J Coast Conserv (2007) 11:105–119
DOI 10.1007/s11852-008-0011-1

Development of rapid, cost effective coral survey techniques: tools for management and conservation planning

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Received: 5 November 2007 / Revised: 28 February 2008 / Accepted: 22 March 2008 / Published online: 25 April 2008

Abstract Coral reefs are highly dynamic and productive marine ecosystems, providing habitat and refuge for an enormous number of species including fish, invertebrates and algae. With increased anthropogenic pressures and global climate change, many coral reefs are rapidly declining. Currently, there is limited knowledge on condition and community assemblage composition of shallow fringing coral reefs along the south-eastern coast of Queensland, Australia. With increased demand to determine existence of coastal fringing reefs by National Regional Management groups, a rapid cost effective method to determine reef composition and condition was required. The aim of this study was to determine the benthic structure and extent of two small coastal fringing reefs (Hummock Hill Reef and Stringers Reef) along the Southern Great Barrier Reef. Reef substrate assessments were carried out using a rapid assessment technique and a Point Intercept Method (PIM). The data were analysed and classified using a Geographic Information System (GIS). Percent substrate cover was calculated using a visual basic image analysis program. The Point intercept method showed higher accuracy over the rapid assessment technique (up to 15–40% difference) and was thus deemed a more suitable classification tool for reefs with high structural complexity and heterogeneity. This study focused on piloting a rapid, cost effective Point Intercept Technique using random point count methodology to document coral benthic habitat and extent over a commonly used rapid assessment method as a tool for reef coastal management and conservation. The two techniques were compared and substrate classification success, limitations and errors were discussed.

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Keywords Coastal management · Conservation · Coral reef classification · Field validation · Geographical information system · Image analysis · Rapid assessment

Introduction

Coral reefs are extremely diverse and productive marine ecosystems, providing habitat and refuge for an enormous number of species including fish, invertebrates and algae. Consequently, coral reefs are one of the most high-profile marine systems in terms of conservation. However, anthropogenic influences have put a large proportion of coral reefs into imminent danger of collapse, with 20% already severely damaged or degraded world wide (Knight et al. 1997a, b; Holden and LeDrew 1998; DeVantier et al. 2006).

The Great Barrier Reef (GBR) contains more than 3,000 reefs stretching a distance of over 1,800 km along the Queensland coast with the majority of reefs located offshore. However, there are many coastal fringing reefs that are located close to mainland shores (DeVantier et al. 2006). High abundance and diversity exists in the GBR with distinct changes in species richness and diversity across the shelf, mainly attributed to changes in habitat diversity, natural disturbances, water depths and light penetration (water clarity), and nutrient and pollution inputs (Done 1982; Knight et al. 1997a; DeVantier et al. 1998; Fabricius and De'ath 2004; Phinn et al. 2005). With increased anthropogenic and natural pressures on coral reefs, it is important for conservation management practices to monitor changes in reef condition.

In the past, managers have applied different coral mapping and remote sensing techniques to assess coral reef health, all of which have limited applications. Medium and high resolution remote sensing using satellite imagery, such as Landsat ETM, SPOT 5, Quickbird and IKONOS products are suitable for identifying changes in reef health by using current and historical data and thus, determine trends in condition/degradation of reefs. These products are suitable for detecting coral bleaching on large spatial scales (Yamano and Tamura 2004; Kutser and Jupp 2006), however, are limited in providing complex reef classifications for management purposes (Andrefouet et al. 2003). Remote sensing also allows for the assessment and extent of water quality parameters such as algae and turbidity in the water column (Hochberg and Atkinson 2003). Some of the issues in using satellite imagery are their limitations in sensor capabilities, spectral and spatial resolutions, digitization rates and thus distinguishing between different substrate classifications. For example, studies have shown that Landsat-ETM imagery can only distinguish between three broad coral classes including coral rubble, sands and living corals, with no discrimination among distinct coral communities, including soft corals against hard corals (Hochberg and Atkinson 2003; Kutser and Jupp 2006). Furthermore, ETM imagery is only suited for larger areas and courser scaled classification, thus smaller reefs cannot be sufficiently differentiated at pixel sizes >10 m, making it impossible to classify corals at finer spatial scales (Andrefouet et al. 2003; Hochberg and Atkinson 2003; Yamano and Tamura 2004). Although higher resolution imagery and increased digitization rates (8 Bit to 11 Bit) increases the number of classes and the accuracy of detection, it would still be unsuitable for use on smaller coastal fringing reefs requiring very high resolution (square meter as opposed to square kilometer) (Andrefouet et al. 2003). Other techniques for mapping benthic cover on coral reefs include, high resolution (<1 m pixel size) remotely sensed imagery, colour aerial photography, expensive airborne hyper spectral digital data, diver-assisted photography and videography by free swimming or using manta tows (Hochberg and Atkinson 2000; Kenyon et al. 2006; Lam et al. 2006). Coral and benthic cover can be assessed using quadrats and/or point intercept techniques along transect lines. These techniques are more suited for smaller scale reef classification from 10–100's of metres (Kenyon et al. 2006; Lam et al. 2006). These substrate classification techniques also have their limitations. For example, detecting changes in coral cover using point intercept methods over videography is less accurate, however, assessing long transects using videography can be time consuming, spending long hours in the laboratory doing image analysis (Kenyon et al. 2006; Lam et al. 2006; Stevens and Connolly 2005).

There is limited knowledge on the existence and condition of small (<100 ha) isolated patchy shallow fringing coral reefs along the east coast of Queensland, Australia. Many of these coral reefs fall within significant National Regional Management (NRM) group areas. With changing land use practices and increased anthropogenic stress to coastal reef systems, sound management practices are required to sustain and conserve such reefs. Many NRM groups require rapid, cost effective means to determine the extent, composition and condition of such small coastal reefs for planning purposes. The general aim of the study was to pilot the suitability of a rapid assessment and image classification technique using digital underwater photography coupled to point intercept methods (PIM) and aerial photograph to classify small fringing coastal coral reefs for NRM planning purposes. The specific aims of this project were to: (a) identify and determine coral and benthic substrate cover of two small coastal fringing reefs located in the southern GBR; (b) examine the suitability of a random point count method and *in situ* rapid assessment technique along point intercept transect lines; and (c) document and classify the benthic substrate of the two reefs using GIS.

Material and methods

Two small (<100 ha) isolated coastal fringing coral reefs within the southern GBR (Capricorn Section) were identified from digital colour aerial photographs (Urangan to St Lawrence, 1:12,000, 2001 series). The digital colour aerial photographs were geo-referenced and entered into ESRI® ArcMap™ 8.3 Geographical Information System (GIS) software and ERDAS Imagine 9.1 (1991–2006 Leica Geosystems Geospatial Imaging, LLC) image analysis software. Positional accuracy of the photographs was within 5 m of the field captured Global Positioning System (GPS) data.

The first reef, Hummock Hill Reef (HHR), was located adjacent to Hummock Hill Island (23.99S; 151.48E) Queensland, Australia. The second reef, Stringers Reef (SR), was located 1.6 km north of the mouth of Baffle Creek (24.48S; 152.03E) Queensland (Fig. 1). Both reefs had similar average depth profiles (Hummock Hill Reef; depth range 2.8–5.0 m, mean 4.0±0.2 m; Stringers Reef depth range 2.0–8.2 m, mean 3.9±0.5 m), and were located within 50 m from the low water mark.

