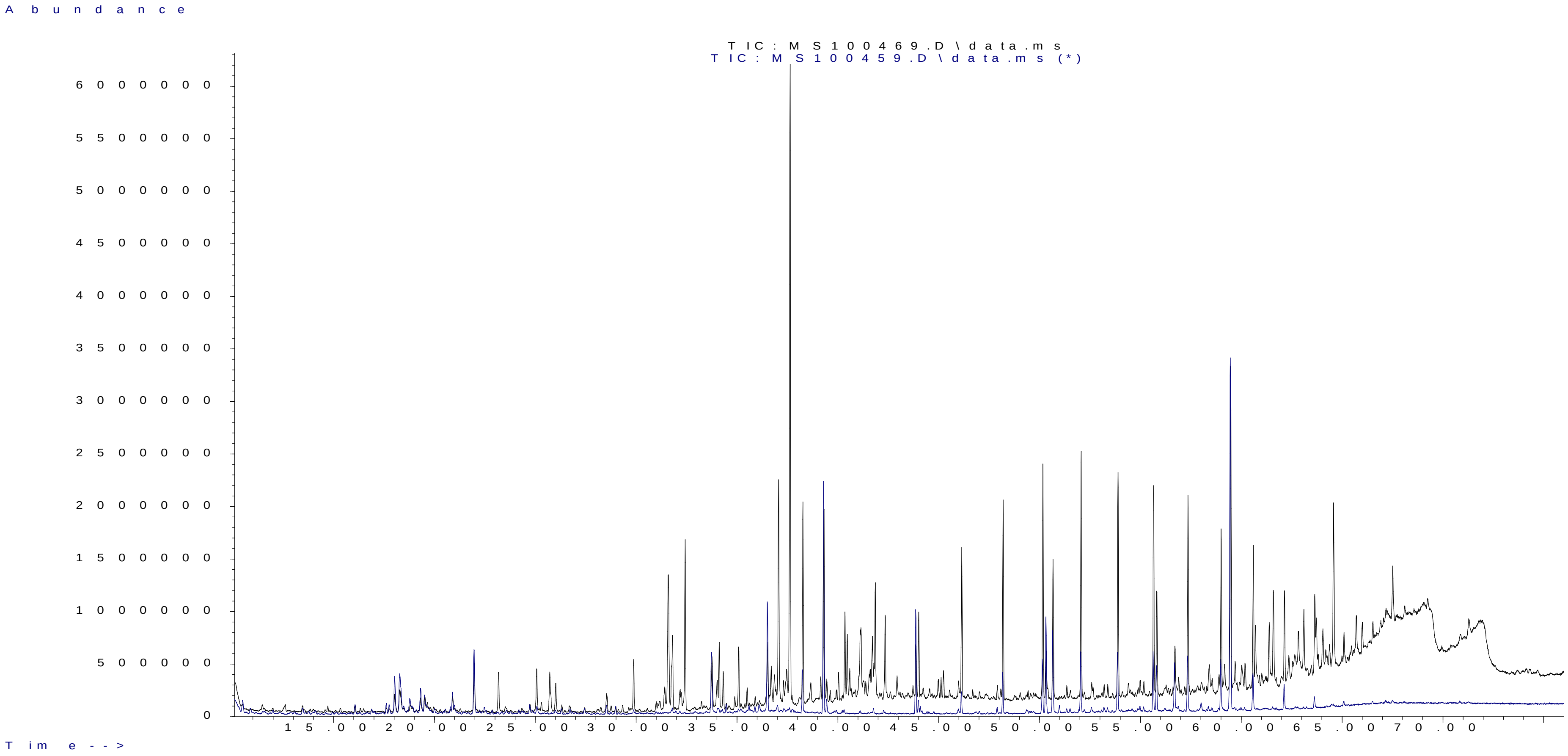


Figure A3.6 Sample 32 B Total Ion Reconstructed Chromatogram with analytical blank underneath.