Field surveys

Four transect lines between 100–350 m (depending on reef extent) were laid out using a boat at each reef. Transects were then swum by two divers using SCUBA. Start and

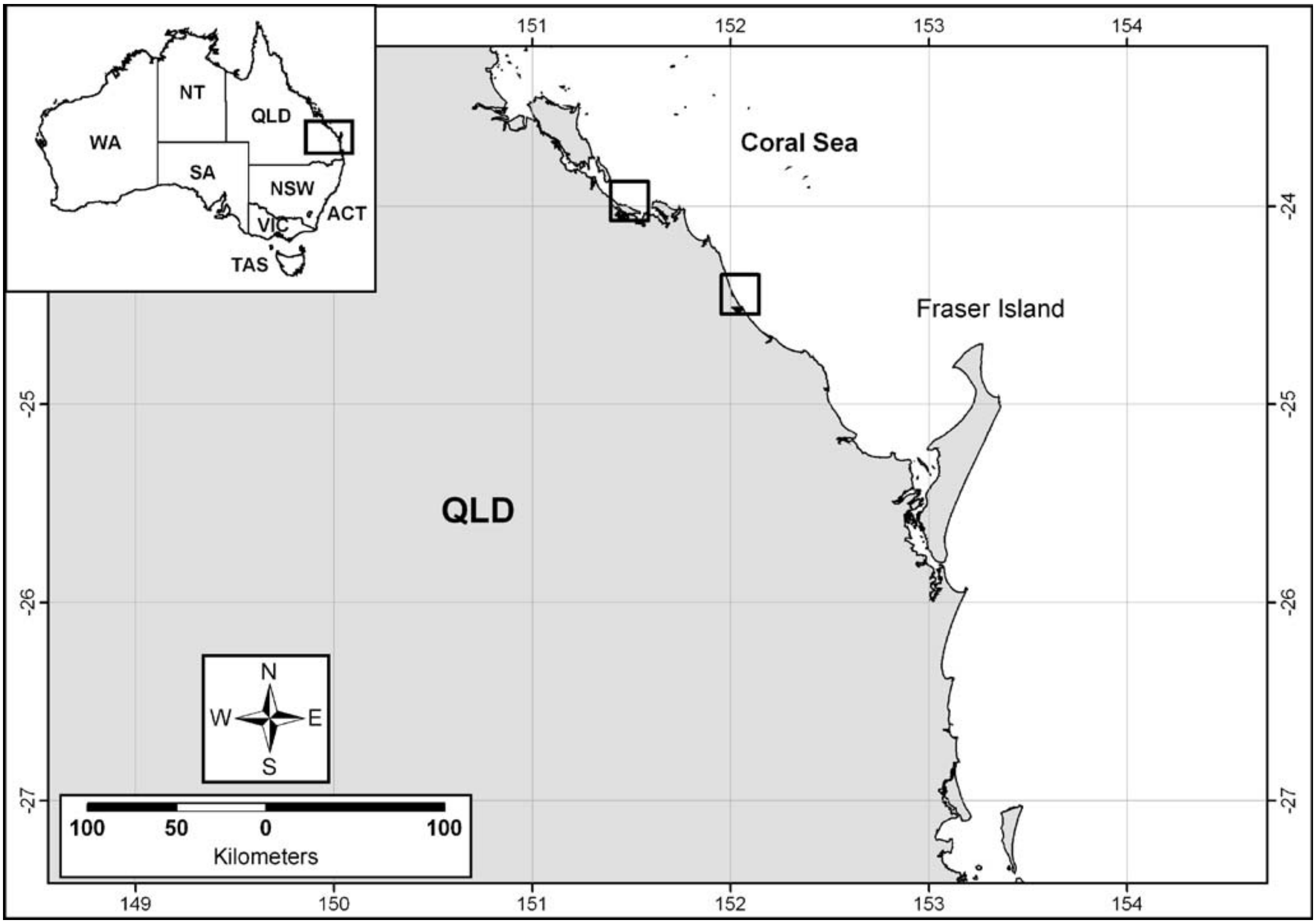

Fig. 1 Map of the southern Great Barrier Reef region showing the two study reef locations. *Insert*: Map of Australia showing study area

end points were marked using a GPS. Two techniques were used, a rapid assessment technique where a diver recorded benthic substrate types based on visual census over an area of 1 m^2 every 5 m on each transect, and a still photographic frame assessment where each frame taken every 5 m was analysed *ex situ* using a visual basic program, Coral Point Count estimate (CPCe) with excel extensions (Kohler and Gill 2006). Coral cover was visually estimated and photographed (point intercept technique—single frame quadrat) every 5 m using a digital camera in an underwater housing. Each frame was taken 1 m above the substrate using a fixed reference bar. A 5 cm scale was incorporated in each frame in order to calculate total area (0.25 ± 0.01 m^2) per quadrat. Photographs were taken parallel to the substratum to minimise parallax error.

Data analysis

The rapid assessment technique involved recording different benthic substrate types; sand, pavement (dead coral with macroalgae), macroalgae, soft corals, hard corals (plate corals, branching corals massive/porites), sponges and hydroids, and expressed as a percentage (%) of the total substrate type encountered per transect.

A random point count methodology was used to estimate coral community assemblages and other pavements and sands. Twenty points were randomly distributed along each frame and substrate cover was identified beneath each point by visual observation and percent substrate cover was calculated as for each frame. Five points, 10 points, 20 points and 50 points were tested to determine the level of error and Coefficient of Variation (CV) of the calculated percent substrate cover within each frame. Five point estimates showed errors of up to 20% (CV 30%), 10 points up to 10% (CV 20%), 20 points up to 4% (CV 7%) and 50 points, errors of 2% (CV 5%). Although 50 points showed the highest accuracy, the analysis time outweighed the accuracy gains and therefore 20 random points were selected as the optimum number for this study. Mean (± SE) percent substrate cover was then calculated per transect using photographic quadrats as replicates. Shannon–Weiner species diversity (H') was also calculated for each transect. Differences ($P<0.05$, 95% confidence intervals) in (a) percent substrate cover and (b) species diversity among transects were tested using one-way Analysis of Variance (ANOVA). Data were tested for homogeneity of variance and normality and significance levels were increased ($P<0.01$, 99% confidence intervals) where data did not meet these criteria (O'Neill 2000; Underwood 1997).

Substrate cover was calculated based on major and sub-categories over the whole transect. The major categories for the frame analysis consisted of sands, hard corals, soft corals, pavement (dead coral with algae), sponges, macro-algae and hydroids. Sub-categories consisted of substrate (coral) species and sub-families.

Major coral/substrate categories were further classified using hierarchical clustering analysis. Euclidian distances were calculated using percent substrate cover. Classifications were clustered based on their similarity and maximised to produce homogeneity among similar classifications. Cluster analysis results were then cross referenced with actual percent substrate cover categories. Each quadrat on every transect were classified accordingly. These data were then added to the GIS (see "Spatial data analysis and reef classification" section below). The following classes were derived for the GIS analysis: sands, pavements (dead corals with algae), hard corals, soft corals, mixed substrates and bare rock/unknown. Sub-classifications included dominant substrates, where the dominant substrate consisted of >90% substrate cover per frame, for example, dominant sand, dominant hard coral or dominant soft coral; dominant substrate with other sparse substrate, where the dominant substrate consisted of 89–60% substrate cover with up to 40% of other substrates; and mixed substrate where equal (~50%) amounts of substrates where encountered (Table 1).

Reef reports were then generated for each reef and an overall assessment was established based on health/condition of each reef. Reef condition was ranked in the following categories: 'Excellent condition', Very high coral biodiversity, no bleaching present, <1% coral death, minimal algal cover, no disease; 'Good condition', High biodiversity, limited evidence of coral bleaching or algal cover with good evidence of coral recovery or recruitment; 'Moderate condition', Some evidence of anthropogenic or climate related (bleaching) impacts, and 'Poor condition', Severely impacted, high percentage of dead coral or disease, high percentage of algal cover, little or no recruitment.

Spatial data analysis and reef classification

Study area outlines reflecting the reef extents were created from visual interpretation of the aerial photographs and confirmed by field survey transects. Reef boundaries were arbitrarily created such that the sampled reef areas were entirely within the boundary, i.e. boundary lines were drawn across sand dominant areas immediately adjacent to the known reef area. The study area outlines were used to further extract raster cell values (pixel size; 3.7 m for Hummock Hill Reef and 1.3 m for Stringers Reef) from the aerial photographs for further classification purposes. These raster data were classified using ISODATA (Iterative Self Organising Data Analysis) Unsupervised Classification (UC), (25 arbitrary classes with 98% convergence) (Leica Geosystems 2005). The ISODATA clustering method uses the minimum spectral distance formula to form clusters of shading related classes derived from the original RGB

Table 1 Coral reef and substrate classifications used for the analyses

Category	Classification	Percent cover
1	Sand dominant	Sand cover >90%
2	Sand dominant sparse mix	Sand cover 89–60% with up to 40% other substrates
3	Pavement dominant	Pavement cover >90%
4	Pavement dominant sparse sand	Pavement cover 89–60% with up to 40% sand cover
5	Pavement dominant sparse coral	Pavement cover 89–60% with up to 40% coral cover
6	Mixed substrate	Equal amounts (50%) of substrates dispersed evenly
7	Hard coral dominant	Hard coral cover >90%
8	Hard coral dominant sparse mix	Hard coral cover 89–60% with up to 40% mix of other substrates
9	Hard coral dominant sparse pavement	Hard coral cover 89–60% with up to 40% pavement cover
10	Soft coral dominant	Soft coral cover >90%
11	Soft coral dominant sparse sand	Soft coral cover 89–60% with up to 40% sand
12	Soft coral dominant sparse pavement	Soft coral cover 89–60% with up to 40% pavement
13	Soft coral dominant sparse mix	Soft coral cover 89–60% with up to 40% mix of other substrates
14	Sand dominant sparse pavement	Sand cover 89–60% with up to 40% pavement
15	Pavement dominant sparse soft coral	Pavement cover 89–60% with up to 40% soft coral
16	Pavement dominant sparse mix	Pavement cover 89–60% with up to 40% mix of other substrates
17	Macro algae dominant	Macro algae cover >90%
18	Rock/unknown	Unknown substrate or bare rock

(Red, Green, and Blue) pixel values. The 25 classes were then rationalised into *a priori* classifications.

Field captured GPS data were used to generate transect lines as a vector spatial layer. Points, at 5 m intervals, were generated along each transect. The surveyed and subsequently classified data were then linked to their applicable 5 m transect quadrats and colour coded as per derived reef sub-category classification (Table 1). The points were rasterized to their specific image pixel sizes and interpolated onto the reef raster image by means over overlaying the transect classifications on the reef raster. Hence, quadrat classifications along each transect were used as a generalised template to interpolate the whole of reef classification. Reef area and substrate classification areas were then calculated using these data (pixel number per class by pixel size). Study area outlines, transect localities, and transect plots with whole of reef classifications were reproduced as high quality maps.

Results and discussion

Coral cover and condition assessment

A total of 20 species/genera/sub classes were found in the two study reefs with only two of the sub-classes occurring in both reefs. Hummock Hill Reef was dominated by hard corals (Fig. 2) however, Stringers reefs was dominated by soft corals (Fig. 3). The main coral type, found in Hummock Hill reef, was *Montipora capricornis* (Fig. 4, Table 2), whereas stringers reef was dominated by the soft coral *Lobophyton* sp. (Fig. 5, Table 3). Changes in reef community types can be influenced by a number of factors including light penetration, water temperature, depth, and currents (Veron 2000). Soft corals like *Lobophyton* thrive in relatively turbid waters, however hard corals require higher light intensity and therefore live in relatively clearer waters (Veron 2000; Sanders and Baron-Szabo 2005). Further-

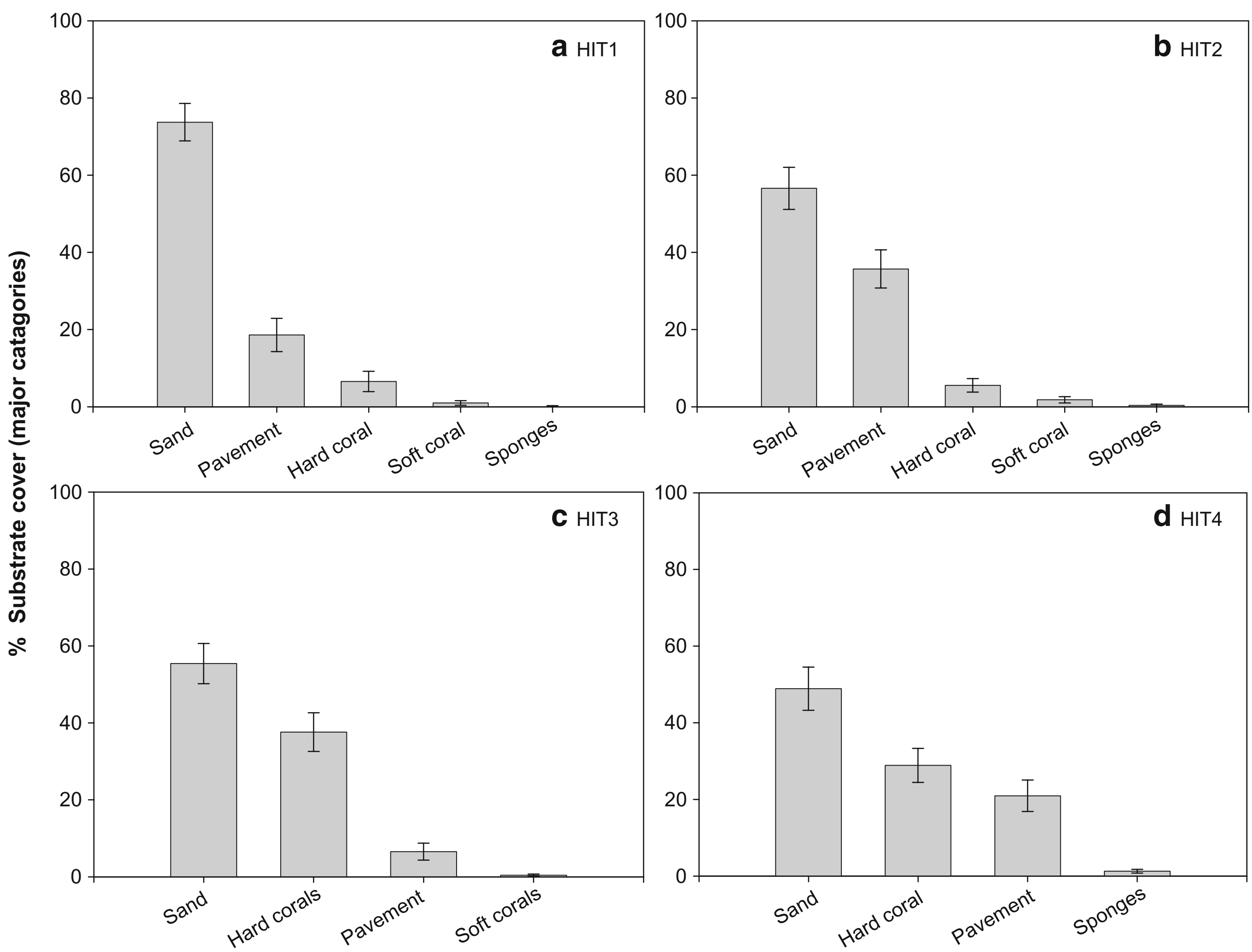

Fig. 2 Major category substrate cover (%) at Hummock Hill Reef calculated from transect data. Mean ± SE