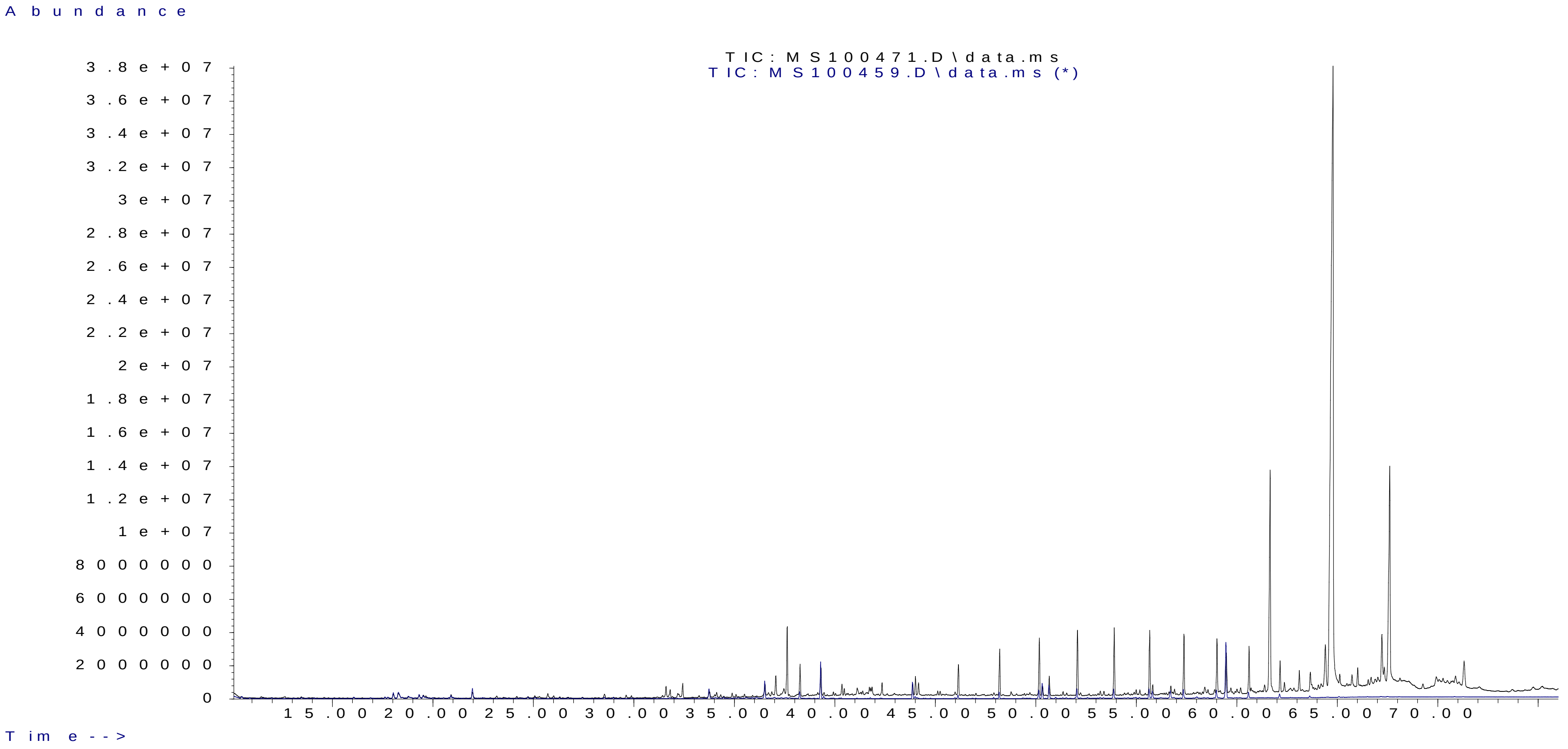


Figure A3.7 Sample 36 B Total Ion Reconstructed Chromatogram with analytical blank underneath.