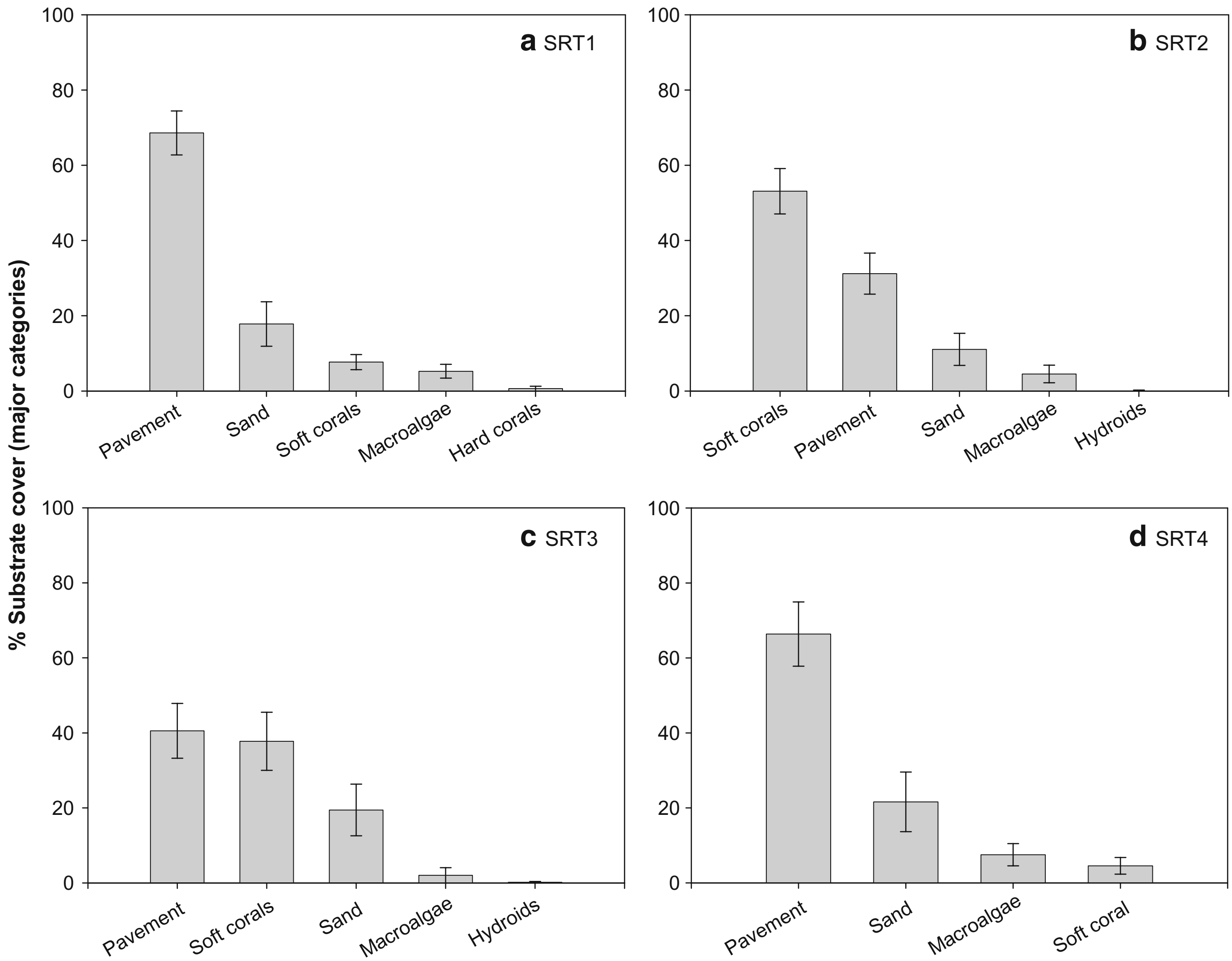

Fig. 3 Major category substrate cover (%) at Stringers Reef calculated from transect data. Mean ± SE

more, studies have shown that changes in turbidity and sedimentation rates on coral reefs can alter community assemblages (Sanders and Baron-Szabo 2005).

Stringers Reef was almost twice as large as Hummock Hill Reef, however, both reefs had similar average depth profiles of ~4 m (Table 4). At Hummock Hill Reef, percent live coral cover increased significantly ($P<0.05$) with transect distance from shore, with highest sand/coral rubble/pavement cover for transects HIT1 & HIT2, and highest hard coral cover for transects HIT3 & HIT4 (Figs. 2 and 4). Stringers reef also contained a significantly ($P<0.05$) higher percentage of soft coral cover at the deepest section (transects SRT1 & SRT2) (Figs. 3 and 5). Increased live coral cover could have been attributed to depth, as studies have shown greater coral abundance and diversity in deeper waters; however, other factors such as increased turbidity, temperature and wave action/intensity could also influence substrate cover (DeVantier et al. 1998, 2006). A study by DeVantier et al. (1998) found that reefs in the Mackay–Whitsunday region, closer to the coast, had higher densities of dead standing coral, turf algae, macro algae and *Sargassum*, possibly due to increased wave exposure, nutrient output from local river mouths and increased turbidity. Furthermore, differences in coral community assemblages may have been attributed to differences in adjacent land use practices. For example, Hummock Hill reef was adjacent to a national park with minimal anthropogenic disturbance. Stringers reef was situated adjacent to macadamia and sugarcane plantations (Tables 2 and 3), possibly influenced by increased nutrient and sediment runoff, however, this statement should be taken with caution as no water quality parameters were measured at either of the two reef. Stringers and Hummock Hill reef showed no evidence of coral bleaching or disease in any of the areas assessed. Significantly ($P<0.05$) higher coral species diversity was also encountered in transects with highest depth gradients (Transects 3 & 4 at Hummock Hill Reef and Transect 1 & 2 at Stringers reef; Table 4). Both reefs had similar species diversity (range 0.1–0.3 H', $P>0.05$), however, diversity encountered at these reefs was

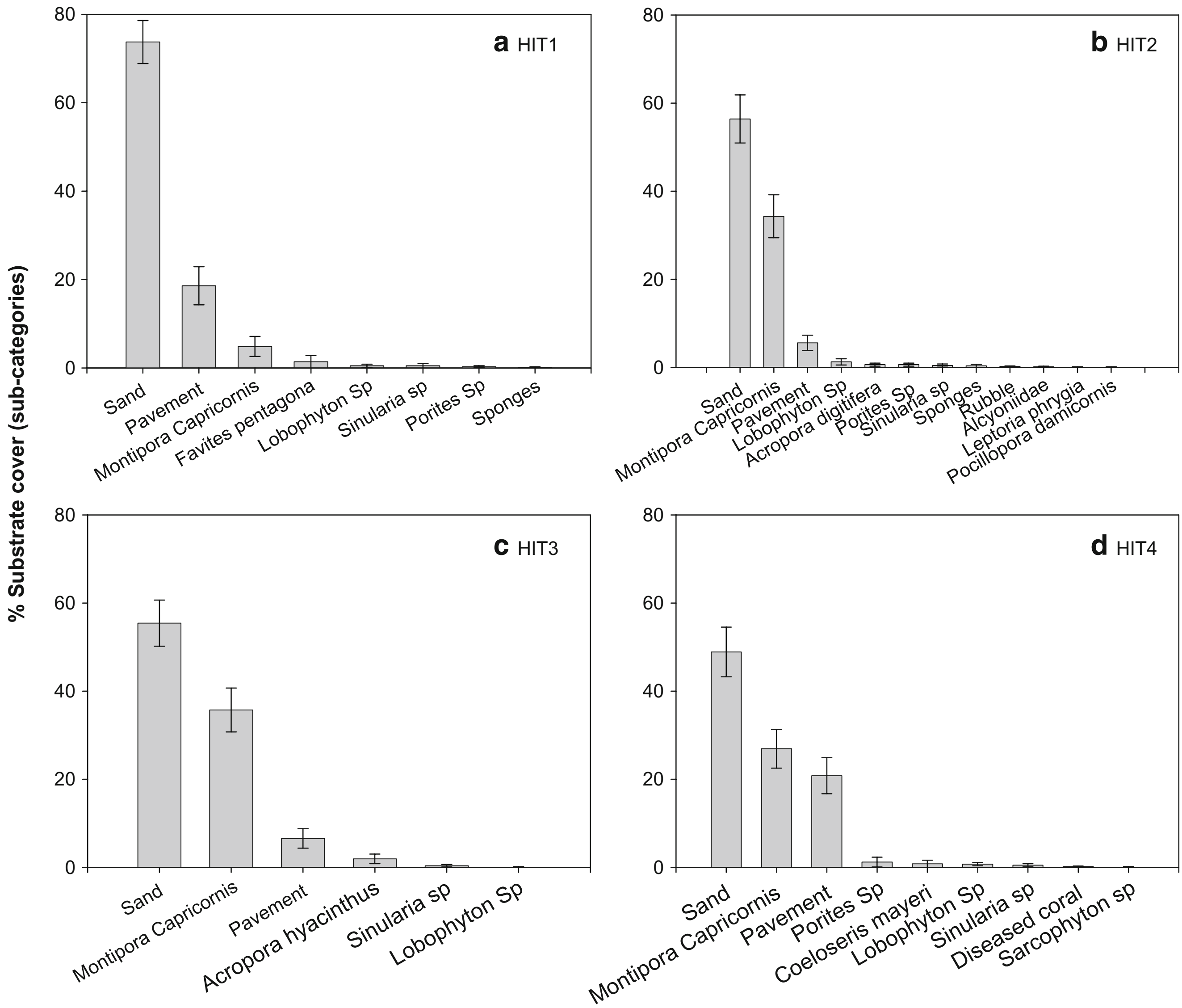

Fig. 4 Sub category substrate cover (%) at Hummock Hill Reef calculated from transect data. Mean ± SE

Table 2 Ecosystem health report table for Hummock Hill Reef

	Details
Location	23.99S; 151.48E
Size	33.9 ha
Depth range (mean ± SE)	2.8–5.0 m (4.0±0.2 m)
Coral species richness	14 coral species encountered
Dominant species	*Montipora capricornis*
Pavement/substrate cover	Coral pavement encrusted in micro/macro algae and sediment
Habitat type	Hard coral dominant
Coral bleaching	<2%
Coral diseases	No diseases detected, minimal sedimentation present
Other notable features	Reef structure adjacent to Hummock Hill National Park
Overall condition assessment	Good condition

significantly lower than diversity encountered at reefs from other studies (DeVantier et al. 1998). DeVantier et al. (1998) found that highest species abundance and diversity were encountered at reefs in deeper water (4–8 m below crest). On average, species diversity was higher in reefs at the Mackay–Whitsunday section compared to the two reefs in this study (H' 0.8±0.1; 0.2±0.1, respectively), however, this may have been attributed to the close proximity of the current study reefs to the coastline and/or average water temperature gradients being on average lower in the Capricorn section, as opposed to the Mackay–Whitsunday section (Hoegh-Guldberg and Smith 1989; Isern et al. 1996).

Rapid assessment versus point intercept image analysis

The rapid assessment technique, although it had its limitations, was a simple and inexpensive method. Sub-

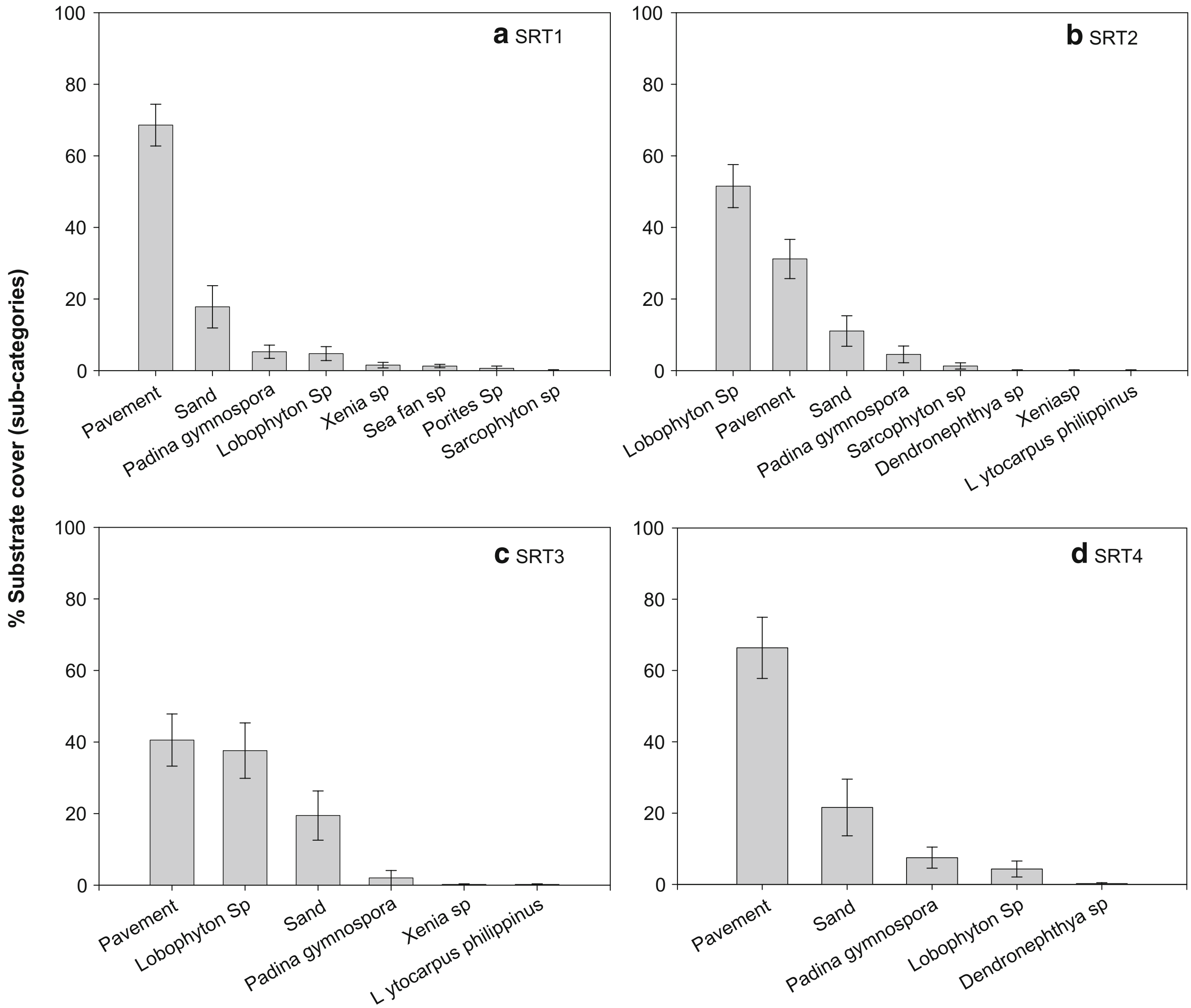

Fig. 5 Sub category substrate cover (%) at Stringers Reef calculated from transect data. Mean ± SE

Table 3 Ecosystem health report table for Stringers Reef

	Details
Location	24.48S; 152.03E
Size	79.8 ha
Depth range (mean ± SE)	2.0–8.2 m (3.9±0.5 m)
Coral species richness	8 coral species encountered
Dominant species	*Lobophyton* sp.
Pavement/substrate cover	Granite rock encrusted by soft coral and micro/macro algae
Habitat type	Soft coral dominant
Coral bleaching	<1%
Coral diseases	No diseases detected
Other notable features	Limited agricultural runoff from adjacent macadamia and sugarcane plantations
Overall condition assessment	Good condition

strate cover was calculated on the basis of frequency, not as a measure of total area. This technique is useful in covering a larger area and determining a rough estimate of substrate cover and type. Although the results obtained using the rapid assessment technique were similar to the results using a frame quadrat and random point method technique, the rapid assessment technique tended to underestimate coral cover by up to 10–50%, resulting in more generalised classifications. For example, sand cover calculated using the random point method technique estimated sand substrate to be around 75% at Transect 1 of Hummock Hill Reef (Fig. 2a), however, the rapid assessment technique calculated sand cover to be ~65%, a proportional difference of up to 15% (Fig. 6a). This was similar for other classification groups such as pavements, which had a difference of up to 5–50%; hard corals, 15–40%; soft corals, 15–30% for Hummock Hill and Stringers Reef

Table 4 Shannon–Weiner diversity index for all transects at Hummock Hill Reef and Stringers Reef

	Transect 1	Transect 2	Transect 3	Transect 4
Hummock Hill Reef (HIT)—area 33.9 ha	0.22±0.04 (3.9 m)	0.12±0.03 (4.0 m)	0.23±0.04 (4.1 m)	0.33±0.05 (4.2 m)
Stringers Reef (SRT)—area 79.8 ha	0.34±0.06 (4.5 m)	0.38±0.06 (4.3 m)	0.33±0.06 (3.7 m)	0.30±0.06 (3.0 m)

Mean ± SE; brackets indicate average depth gradient per transect

(Fig. 7). Furthermore, the rapid assessment technique only allowed a limited number of group classifications such as sand, hard corals, soft corals, pavements, and limited sub categories like branching corals, massive corals and plate corals. The photographic quadrat and image analysis technique allowed a greater number of group and sub-group classifications, refer to Figs. 3 and 5 for sub-category classifications at Hummock Hill Reef and Stringers Reef using the random point intercept method.

Random point intercept methods also have their limitations. For example, distances between point intercept frames can range from 1 m to 100’s of metres depending on spatial resolution required and the extent of the reef, thus allowing for broad spatial habitat characterisation. Increasing the frequency of frames to every 1m, increases the accuracy of coral cover, however, it also increases the sampling effort, analysis time and costs (see below). Due to the small reef extents of the study areas, 5 m intervals were selected. Lam et al. (2006) compared video and Point Intercept Methods (PIM) to survey a subtropical coral reef and found that PIM were inferior in detecting changes in coral cover and over estimated percentage coral cover (up to 12%) compared to the video transect technique. Furthermore, detecting rare coral species was more likely using the video method as opposed to the PIM, however,

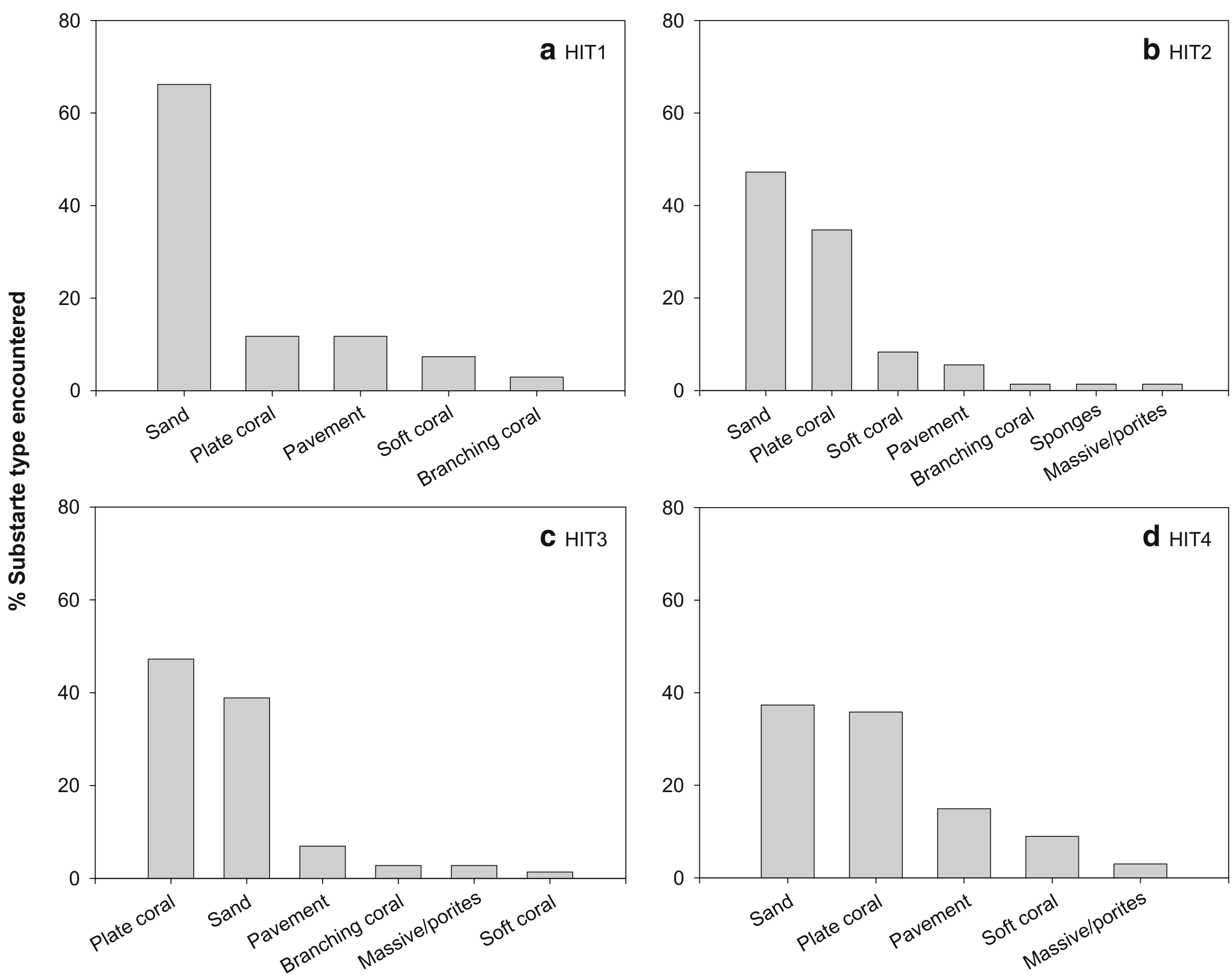

Fig. 6 Percent substrate type encountered at Hummock Hill Reef using a rapid assessment technique

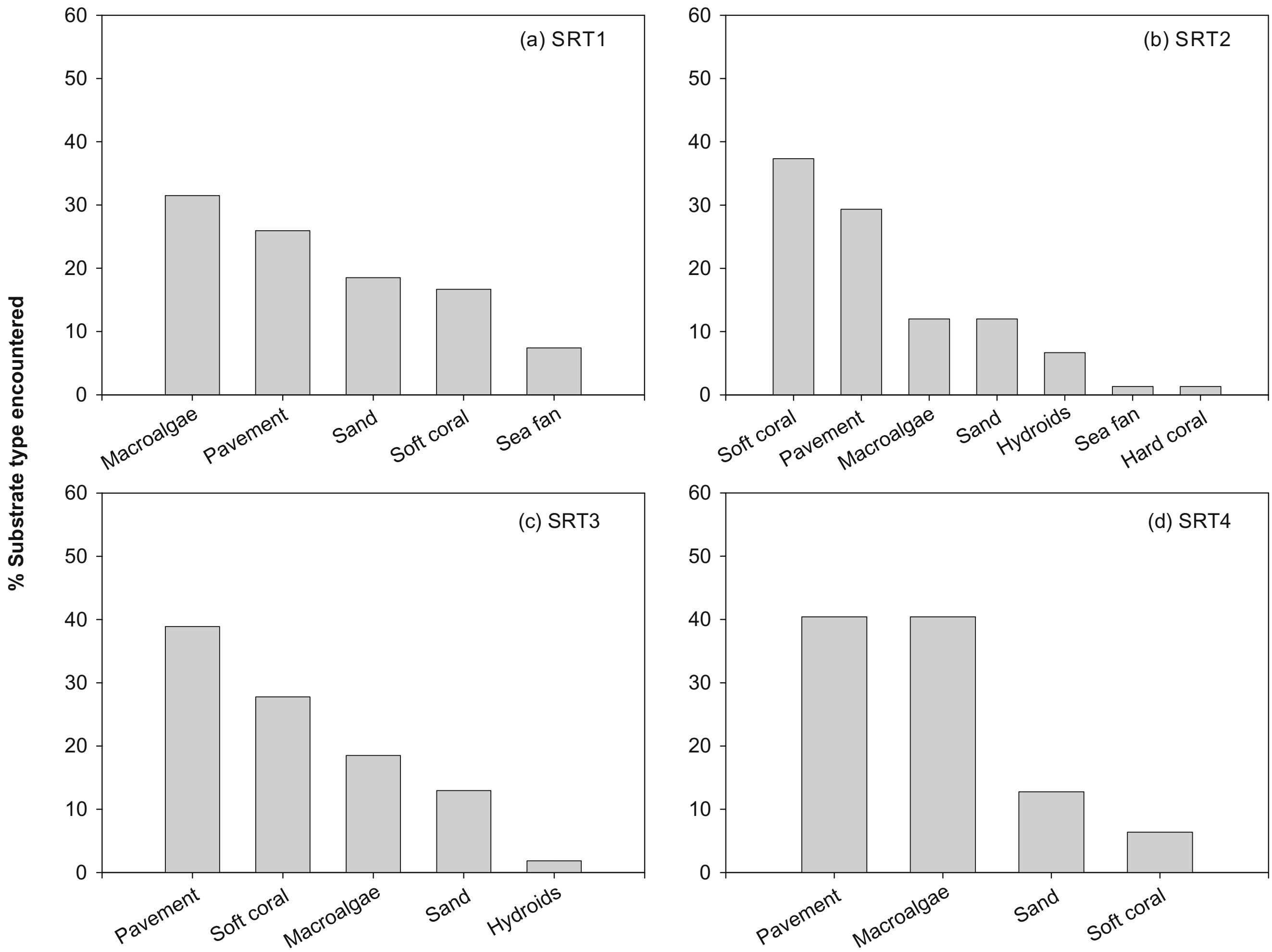

Fig. 7 Percent substrate type encountered at Stringers Reef using a rapid assessment technique

video transect techniques required much more time in the laboratory undertaking post capture image analysis. Although the video method is more accurate in detecting rare species and change in coral communities, PIM's have been useful tools in monitoring the general state of coral communities and have been used for management and habitat conservation practices (Knight et al. 1997a; Hill and Wilkinson 2004; Kenyon et al. 2006; Lam et al. 2006; Leujak and Ormond 2007).

Random point count methods using computer programs are increasingly being used to estimate coral community demographics by means of statistical algorithms (Kenyon et al. 2006; Kohler and Gill 2006). Points are randomly placed on an image frame (photo or video grab frame) and benthic substrates are identified under each point using visual interpretation. Data from individual frames are then combined to produce both inter- and intra-specific differences among frames within each transect.

Finding the appropriate sampling rigor to maximise the cost/benefit ratio is important for this type of analysis. Increasing the number of random data points increases the likelihood of reaching the true value of percent cover; however, being an asymptotic relationship, at some point, as cost and time reaches an infinite (∞) value, there is minimal change in accuracy/error. For the purpose of this study, 20 points per frame at 5 m intervals were a good estimate of substrate cover (<5% error) based on the small extent of both reefs (<100 ha). Moreover, the four transects covered a significant area to encompass the extent of both small reefs. Larger reefs would require an increased number of transects. Although this study lacks a groundtruthing component, the area covered by the transects and the frequency of quadrats per transect have covered a significant area allowable to produce benthic substrate classifications.

Whole of reef benthic substrate classification

The study area outlines presented indicated the presence and extent of surveyed reef (Figs. 8 and 9). Sand was the dominant substrate at Hummock Hill Reef, covering an

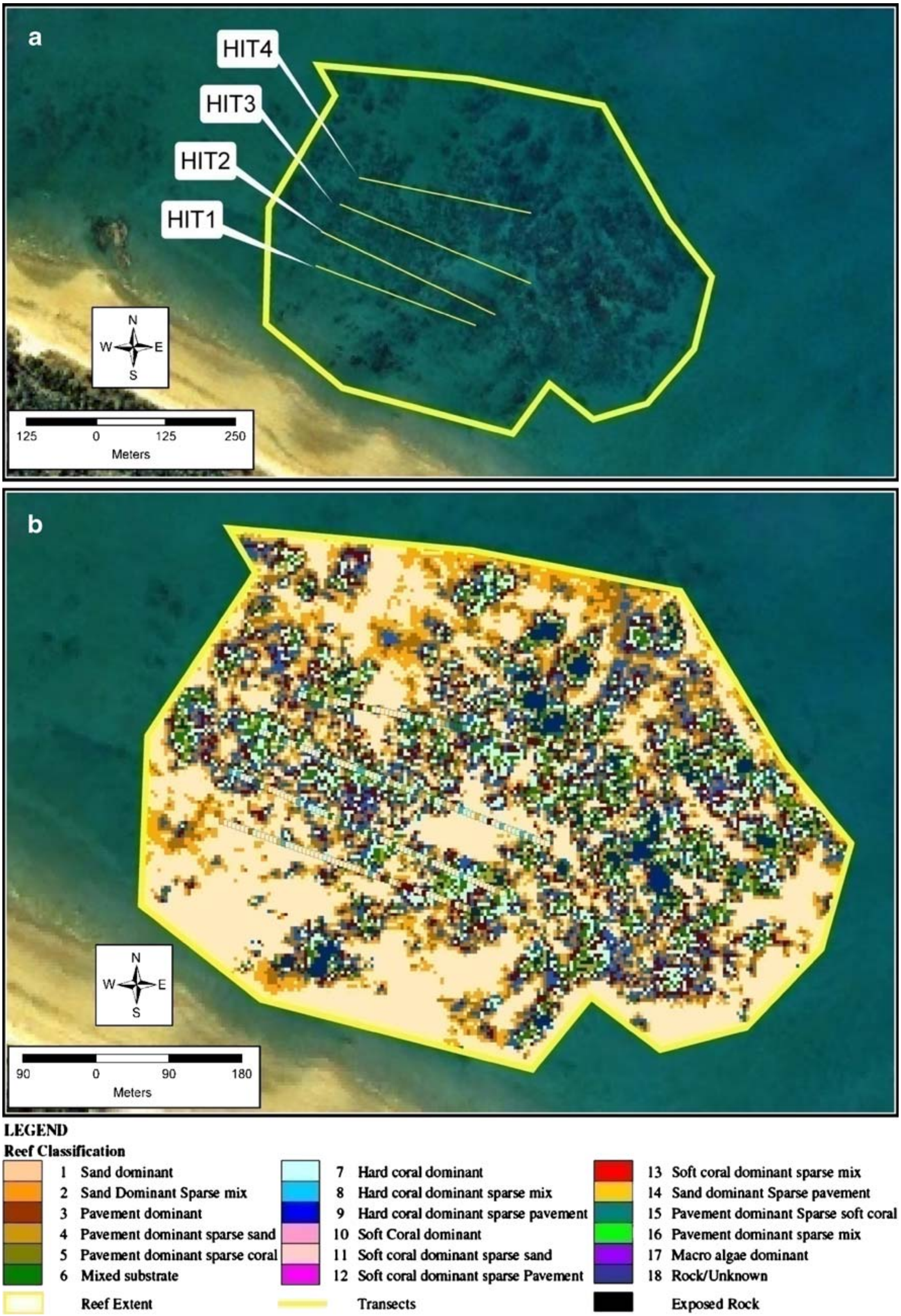

Fig. 8 Hummock Hill reef classification map showing all **a** transects and **b** categories

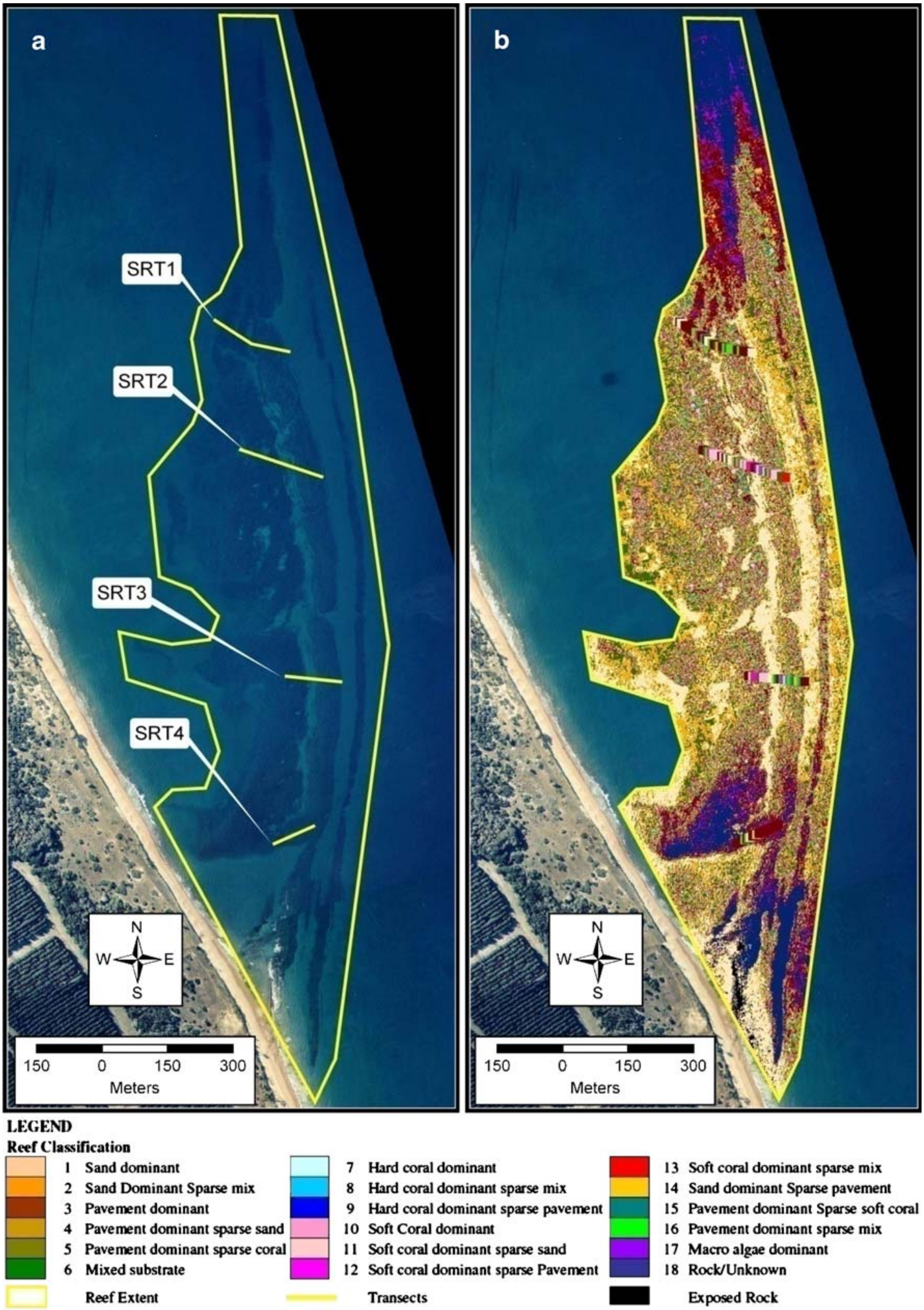

Fig. 9 Stringers reef classification map showing all **a** transects and **b** categories

approximate area of 12 ha (34%) with hard coral being the dominant live substrate, covering an approximate area of 3.4 ha (10%). Exposed rock and unknown substrate was the least encountered substrate at Hummock Hill Reef, covering an area of 1 ha (3%) of the total reef (Table 5). Sand was also the dominant substrate encountered at Stringers Reef, covering an estimated 15 ha (19%) with mixed substrate covering an area of 12 ha (15%) of the total reef area. Macroalgae was the least dominant substrate encountered at Stringers reef, covering an approximate area of 2.5 ha (3%) of the total reef area (Table 5).

Accuracy issues resulting from initial aerial photograph geo-referencing, inherent GPS inaccuracies and physical constraint issues such as boat drift transect line movement, stretching and shrinking, coupled to diver drift and tow could result in mapping errors of up to 10 m. It was therefore recommended that future mapping exercises would incorporate GPS points being marked every 50 m, as opposed to start and end points only, with track marks recorded in true time as transects are laid out using the boat. This should decrease spatial errors to <5 m. Standard mapping groundtruthing assessments, based on generating and evaluating stratified random points to determine classification and mapping accuracies were beyond the scope of the study due to budgetary constraints.

The classification and patterning effect achieved from the transect data, used as a reference, has been instrumental in obtaining a rapid workable potential reef classification. By using more costly orthophotos and differential GPS equipment, spatial errors can be further minimised, however, the physical constraints and their resulting positional errors would be very difficult to improve on and as such, would potentially dilute any other spatial accuracy gains. The dynamic heterogeneous nature of coral reef structure further minimises the probability of achieving high repeatability with respect to change analysis and monitoring surveys. Thus, this rapid, cost effective survey method, over more costly highly precise alternatives, is recommended.

Automated shallow reef classification methods based on aerial and underwater photography have been used in the past, however, these methods have only been tested at constant water depths under consistent environmental conditions (Cuevas-Jiménez et al. 2002). Both Hummock Hill Reef and Stringers Reef exhibited definite depth gradients. Although reef elements with low radiometric values (hard coral, macro-algae, pavement etc.) were difficult to differentiate out, based only on their spectral value, the overall classification of the two reefs by means of a combination of frame analysis and field survey techniques resulted in the density and pattern of substrate types being correctly classified (Figs. 8 and 9). The technical and physical constraints influencing positional accuracy meant that the precise spatial distribution of the categories were generalised. A change in reflectance with a change in water depth (larger water column less reflectance) and other similar dark patches resulted in these substrates being categorised as reef but with an "unknown" classification (Figs. 8 and 9). To increase the accuracy of the reef substrate types and decrease the amount of areas with unknown classifications, transects should be carefully laid

Table 5 Substrate classification areas as percent (%) and hectares (ha) of total reef area calculated from the GIS

Category	Classification	Hummock Hill Reef		Stringers Reef	
		Percent	Area (ha)	Percent	Area (ha)
1	Sand dominant	34.3	11.6	19.1	15.2
2	Sand dominant sparse mix	13.4	4.5	15.0	12.0
3	Pavement dominant	9.3	3.2	9.7	7.7
4	Pavement dominant sparse sand	11.7	4.0	0	–
5	Pavement dominant sparse coral	3.6	1.2	0	–
6	Mixed substrate	6.2	2.1	14.8	11.8
7	Hard coral dominant	8.1	2.8	0	–
8	Hard coral dominant sparse mix	0	–	0	–
9	Hard coral dominant sparse pavement	10.1	3.4	0	–
10	Soft coral dominant	0	–	4.3	3.4
11	Soft coral dominant sparse sand	0	–	4.4	3.5
12	Soft coral dominant sparse pavement	0	–	4.4	3.5
13	Soft coral dominant sparse mix	0	–	3.0	2.4
14	Sand dominant sparse pavement	0	–	3.5	2.8
15	Pavement dominant sparse soft coral	0	–	3.9	3.1
16	Pavement dominant sparse mix	0	–	4.0	3.2
17	Macro algae dominant	0	–	3.1	2.5
18	Rock/unknown	3.4	1.1	10.8	8.6

– Type of substrate not encountered

to encompass as many reef substrates as possible. Although there were some areas of unknown classification, spatial resolution remained higher than using remote sensing techniques such as traditional satellite imagery, where reef generalisation errors of up to 100's of metres can be expected (Hochberg and Atkinson 2003; Yamano and Tamura 2004). High resolution satellite imagery although available is still costly, especially for remote areas.

This reef benthic substrate classification technique, although limited to small structurally heterogeneous coastal reefs, can be used for a number of coastal management applications including establishing baseline information, assessing spatial and temporal changes and managing coral reef condition including coral bleaching, disease and other disturbances over time.

Conclusion

The results from this study indicated that the two *in situ* sampling techniques tested showed that the Point Intercept Image Analysis method was a more accurate and reliable technique to the rapid assessment technique. Stringers Reef and Hummock Hill Reef both exhibited similar average depth profiles and were in close proximity to the coast. However, both reefs showed different community assemblages with the hard plate coral, *M. capricornis*, dominating Hummock Hill Reef and the soft coral, *Lobophyton* sp., dominating Stringers Reef. Both reefs were in good condition with minimal/no coral bleaching or diseases present.

This cost effective method for classifying and deriving coral reef maps is highly suitable for small reefs (<100 ha) with high structural complexity and heterogeneity, much like the shallow coastal fringing reefs of the South Eastern Great Barrier Reef.

Acknowledgements The authors wish to thank the Burnett Mary Regional Group for funding this study. We wish to also thank the following people for all their help and support in providing assistance with this project. Maria Zann and Sue Sargent for constructive input into original design and analysis of coral reef surveys and supplying colour aerial photographs, Scott Wilson for constructive comments on an earlier manuscript, Ashley Campbell for organising diving logistics and underwater photography, Andrew Davis "Skipper" and Kelly Jacobs for boat and dive assistance. Finally, we wish to thank two anonymous reviewers for constructive comments to previous versions of the manuscript.

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